

## DETERMINING THE INDUSTRIAL REVOLUTION\*

*The British industrial revolution in global perspective.* By Robert C. Allen. Cambridge: Cambridge University Press, 2009. Pp. 342. ISBN 9780521868273. £48.00.

*Childhood and child labour in the British industrial revolution.* By Jane Humphries. Cambridge: Cambridge University Press, 2010. Pp. 456. ISBN 9780521847568. £60.00.

*Energy and the English industrial revolution.* By E. A. Wrigley. Cambridge: Cambridge University Press, 2010. Pp. 286. ISBN 9780521766937. £45.00.

The quest to divine the first industrial revolution's origins may be likened to the pursuit of the philosopher's stone: a legendary elixir capable of transforming base metals into gold. Each of these major studies explores pro-economic explanations of Britain's metamorphosis from European backwater into the world's premier workshop. They differ, however, in the treatment of impersonal forces and adopt divergent approaches to the central problem of determinism. For Sir Tony Wrigley, demography and energy set the decisive parameters: population initiated structural change and coal ensured that growth did not peter out. For Bob Allen, the intractable problem of industrialization is resolved by a *deus ex machina*: innovations induced by factor prices play a pivotal role. In contrast, Jane Humphries demonstrates that a central feature of the transition – the widespread employment of children – was socially shaped and not pre-ordained by a unique combination of resources, population, and technology.

*Energy and the English industrial revolution* begins by setting out the limits of growth confronting economies reliant on the annual harvest cycle. Wrigley estimates that over half of all power employed in the mid-sixteenth century was provided by food-consuming draft animals and labourers. Since wood fuel provided a further third of needs, land was directly responsible for almost nine-tenths of energy consumption. In contrast, coal burning contributed barely 10 per cent of requirements and wind and water very little indeed. Malthus and Ricardo recognized that dependency on agriculture and forestry generated a problem of diminishing returns to capital and labour owing to land's essentially fixed supply. The impossibility of sustaining significant increases in energy

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output ensured that population growth and living standards moved inversely, constrained by an 'arresting mechanism' (p. 4).<sup>1</sup> Wrigley concludes that the only escape route lay underground in the form of 'ghost acres' (p. 38): the accrual of millions of years of photosynthesis trapped in carbon deposits.

By 1800, fossil fuel provided nearly 80 per cent of power consumed in Britain, accounting for almost 90 per cent of an eightfold rise in energy use over the preceding two and a half centuries. The switch from organic to non-renewable is hailed by Wrigley as the first major transformation of the human race's 'production horizon' (p. 206) since the Neolithic Revolution. The proposition that coal mattered is unassailable yet at the same time it is a subordinate theme. If coal, for all its potential, lay passively in the ground waiting to be mined, it can hardly be heralded as the prime mover of industrialization and it is not presented as such by Wrigley. No serious challenge is offered to the view that, aside from the adoption of steam pumping engines and experiments with ventilation furnaces and underground haulage, the mining industry responded to increased demand largely within existing technical parameters. In consequence, annual output per miner after the industrial revolution was only moderately higher than at its start.<sup>2</sup> Certainly, Britain was fortunate in possessing surface deposits in Northumberland and Durham, located near enough a navigable waterway to permit increasing quantities of coal to reach the capital at constant prices. This circumstance alone, however, is insufficient to explain the timing of industrialization. Fossil fuel's significance 'did not consist principally in generating an early momentum, in causing a "take-off"' (p. 101). Its strategic importance lay in averting Malthusian catastrophe by relaxing renewable energy constraints. To illustrate the impracticality of sustaining coal-less growth, Wrigley estimates that as early as 1800 one third of Britain's entire surface area would have needed to be devoted to woodland in order to make good the heating shortfall.

Notwithstanding its title, this book's chief interest lies in analysing the feedback relationships between urbanization, agricultural productivity, and structural change. The origins of British industrialization are located in 'the conjunction of a favourable demographic regime with the progressive escape from sole dependence on the annual cycle of plant growth' (p. 175). Central findings of the Cambridge Group for the History of Population and Social

<sup>1</sup> More precisely, Wrigley argues that growth in income per head was only sustainable at very low rates since inhabitants of England and Wales in 1700 were (on average) almost certainly wealthier than their counterparts three centuries earlier.

<sup>2</sup> Gregory Clark and David Jacks offer conjectural evidence that horse winders might have been a viable second-best solution to Newcomen's in 'Coal and the industrial revolution, 1700–1869', *European Review of Economic History*, 11 (2007), pp. 39–72. Even this article, however, concludes that steam power by the early eighteenth century was *at least* 25 per cent cheaper than horse power. Wrigley cites estimated output per miner of 200 tons in the late seventeenth century, rising to 300 tons in 1851, and falling back to 260 tons in 1913, *Energy and the English industrial revolution*, pp. 46, 206.

Structure are drawn on to emphasize the importance of the nuclear family, delayed marriage, celibacy, and a strong social taboo against illegitimate births. These mechanisms served to regulate fertility levels in line with economic opportunities. The resulting growth-promoting cycle is summarized in a simplified model consisting of eleven variables. Although Wrigley refrains from formal econometric analysis of this macro-economic system, the text discusses and quantifies two of its principal features. First, London's population growth is documented and linked to improved agricultural performance in surrounding counties. Growth of the capital was remarkable, expanding from c. 55,000 inhabitants in 1520 to c. 575,000 in 1700, by which date London was already the largest city in Europe. The feedback mechanism, however, suffers from certain ambiguities. It does not appear that yields in areas closest to London were necessarily higher than comparable farms located further away. Nor is it clear whether growth in agricultural output was the product of market expansion and integration, the fruit of higher investment, or the outcome of innovations raising total factor productivity.

