Precocious Albion: Factor Prices, Technological Change and the British Industrial Revolution.

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Preliminary

Introduction.

Why was Britain first? The question of British precocity continues to stimulate debate that is as lively as it is inconclusive. Recently, factor-saving biased technological progress has been introduced into this literature. The idea of induced innovation has a long lineage in economic history. Starting with the seminal work of Rothbart (1946) and Habakkuk (1962), scholars have tried to link factor prices with the rate of innovation.[1] While this literature seemed to have run out of steam in the late 1970s, it has recently been revived by Robert Allen in the context of the British Industrial Revolution in a set of sophisticated essays, building on his pathbreaking work on real wages in Europe in the pre-modern age. Allen's argument is that the British Industrial Revolution was at base 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 he takes to be representative of the rest of Europe). The high level of wages is attributed by Allen to labor-demand: the growing commercial and maritime sector and the growth of urban centers raised real wages in Britain, as it did elsewhere. As argued in Mokyr (2009a, pp. 268–71), as a full explanation of the British Industrial Revolution, the argument seems incomplete for the simple reason that many of the technological breakthroughs of the age are simply hard to interpret as labor-saving process innovations.[2] If we take the Industrial Revolution to be a "wave" of technological advances that covered more than just textiles and iron, in the tradition of Berg-Hudson (1992) and Temin (1997) (as opposed to Crafts and Clark), it becomes clear that a considerable amount of new technology was product-innovation, and hard to classify as factor-saving

[1]Among the more notable contributions are David (1975) and Temin (1966, 1971).

[2]Many of the inventions of the age that took the form of new or vastly improved products, including the marine chronometer, colored Jasper (in Wedgwood's Burslem pottery), chlorine bleaching, and gaslighting, are simply hard to interpret in this light.

biased. It seems, therefore that something deeper than just factor prices was at work here.

Yet there is an equally serious flaw in Allen's argument, which is the main theme of this paper, and that is that he makes an implicit argument that the supply and quality of labor is identical in both high and low wage economies. In Allen's view, the higher wages were the result of demand-side factors: Britain's success in the global economy, and its large deposits of coal (2010, pp. 8-11). A problem would emerge for his view if the high British wages were primarily the result of a higher productivity of British workers; in that case the nexus between high real wages and "dear labor" would break down and could be entirely the result of measuring labor in natural units, as opposed to efficiency units.[3] Moreover, in that case the high wages were little more than a transmission mechanism: those factors that made Britain's workers more productive may well have been important in generating the inventions, and (equally important), in disseminating and absorbing new knowledge and putting it to good use.

There is little doubt that the Industrial Revolution witnessed a considerable amount of labor-saving innovation. This was particularly the case in the cotton industry, where workers were replaced by machinery, first in spinning and carding, then in printing, and later in weaving.[4] Other examples, such as the mechanization of threshing and certain processes in the toymaking industry and paper

[3]This was first noted in a passage by Arthur Young commenting on the low cost of French labor: "labour is generally in reality the cheapest where it is nominally the dearest" (Young, 1790, p. 311). In 1824 Thomas Malthus held the same opinion: "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).

[4]Even in textiles, the evidence that high wages and cheap coal were the prime mover in mechanization is mixed. Arthur Young reported in 1807 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, 1807, p. 326).

industry also can be regarded as labor-saving.[5] As a characterization of the Industrial Revolution as a whole, however, the evidence that technological change was on balance labor saving is at least questionable.[6] The question of relative advantages of dear vs. cheap labor in the industrialization process has been discussed since W. Arthur Lewis's classic work on surplus labor and economic growth. In simple models in which technology is exogenously given and labor productivity identical across economies, low wages imply high profits and thus more rapid capital accumulation (Lewis, 1955; Mokyr, 1976, 1991). If technology is endogenous, however, it is easy to think of ways in which high wages may influence the direction and even the rate of technological progress. The canonical conditions for this to happen were laid out by David (1975) in his classic essay on the topic and on which Allen (2009b) relies. David shows how in an economy in which there are more and less labor-intensive techniques, high wages will encourage the choice of more resource- or capital-intensive techniques; once we add the assumption that technological progress is mostly local (that is, around the technique in use) and that this learning process is faster in capital-intensive mechanized techniques, the result will be that the high-wage economy will experience more technological progress. Eventually, the new labor-intensive techniques will continue to improve to the point at which even low-wage economies will adopt them. It is this model that Allen sees as causal in the British Industrial Revolution and its diffusion, with a long lag, to low-wage economies on the European Continent.

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[5]The application of steam power in some cases may well have saved labor, but wherever it replaced water- or animal-power, it was one form of capital replacing another. In that case it is far from obvious how high labor-costs were instrumental in stimulating it.

[6]The macroeconomic record, questionable as it is, is summarized by von Tunzelmann (1994, pp. 289–91). Apart from a short period during the Napoleonic Wars, there is little evidence that technological change in Britain *as a whole* 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 was dampened by "the continuing labour-surplus of males" (ibid., p. 291).