More telling is the emphasis placed on the long-term growth in manufacturing and tertiary employment. Two significant sets of data are presented illustrating these developments: a re-ordering of the country's urban hierarchy (unparalleled elsewhere in Europe) and a map of differential rates of population growth at the level of the English hundreds.<sup>3</sup> Significantly, Wrigley establishes that natural increase varied far less than population growth between districts, indicating that substantial internal migration took place. These demographic trends are consistent with the creation of jobs outside farming, removing the burden of supporting extra numbers from rural communities. Restructuring is similarly evoked to resolve the paradox of rising consumerism yet static real wage gains during the eighteenth and early nineteenth centuries. Simple arithmetic establishes that a shift resulting in proportionately more non-agricultural employment can lead to a rise in average income even if relative wage rates remain constant, thereby increasing demand for manufactured goods.

*Energy and the English industrial revolution* encapsulates the life's work of an exceptional scholar. It is impressive how articles published by Wrigley in the 1960s set out a research agenda subsequently fulfilled over a long and prolific career.<sup>4</sup> As a work of historical geography, however, the book has surprisingly little to say about the political and social power relations which influence access to energy sources and the uses to which resources are put. Wrigley merely alludes to these processes when commenting that 'The industrial revolution brought with it some markedly regressive features' (p. 228). In the penultimate

<sup>3</sup> The English hundreds consisted of 610 county divisions of varying geographical size which provide the smallest disaggregated units of population currently available for demographic analysis.

<sup>4</sup> E. A. Wrigley, 'The supply of raw materials in the industrial revolution', *Economic History Review*, 15 (1962), pp. 1–16; idem, 'A simple model of London's importance in changing English society and economy, 1650–1750', *Past and Present*, 37 (1967), pp. 44–70.

chapter, the contributions of culture and institutions are perhaps dismissed preemptorily. Although accompanied by cautions against country-wide comparisons, the basis for rejection is primarily the example of the Netherlands. Citing the work of de Vries and van de Woude, Wrigley observes that the Dutch developed a recognizably modern market economy yet failed to industrialize.<sup>5</sup> The divergent trajectories of Britain and Holland lead him to express doubts that modernization was even a necessary, let alone a sufficient, cause of industrialization. Demand-driven systems and structures form the backbone of this study and the capacity of British society to create and apply technical knowledge is almost taken for granted.

*The British industrial revolution in global perspective* adopts a different approach to synthesizing the base elements of energy, urbanization, and innovation. Allen's core thesis is reminiscent of a theory of economic development popularized by Richard Eckhaus. Observing that research and investment into improving technology has historically been the preserve of Europe and the United States, Eckhaus suggested that growth-promoting invention is concentrated in high-wage economies possessing favourable capital-labour ratios. Only such economies find it profitable to develop and use efficient technologies that raise output while lowering unit costs.<sup>6</sup> Technological dualism predicts a division of the world into rich and poor countries. Unless an economy reliant on labour-intensive techniques succeeds in increasing its savings rate in order to switch to capital-intensive production, it is destined to remain underdeveloped. The implication of Allen's monograph is that global dualism was as much a cause as a consequence of the industrial revolution. He argues that high wages and cheap energy (the former generated by commercial expansion of the early modern economy, the latter a gift of nature) generated unique opportunities for Britons to industrialize, unavailable to their European counterparts. A favourable legal framework and culture (also attributable to commercial roots) enabled a positive response to these incentives, resulting in the invention of game-changing technologies that substituted capital and coal for labour.

The book's opening gambit is that 'at the exchange rate, British wages were among the highest in the world' (p. 33). Given disagreement over how to construct credible cross-country wage comparisons in the present day, this is a bold claim. Allen's approach, however, is measured and adroit: he concentrates on one well-defined job, building work, which is common to the countries examined. Wages of this benchmark occupation in four European cities (Amsterdam, Vienna, Florence, and London) and two Asian urban centres (Delhi and Beijing) are measured by valuing daily rates in a common currency

<sup>5</sup> Jan de Vries and A.M. van de Woude, *The first modern economy: success, failure, and perseverance of the Dutch economy, 1500–1815* (Cambridge, 1997).

<sup>6</sup> R.S. Eckhaus, 'The factor proportions problem in underdeveloped areas', *American Economic Review*, 45 (1955), pp. 539–65.

(‘silver’).<sup>7</sup> The results provide evidence for European factor price convergence during the late middle ages since the observed differences are small relative to probable measurement-error resulting from such issues as unemployment, compensating differentials, working hours, and the ratio of wages to family earnings. Two baskets of goods (‘respectable’ and ‘subsistence’ budgets) provide an indicator of workers’ living standards adjusted for one simple measure of purchasing power parity. The resulting welfare ratios reveal a decline in all four European cities from their fifteenth-century peak, but rebounds in the late sixteenth century (Amsterdam) and early seventeenth century (London). The bumps are driven primarily by wage gains.

Allen draws the reasoned conclusion that workers in London doing the same jobs as their counterparts in other European cities were paid a premium and enjoyed a relatively high standard of living.<sup>8</sup> On balance, he observes that nutritional and other differences between British and European urban workers were probably not large enough to matter. Why then were London wages so high? Allen’s solution is commercial expansion: Britain gained disproportionately from growth in world trade between 1500 and 1700. As Wrigley points out, however, a convincing explanation of London’s extraordinary rise has still to be written and until this situation is rectified the contribution of foreign trade must remain speculative. Profits from overseas ventures are certainly a plausible source of metropolitan capital accumulation and Allen’s work provides encouragement to researchers to quantify the flow of investment and to investigate the extent to which London manufacturing techniques were more capital intensive than rural industries, even within a predominantly workshop setting. Nevertheless, the existence of so pronounced and long-lasting rural–urban wage gap raises a conundrum. Todaro and Harris’s analysis of the contemporary developing world demonstrates that the creation of jobs outside agriculture may paradoxically raise aggregate unemployment and depress economic growth if internal migration responds too vigorously.<sup>9</sup> It would be fruitful, therefore, for historians to re-examine internal mobility in order to ascertain whether British conditions were more favourable than in other regions of Europe.

Allen’s next gambit is that ‘The burden of high wages in England, however, was offset by cheap energy’ (p. 105). Initially, a similar line to that of Wrigley is pursued by presenting coal as a ‘backstop technology’ – a concept originally

<sup>7</sup> Florence (more accurately, Florence spliced with Milan) and Vienna are representative of a larger body of data analysed by Allen in his 2001 article that provides additional information on methods and sources, Robert C. Allen, ‘The great divergence in European wages and prices: from the middle ages to the First World War’, *Explorations in Economic History*, 38 (2001), pp. 411–47.

<sup>8</sup> Comparisons with Delhi and Beijing are based on less complete data and in consequence larger margins of error attach to them.

<sup>9</sup> M. P. Todaro and J. Harris, ‘Migration, unemployment and development: a two sectors analysis’, *American Economic Review*, 60 (1970), pp. 126–42.

devised by William Nordhaus to analyse the transition from one type of energy source to another.<sup>10</sup> A backstop technology is defined as a method of producing unlimited quantities of a perfect substitute for the existing fuel at constant cost, setting a ceiling price for energy. Allen modifies Nordhaus, recognizing that coal (because of its impurities) was not a perfect substitute for wood and its backstop price, therefore, incorporated a discount reflecting this disamenity. The model works well for London: a rise in the price of wood fuel from 1550 onwards encouraged investment in Northumberland and Durham mining. However, Midlands data tell a different story, since from 1538 coal was already cheaper than wood fuel. Allen attempts to resolve this quandary by arguing that collective invention in an urban concentration such as London was necessary to perfect the technology of the coal-burning house.<sup>11</sup> Until detailed work is completed, these must remain working hypotheses. Smoke bays and hoods do appear to have been installed in non-elite dwellings as precursors to the chimney house during the early sixteenth century and it is reasonable to link adoption of the brick-built flue to the growth of London.<sup>12</sup> By 1662, hearths (brick-lined fireplaces) were sufficiently common to be subject to nation-wide taxation yielding 'chimney money'. Perhaps the spur, however, was a movement from single- to two-storey structures, since smoke needed to be vented upwards out of the building regardless of the heat source. Sociological factors, which influenced other European cities such as Paris, included the desire for smaller private rooms and consumer demand for taverns and coffee houses. That said, labour scarcity probably pulled in the same direction, since improvements in heating undoubtedly raised productivity during winter months. Would a multi-storey house with a wood fire differ substantially from one using coal? Remarkably, the first dedicated work dealing with chimney design published in English did not appear until 1715. In its preface, Desagulier noted that the original French treatise 'considered only the improvement of Wood-Fires but I have shewn how Turf or Coal may be burnt in these Chimneys, with all the advantages that he proposes from his new Construction'.<sup>13</sup> Be that as it may, recognizably modern solid-fuel heating appeared comparatively late and incorporated both British and non-British inventions: for example, efficient stove technology took more than a century to develop and was an international project (utilizing both coal and wood fuel)

<sup>10</sup> W. D. Nordhaus, 'The allocation of energy resources', *Brookings Papers on Economic Activity*, 3 (1973).

<sup>11</sup> The discussion of early modern chimneys and hearths resembles Allen's earlier analysis of chimney stacks and blast furnaces of the later nineteenth-century iron and steel industry, Robert C. Allen, 'Collective invention', *Journal of Economic Behavior and Organization*, 4 (1983), pp. 1–24.

<sup>12</sup> Aside from one publication dated 1483, the first appearances of the chimney and its variants in *Early English Books Online* occur during the early sixteenth century, with the first cluster appearing in the 1530s.

<sup>13</sup> Nicholas Gauger translated by John T. Desagulier, *Fires improv'd: being a new method of building chimneys, so as to prevent their smoaking* (London, 1715).

that included contributions from Prince Rupert of the Rhine, François de Cuvilliés, Benjamin Franklin, David Rittenhouse, and Count Rumford.<sup>14</sup>

What were the consequences of high wages and cheap energy? The short answer is industrialization. While Allen demonstrates affection for the cultural revolution of the early modern period, he judges that Britain was not endowed with a heritage offering substantially better prospects for development than much of the rest of north-western Europe. Economic hegemony is ascribed instead to a unique material endowment: ‘The British were simply luckier in their geology’ (p. 275) and in possessing (courtesy of the Black Death) pastoral farming that favoured breeding of long-haired sheep. The latter supplied the raw material for the new draperies devised, in no small part, by Huguenot refugees. Exports of these products led to London’s growth and raised wages. It is conceded that industrialization was helped into existence by the nation’s reserves of human capital (education and skills), a favourable demographic regime, and a work ethic driven by consumerism – but all of these preconditions, Allen insists, were causally linked to high wages. At the core of the book lies technology-led transmutation: to understand why it is necessary to examine the process of innovation.

Primers on technology distinguish between invention and innovation. Gas light (conventionally attributed to William Murdock and Philippe Lebon) is an example of an invention. The successful commercial exploitation of flammable gas is an example of innovation. In the case of gas, the time taken to turn the first public demonstrations (1801–2) into a viable product or service was comparatively short: by the 1820s, central streets in large cities and towns were illuminated by gas supplied from central stations and the technology had spread to Europe and the United States. The terms macro- and micro-invention (popularized by Joel Mokyr and adopted by Allen) are often applied to these twin processes.<sup>15</sup> Conventionally, macro-invention is regarded as less sensitive to market conditions and therefore less predictable than micro-invention. One reason for this is that inventors operate with a bounded horizon: they seek modest improvements over existing practice, rather than setting out to change the world, but hit upon solutions that have extraordinary potential. It is easy for historians to fall into the trap of retrospective analysis when interpreting these breakthroughs. After the fact, narratives can be constructed reinforcing the notion that a country’s heritage or an individual’s biography led inexorably to the moment of discovery. In a famous paper, Nick Crafts evoked

<sup>14</sup> A search for specialist literature on this topic proved elusive but the following provide useful perspectives: LeRoy Dresbeck, ‘The chimney and social change in medieval England’, *Albion*, 3 (1971), pp. 21–32; Caoimhín Ó Danachair, ‘Hearth and chimney in the Irish house’, *Béaloides*, 11 (1946), pp. 91–104; Samuel Y. Egerton, ‘Heating stoves in eighteenth-century Philadelphia’, *Bulletin of the Association of Preservation Technology*, 3 (1971), pp. 15–104.

<sup>15</sup> Joel Mokyr, *The lever of riches: technological creativity and economic progress* (Oxford, 1990), pp. 291–7. On gas illumination, see M. E. Falkus, ‘The early development of the British gas industry 1790–1815’, *Economic History Review*, 35 (1982), pp. 217–34.

such reasoning to argue that the precise timing and exact location of the first industrial revolution included a random element. By this, Crafts meant that macro-breakthroughs are inherently unpredictable: that a cluster of them occurred in Britain during the eighteenth century did not preclude the possibility that they could have occurred elsewhere, in France for instance.<sup>16</sup> Conversely, micro-improvement is considered more responsive to market forces as individuals or firms seek to maximize income streams from new techniques by improving them incrementally. Very often, macro-breakthroughs are eponymous: they are associated (not always correctly or unambiguously) with single individuals. In economic history, the phrase ‘vital few’ crops up to herald such achievement notwithstanding a large literature (much of it inspired by Merton and Simonton) pointing out the prevalence of simultaneous invention and multiples.<sup>17</sup> In contrast, micro-invention is a more anonymous process in the sense that improvers’ achievements are not generally advertised in the historical record.

Allen turns convention on its head by arguing that macro-breakthroughs are responsive to market forces. More specifically, he attributes the technological breakthroughs of the industrial revolution to Britain’s unique mix of factor prices. The technical term for this hypothesis is induced innovation: a concept associated strongly with its originator, Sir John Hicks, and applied to economic history in modified forms by Sir John Habakkuk and Paul David. To illustrate the theory, the example of the spinning jenny (purportedly invented by James Hargreaves but an example of a Merton multiple) is analysed. Two simpler economic concepts are utilized to support the case that the jenny could only have been developed in Britain since only in Britain was the device profitable. These concepts are net present value (NPV) and the internal rate of return (IRR). A new technique (like an investment) has an up-front cost (C) but generates a flow of income (the saving over the existing technique in current use, in this case hand spinning). Discounting the flow of income using the prevailing interest rate generates the investment’s NPV. Clearly, no rational investor will be interested in a project if NPV is less than C. A shrewd investor will also walk away if he or she believes the return is lower than that available from a known alternative. The IRR is the discount rate that makes  $C = NPV$  and unless it is higher than the opportunity cost a wise venture capitalist will not part with his or her money. Allen calculates that, in the case of the spinning jenny, only in Britain was the IRR (at about 38 per cent) significantly above the return on commercial alternatives (set at approximately 15 per cent). The jenny’s

<sup>16</sup> N. F. R. Crafts, ‘Industrial revolution in England and France: some thoughts on the question “Why was England first?”’, *Economic History Review*, 29 (1976), pp. 226–35.

<sup>17</sup> Jonathan R. T. Hughes, *The vital few: the entrepreneur and American economic progress* (Boston, MA, 1966). For correctives, see Robert K. Merton, ‘Singletons and multiples in scientific discovery: a chapter in the sociology of science’, *Proceedings of the American Philosophical Society*, 105 (1961), pp. 470–86; Dean K. Simonton, ‘Independent discovery in science and technology’, *Social Studies of Science*, 8 (1978), pp. 521–32.



invention in Britain, therefore, was no accident: it reflected the fact that wage costs were expensive relative to capital. A similar line of argument is adduced to explain other macro-breakthroughs: Newcomen's steam engine, coke smelted iron, Arkwright's water frame, and Crompton's mule. In each case, Allen attributes invention to the ratio of wages to energy and capital prices. Innovation was thus induced – that is, it was biased towards economizing on the use of the scarcest factor (labour) and exploiting the factors in relative abundance (capital and coal resources).

The accounting Allen uses to analyse the spinning jenny raises some questions. For example, it might be asked by how much hand spinners' earnings in England would have to fall to render the jenny a non-starter? On the figures presented, the answer is around 40 per cent. Allen duly estimates that French wages were indeed 38 per cent lower (a result arrived at by dividing the ratio of a spinner's wage in France to the price of a jenny by the English ratio).<sup>18</sup> The exercise suggests, however, that while not profitable at prevailing French wages, the jenny would have been feasible across a wide range of European labour costs (or indeed English costs) at different time periods. Moreover, the underlying argument possesses a curious feature. Allen starts from the premise that a hand spinner laboured an average of 100 days a year (40 per cent of an assumed 250 days available for work) and he estimates that the jenny enabled a woman to spin the same amount of cotton in one third the time of a hand spinner. Yet the attraction of higher earnings (an incentive the book attaches great weight to elsewhere) might be expected to encourage greater industry among spinners owing to the fact that their productivity at this activity has risen relative to alternative uses of their time. If work days increased to 150 out of 250, the IRR rises to 45 per cent in England and it would still be 20 per cent if wage rates were at French levels.<sup>19</sup> As Allen reports, by placing jennies in a factory and offering a wage such as 8–10s a week, industrialists of the 1780s sought to tempt workers away from hand spinning, which commanded 3–5 shillings. To be sure, these entrepreneurs did not run their operations for only a third of the year: they aimed to maximize capital utilization and in consequence the wage premium fails to capture all of the gain resulting from the innovation. Allen is also of the view that the capital and maintenance costs of the jenny would be higher across the Channel owing to a smaller clockwork industry capable of supplying gearing and other components. The French, however, were world leaders in robotics

<sup>18</sup> Comparable earnings of 7s to 8s are reported for Lancashire for the 1760s and 1770s, Paul A. Custer, 'Reconfiguring Jemima: gender, work, and politics in Lancashire, 1770–1820', *Past and Present*, 107 (2007), p. 128.

<sup>19</sup> This assumption is likewise criticized in Nicholas Crafts, 'Explaining the first industrial revolution: two views', *European Review of Economic History*, 15 (2011), pp. 153–68. Crafts similarly concludes that as working time rises, the IRR increases leading the jenny to become profitable in a widening range of locations and at different time periods.

(automata) and this trade could conceivably have provided reasonable substitutes.<sup>20</sup>

In his discussion of micro-invention, Allen argues that factor bias ceased to operate as the users and subsequent improvers of the industrial revolution's technology sought gains that were Hicks-neutral (that is, equally likely to save all inputs including those relatively abundant in Britain). 'Local learning', a concept associated with Paul David, is put forward as the main explanation for this tendency. By local learning is meant ideas for improvement originating from users' experience of a technology. Allen further observes that resources for micro-improvement came from ploughed-back profits (rather than externally funded research-and-development) and often featured collective innovation. As re-engineering of inventions steadily economized all factors over time, technology became profitable in different economic environments. Paradoxically, Allen proposes that British success eventually undermined the country's competitive advantage, creating opportunities for rivals to leap-frog the development stage – provided that the economies in question possessed the capacity to raise their savings rates in order to move from labour-intensive to capital-intensive production methods. Much of this analysis is persuasive. Successful technologies tend to be those which adapt in response to the requirements of more sceptical and risk-adverse adopters. Mechanisms that involve users in a technology's development can therefore contribute to rapid diffusion. Whether continuous improvement and re-invention is factor neutral is less clear. Allen presents some evidence in support of the proposition for iron manufacturing but the relative cost shares of capital and resources in this industry were higher than in textiles and the local factor price environments may have been more uniform.

A standard criticism of induced innovation is that it neglects supply-side considerations. Allen anticipates this objection and provides a twofold answer to the question of how inventors were able to respond to the opportunities created by a high-wage economy. First, he argues that British culture developed in ways that raised the propensity to invent. Secondly, he postulates that human capital accumulation increased prior to industrialization as key sections of the population became more literate, numerate, and skilled. The discussion of culture jousts with Mokyr's *Enlightened economy*: the battleground consisting of a small sample of seventy-nine 'important inventors' (Allen, p. 242) active during the seventeenth and eighteenth centuries.<sup>21</sup> With the exception of a few exceptional industries such as chemicals, the propensity to patent (a rough proxy for invention) lay around 0.1 or 0.2 per 1,000 workers during the

<sup>20</sup> Reed Benhamou, 'From *curiosité* to *utilité*: the automaton in eighteenth-century France', *Studies in Eighteenth-Century Culture*, 17 (1987), pp. 91–105.

<sup>21</sup> Joel Mokyr in *The enlightened economy: an economic history of Britain, 1700–1850* (New Haven, CT, 2010), pp. 30–62.

industrial revolution period.<sup>22</sup> In consequence, Allen and Wrigley are undoubtedly correct in arguing that restructuring exerted a significant supply-side influence on innovation, since growth in non-agricultural employment will boost the expected number of patents. When considering innovation, however, it is important not to lose sight of the fact that the objective of a technology's users was to produce marketable goods and services. The concept 'macro innovation' possesses some of the properties of disembodied technologies: both refer to a bundle of theoretical knowledge, tools, and applied techniques that can be used to design new goods, systems, or services. Both also imply a deterministic view of technology's impact on history by portraying innovation as diffusing across economic sectors, replacing old techniques, and re-shaping society. In contrast, embodied technologies represent knowledge manifested in specific processes, such as workers' training and the designing of new systems of logistics and marketing.<sup>23</sup> Embodied technological change is strongly endogenous and non-deterministic: social adaptation of technology through the construction of viable systems is required to bring about change. In consequence, it is dangerous to relegate culture and the social environment to a supporting role and to adopt a purely demand-side, deterministic position. Similarly, it is limiting to concentrate primarily on inventors and to ignore the diffusion of experimental ideas and commitment to rationality among the creators of embodied technology.

As well as highlighting the importance of coal, another trait Allen shares with Wrigley is his abridgement of industrialization through the construction of a simplified model. Unlike Wrigley, he opts to test this model formally in a chapter that begins with Galileo paying homage to mathematics and ends with Allen's own highly quotable conclusion that 'The success of the British economy was, thus, due to long haired sheep, cheap coal and the imperial foreign policy that secured a rising volume of trade' (p. 130). A simultaneous equation model of European development is employed to break down the alchemy of industrial transformation. In econometric forecasting, this technique is known as the complete system approach: a computationally intensive branch of applied statistics. Four elements lie at the heart of Allen's system: (1) the real wage rate, (2) the urban share of population, (3) agricultural total factor productivity, (4) the proto-industrial share of population. These variables are endogenous: that is to say, each influences the other. Other variables Allen identifies as exogenous: they operate as outside influences on one or more of the endogenous elements. The full list of relationships is as follows: enclosure influences agricultural productivity, the land-labour ratio affects the real wage

<sup>22</sup> R. J. Sullivan, 'The revolution of ideas: widespread patenting and invention during the English industrial revolution', *Journal of Economic History*, 50 (1990), p. 354. Sullivan's data are for 1839-41 and 1849-51.

<sup>23</sup> A well-known exploration of these themes is Paul David, 'The dynamo and the computer: an historical perspective on the modern productivity paradox', *American Economic Review*, 80 (1990), pp. 355-61.

rate, productivity in wool textiles acts upon proto-industry, and the following variables all impact upon urbanization: energy prices, growth in the value of overseas trade per head, regime type (a binary variable equal to one if a country has an absolutist monarchy and zero otherwise), and the lagged urbanization rate itself. In each time period, four equations are specified and solved for each of the endogenous variables.<sup>24</sup> Allen validates his model by forecasting urbanization, agricultural productivity, and real wages for England, Italy, France, and the Netherlands. He reports that the projected point estimates match historical data of performance closely. Drawing confidence from this, the model is employed to simulate counterfactual urbanization, agricultural productivity, and real wage growth in England dropping in sequence the exogenous variables regime type, enclosure, wool textile productivity, trade growth, and energy prices. The simulations are again compared with historical data. Allen's conclusion is that regime type and enclosure contributed little to economic change: the crucial success factors were productivity gains in new draperies, the rise in overseas trade, and the contribution of coal energy.

Galileo notwithstanding, how much credence should be placed in the complete system approach and its results? This is a technically demanding question to answer but Allen's results provoke a few queries. First, one might ask about the confidence intervals associated with the simulations. In forecasting generally, intervals widen with every forward projection making it hazardous to draw conclusions from point estimates alone. Consequently, the fact the model appears to track actual European data closely is not conclusive evidence of its reliability.<sup>25</sup> A second question concerns diagnostics: is the model fit for purpose and (in the spirit of Galileo or Kepler) how well does it withstand attempts at falsification? Since these qualms are not addressed, the robustness of the analysis cannot readily be appraised. Specific components of the model, however, are persuasive – particularly the relationship between urban expansion and agricultural performance. Allen's understanding of the direction of causation is similar to Wrigley's but he is more specific regarding the sources of growth (investment in genetic and environmental improvements, rises in farm size, enclosure of open arable land and conversion to pasture) and clearer regarding the consequences of the rural–urban wage gap. Interestingly, these differences reflect the authors' chosen methods. Wrigley regards the range of factors contributing to industrialization as 'essentially incommensurable' (p. 5), arguing that there is no facility for gauging their relative importance. Allen, in contrast, believes that calibration is intrinsically possible.

Accepting that induced innovation resulted in skill-replacement and capital augmentation, what lies beneath these euphemisms? Insights are available in

<sup>24</sup> More detail is contained in Robert C. Allen, 'Progress and poverty in early modern Europe', *Economic History Review*, 56 (2003), pp. 403–43.

<sup>25</sup> The X-axis of the charts (measuring time) are also concertinaed with intervals of a 100 years up to 1700 and fifty years thereafter.

*Childhood and child labour in the British industrial revolution.* Jane Humphries investigates an uncomfortable truth about Britain's eighteenth and nineteenth-century economy: widespread deployment of child workers. In the textile industry, the introduction of large-scale production resulted in fresh divisions of labour. During the early phases of industrialization, children filled in where new machines fell short: mending broken threads, gathering waste, running messages – bridging the gaps between novel techniques and old ways of doing things. Down deepening shafts drained by Newcomen engines, small hands opened and closed trapdoors to keep air circulating. In London, collectively invented coal-burning-houses evoke the Shakespearian couplet: 'Golden lads and girls all must, as chimney-sweepers come to dust.' Lying at this study's core is a dataset of 617 working-class autobiographies. Humphries acknowledges the potential pitfalls of such evidence and is at pains to establish that her sample is representative of the wider population of child workers active in the labour market between 1627 and 1878. Demographic simulations (provided courtesy of the Cambridge Group) compare the characteristics of households the subjects were brought up in with those of the general population where at least one infant survived to adulthood. She reports the writers had slightly smaller numbers of siblings (attributable to the greater likelihood of losing at least one parent – usually a father – to death or desertion) but that in other respects the results are reassuring.

Humphries reaches three main conclusions on the basis of the evidence contained in the autobiographies. First, she reports high participation rates among children in mainstream branches of economic activity relative to birth cohorts before and after industrialization. Secondly, Humphries rejects technologically determined (demand-side) explanations of child labour, concentrating instead on supply-side factors. Concepts such as 'breadwinner frailty' (p. 156) and 'precociously nuclear' families (p. 191) are evoked to emphasize the dependency of British households on adult male wages earned outside of agriculture. In consequence, she argues that de-skilling (for example, after mechanization of handloom weaving) and military service during the Napoleonic Wars impacted severely on the dependants of male household heads. The plight of families was aggravated further by fertility-led population growth (raising the dependency ratio and increasing household size) and by the inadequate levels of welfare provided by local authorities. Harnessing labour market models (derived from modern applied development economics) to empirical observations, Humphries concludes that families' best coping strategies for dealing with life-cycle poverty or the absence or incapacity of a male head was to send children out to work while mothers stayed at home. A high child participation rate is linked to low maternal paid employment. One of the key insights of this study, therefore, is that child labour was not simply exogenously determined by population, technology, or warfare: its growth and acceptance was largely endogenous – a consequence of the social practices surrounding marriage, household work allocation, and child rearing adopted

by early modern England as solutions to the problems of maintaining subsistence and social stability. Thirdly, Humphries argues that the same factors responsible for pushing children into work also deprived them of the benefits of education and training. Despite their imperfections, institutions such as (non-pauper) apprenticeship and dame schools (much maligned in previous historiography) improved the life chances of subjects. Summarizing her second and third conclusions, Humphries argues that child labour was inversely related to adult male real wages and educational attainment. The result was a dynastic trap: a society with many poor families, whose offspring were prevented from reaching their full potential in life creating a vicious cycle of vulnerability.

One of this book's beauties is its carefully crafted approach: qualitative and quantitative methods are combined in the investigation of a unique set of sources assembled by the author. Examining the qualitative analysis first, numerous direct quotations from the autobiographies are dexterously woven into the text. These illustrations are always interesting and three areas might merit further investigation. First, in a discussion of consumerism, the reader learns that 'The 'new' goods that attracted children were books and magazines' (p. 243). This is an important point and it suggests that the material read by subjects in childhood shaped their identities and understanding of the world. George Acorn, for example, recalled buying a copy of *David Copperfield* and reading it aloud to his family. The autobiographies do, however, offer a corrective to the popular image of a lost childhood propagated by Dickens and other Victorian writers, revealing instead how work could develop a young person's self-esteem as household providers. In addition, the life-stories illustrate that cruelty was not endemic: vulnerable children lacking protectors (then as now) were most at risk of abuse, particularly those supervised by lone adults whose own rate of remuneration depended on a child's performance. Secondly, Humphries uncovers evidence of the strength of the bond between mothers and sons, noting the desire of boys to earn maternal esteem, the use of a mother's self-denial of food as an incentive device, and the command of mothers over their sons' earnings. These sections can be read alongside the book's observations about breadwinner frailty and the incidence of deceased or absent fathers among writers as children.<sup>26</sup> Although Humphries occasionally refers to delinquency and deviance among her subjects, the overriding impression is the rarity of anti-social behaviour. A psychologist might argue that maternal attachment and commitment to work were mutually reinforcing and created strong social bonds, reducing the odds of criminality by increasing an individual's stake in society.<sup>27</sup>

<sup>26</sup> Humphries reports that between 8 and 18 per cent of fathers became separated from or abandoned their families (p. 136). She also records that the percentage of missing fathers among subjects born between 1627 and 1799 was 28 per cent by age fourteen compared with an expected mortality rate of fathers of only 17 per cent by this age (p. 65).

<sup>27</sup> This approach is termed social control theory and is closely associated with Travis Hirschi, *The causes of delinquency* (Berkeley, CA, 1969).

Aside from a brief reference to the use of the passive voice as a mechanism to reflect positively on painful memories, the text does not draw on the extensive literature of autobiographical memory. One theory relevant to this study and worthy of consideration is Csikszentmihalyi and Beattie's investigation of 'life themes' developed by individuals as reactions to critical problems confronted in childhood. These researchers argue that the nature of the response to such existential challenges as acute poverty and social deprivation is a predictor of subsequent occupational attainment. A child conceptualizing a crisis in terms of poverty and its solution in terms of regular employment is predicted to attain a lower occupational rung than a child perceiving the same problem in terms of injustice, for whom social reform acts as a career motivator.<sup>28</sup> Reviewing the volume's contents, there are a number of vivid recollections of critical moments contributing to an individual's self-identity. William Adams was horrified by the rough treatment meted out to his grandmother by the New Poor Law which 'motivated opposition to a callous economic system' (p. 166). William Beswick recalled how he was nursed, ill with measles, on his great-uncle's knee to give his mother respite: 'It was plain to my young mind how deeply the harrowing experiences of my uncle and my parents had bitten into their personalities' (p. 169). Joseph Bell was flogged in a workhouse aged twelve for a trivial offence in front of the Poor Law Guardians and a collection of individuals he ironically described as 'English gentleman' who assembled to see 'justice' administered (p. 363). Humphries hails the 'self selected sample' who invested in additional education because they 'sensed a pay-off' (p. 335). Her admiration for the 'many boys and young men' who 'after punishing physical labour and terribly long hours, strove to equip themselves for something better' (p. 365) is certainly justified. If the 617 subjects, however, consist disproportionately of young people whose chosen life theme was to kick back against oppression, then the sample is unlikely to be representative of all children. Indeed, reading the autobiographical extracts it is difficult to escape the conclusion that their authors form a self-selecting group who judged their lives worthy of record and who chronicled incidents and attributes contributing to this tendency.

Much of the tabular and graphical material presented by Humphries consists of either descriptive statistics or simple bi-variate comparisons. These are well explained and informative. More demanding are the three multi-variate models presented in the text: I) an analysis of the determinants of the age subjects commenced their first job (pp. 205–7), II) an analysis of the determinants of the rank of an autobiographer's adult occupation (p. 281), and III) analysis of the returns to investment in education (pp. 347–9, 351). Model I is employed to substantiate the narrative arc that child labour increased during the industrial revolution. Humphries reports that boys born between 1791

<sup>28</sup> Mihaly Csikszentmihalyi and O. V. Beattie, 'Life themes: a theoretical and empirical exploration of their origin and effects', *Journal of Humanistic Psychology*, 19 (1979), pp. 45–63.

and 1849 started work at younger ages than their predecessors and successors; that sons of factory workers, domestic workers, and casual labourers commenced employment a year sooner than the sons of farm workers; and that paternal absence, receipt of poor relief, and maternal non-participation also depressed starting ages. Does this analysis bear scrutiny? Pre-industrial comparisons are essential in order to place later events in context but the further an historian extends quantitative research methods back in time the harder it becomes to obtain reliable data. The autobiographies contain no information about girls' experiences and for the period before 1790 Humphries is reliant on a slender sample of ninety-one testimonies stating the ages at which work commenced (p. 176). Collectively, these early subjects appear more socially diverse than their nineteenth-century counterparts since their ranks include a few sons of relatively affluent workers such as clothiers and textile merchants. In view of the fact that the strongest occupational predictors are at least as influential as the cohort effects (pp. 205–6), compositional differences are a potential problem. Furthermore, that none of the model's parameters are significant at better than 95 per cent confidence suggests that the dependent variable (age at first job) is measured inaccurately, presumably because of age-heaping.<sup>29</sup> Given that the reduction in average starting ages between the first (1627–1790) and second (1791–1820) birth cohorts is a modest fourteen and a half months, sensitivity analysis would strengthen faith in this crucial statistic.<sup>30</sup>

Considerable weight also attaches to Model II since it is used to support a piece of revisionism: that 'apprenticeship was an important and vital institution in industrialising Britain' (p. 305). Humphries adds her voice to those who have questioned Adam Smith's dismissal of apprenticeship as a backward-looking restrictive practice. The argument that efficient contract design created incentives for both sides to honour their agreements is well made, helping to explain why more than two-thirds of autobiographers' indentures ran their term. Nonetheless, the claim that the institution remained an effective vehicle for the inter-generational transmission of skills would benefit from further testing. The model's dependent variable (adult occupational rank) is author coded since no adequate data are available for actual

<sup>29</sup> John Clare, for example, recalled 'I believe I was not older than 10 when my father took me to receive the scanty rewards of industry.' In contrast, William Arnold recollected with more precision that he commenced work aged six years and two months (p. 173). Provided such errors are distributed randomly across reported ages, however, the regression results are not necessarily invalidated.

<sup>30</sup> The finding that overall starting ages fell is consistent with analysis of family budgets reported in Sara Horrell and Jane Humphries, "The exploitation of little children": child labour and the family economy in the industrial revolution', *Explorations in Economic History*, 32 (1995), pp. 485–516. This article concluded that child participation rates rose during industrialization while children also worked at younger ages. Paternal occupation, however, influenced both measures and a lack of data earlier than 1787 ruled out pre-industrial comparisons.



earnings.<sup>31</sup> Notwithstanding Humphries' careful adaptation of the CAMSIS scale, inevitably measurement error of career success creeps in, helping to explain why none of the reported effects are again significant at above 95 per cent confidence.<sup>32</sup> In this case, there is also missing information about a potentially serious confounder: birth order, which is known for only 305 subjects. Since Humphries reports associations between sibling rank, age at starting work, and exposure to education, it is important to control for this variable. Lastly, the effect of service is small (compared with father's occupational score and adult education) and double-edged since subjects failing to complete their indentures fared worse than those never bound. Perhaps all that can be said with confidence about apprenticeship is that the institution unlocked abilities already possessed by subjects at the point of entering into indentures.

Model III seeks to confront problems that bedevil all attempts to assess the returns from education: unmeasured confounders correlated both with outcome (occupational success) and exposure (years spent in education). As Humphries points out, aptitude for study is a particularly troublesome confounder. Added to this, if exposure to education suffers from misreporting, the regression parameters will be biased when estimated using ordinary least-squares (OLS). In an exemplary display of applied historical econometrics, a way around some of these problems is sought using an instrumental variables estimator. Instruments are variables uncorrelated with the error term in an OLS regression (which contains the confounder) but correlated with exposure to treatment (in this example, education).<sup>33</sup> Humphries selects household variables to serve as instruments, including the number of siblings and (as a proxy for mothers' educational attainment) the maternal participation rate. Interestingly, she also employs measures of school quality for the same purpose. Since multiple instruments are employed, a single generated instrument for implementation in the model is obtained by first running an interim regression (a process referred to in the text as 2SLS).<sup>34</sup> The revised model indicates that educational exposure boosts predicted occupational score by around 4 per cent for every additional year spent at school, leading Humphries to observe that an expansion of provision (such as actually occurred after 1833) would probably

<sup>31</sup> The practice of author coded data is illustrated by Allen's classification of regimes as either absolutist or non-absolutist. In this case, the coding scheme is binary (1 = absolutist states, 0 = other states). The author selects and applies criteria in order to code (classify) the designated variable.

<sup>32</sup> CAMSIS is an acronym standing for 'Cambridge social interaction and stratification' scale. The scale has a minimum value of 1 and a maximum of 99, with a mean of 50 and a standard deviation of 15. Different historical occupations are assigned scores based on a hierarchy of interaction captured by marriage data: see Humphries, *Childhood and child labour*, p. 89.

<sup>33</sup> The error term in the regression equation captures unobservable factors influencing occupational outcome, including ability.

<sup>34</sup> This is a simplified exposition of a complicated estimating technique. A more detailed account is available in Jeffrey M. Wooldridge, *Introductory econometrics: a modern approach* (4th edn; Mason, OH, 2009), pp. 506–45.

have been seized on by poorer families whose access to schooling was deterred by its high opportunity cost. This important finding is corroborated by qualitative evidence, adding credence to the conclusion that a dynastic trap operated during early industrialization.

These three deeply engaging studies of British industrialization are pitched at the undergraduate market but aim far higher, thereby challenging students to rethink the past economically and to confront problems of growth and causation. It is to be hoped that some among the rising generation of researchers will be inspired to pursue further London's expansion, development of the coal-burning house, apprenticeship's merits, and other promising lines of inquiry highlighted by the authors. Each book also deserves an audience beyond economic history specialists. Wrigley offers the most stylish prose and his discussion of the transition from organic to inorganic energy will appeal to researchers investigating environmental change. He cautions that industrialization has proved a mixed blessing, likening the resulting release of carbon to the opening of Pandora's mythical box. One might attach a similar health warning to the Neolithic Revolution: viewed in the long term, human development and escalating risk sadly walk hand-in-hand. If readers are looking for a good argument and reassurance that fossil fuel depletion will induce its own cure, Allen is the man. Potential good news on the energy front, however, is accompanied by pessimism that global poverty will disappear anytime soon. Finally, for insights into a social problem that still blights the world economy and for a demonstration of superlative technique tempered by a human touch, read Humphries.

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