Even David, however, assumes that labor is of homogenous quality. If the high-wage economy has, for some reason, more productive labor, it may well be the case that its real labor costs are actually lower. If the labor productivity is exogenous (for instance, purely a function of natural resources), we need simply to check whether the difference in labor productivity is higher than the difference if real wages to establish whether the cost of labor is higher. But if labor productivity is higher because of higher physical or cognitive abilities of British workers, the story is changed.[7]

An immediate candidate for a cause of different labor qualities is nutrition. Fogel (1989, 1991) has maintained that French workers had considerably worse diets than their British colleagues. As we will argue below, nutrition may well constitute one of the factors that explain the difference in labor-quality between the two economies. This may be related to the one observable difference between the two economies: Britain had a nation-wide poor law which prevented the worst cases of misery and malnutrition. Here, however, there may be considerable positive feedback. Nutritional differences are consistent with models in which high wages lead to high productivity. In such efficiency-wage models there are often multiple equilibria, one with low-wage and low-productivity and the other with high wages.[8]

In what follows, we will 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. We will show a number of things. One is that the differences in productivity between British and

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[7]This illustrates how our account differs from Allen's: he points out (2010, p. 11) that if Britain had higher wages, it could only compete on international markets "if [British businesses's] efficiency was exceptional or if another input was cheap" and points to coal as that other input, without exploring the possibility that British workers may have been more efficient that their competitors.

[8] For a good summary of the efficiency-wage literature, see Akerlof and Yellen, eds., 1986.

French workers is 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 a *symptom* of deeper factors that drive both wages and technological creativity.

A model of technology and wages

In this section we develop a simple model as an alternative to the induced-innovation model proposed by David and relied upon by Allen. Our model, much like the David-Allen one, reproduces the feature that the high-wage economy is the first to modernize, but that it is eventually followed by the low wage one. In our model, human capital is assumed to be the way in which labor quality is improved. In this context it merits emphasis that human capital can take the form of improving the physical characteristics of the young by properly feeding and housing them, and not just through the transmission of skills and knowledge.

In what follows we do not model the act of invention itself and focus on adoption. The adoption of a new technique usually required a fair amount of tweaking and microinvention to adapt a technique to local circumstances. To adopt technology, a country thus needs workers with some minimum level of "competence," which is acquired by investment in human capital through personal contact (master-apprentice). Output is a function of both the quantity of workers and their "quality" (human capital). The model combines the Phelps-Nelson model in which productivity growth depends on the difference between the actual techniques in use and the productivity of best-practice techniques with the Ben Porath model, which postulates how the stock of human capital grows as a function of deliberate investment decisions by parents. Parents invest in the human capital of their children depending on the efficiency of this investment, which depends on the ability of children to process this education and their survival probability. In this system, human capital and productivity growth co-evolve, in a manner similar to Galor and Weil (2000).

The model concerns the diffusion of best-practice knowledge from to the level of ordinary artisans where it can be incorporated into everyday production. We therefore define the level of international scientific knowledge by $\tilde{A}$ and assume that it grows exogenously. Within a given

$$\frac{A_t}{A_{t-1}} = \begin{cases} \left(\frac{\tilde{A}}{A_{t-1}}\right)^{\delta} H_{t-1}^{\epsilon} & \underline{A} < A_{t-1} < \tilde{A} \\ 1 & \text{otherwise} \end{cases} \tag{1}$$

country, the level of technology in use is A. The level of technology evolves according to a Nelson-Phelps process, depending on the gap between scientific knowledge and the country's own technology; and on the level of skill of ordinary workers H:

where $0 < \delta, \varepsilon < 1$. The technology in use in an economy cannot exceed the frontier value $\tilde{A}$, and cannot fall below a minimum level $\underline{A}$. To simplify notation in what follows, we assume that the

$$\frac{H_t}{H_{t-1}} = I_{t-1}^{\lambda} H_{t-1}^{-\mu} \tag{2}$$

minimum technological level is unity: $\underline{A} = 1$. The skill level of each artisan evolves according to the Ben-Porath equation

where $0 < \lambda, \mu < 1$. In this overlapping generations model, I_{t-1} denotes investment in the young generation of workers in period t-1 in the form of nutrition and basic schooling, and needs to equal

$H_{t-1}^{\mu/\lambda}$ to maintain the existing level of human capital of the workforce.

To close this model we need to specify what determines the level of investment in the next generation of workers. We suppose that individuals have two periods in their lives: when young they receive investment from their parents; and when old they receive income as workers that they use

$$U(C_t, I_t) = C_t^{1-\gamma} I_t^{\gamma} \tag{3}$$

to maximize utility which comes from their own consumption C_t and investment in their child (we assume constant population for now):

where $0 < \gamma < 1$. Workers supply one unit of labour inelastically, and live hand to mouth making and

$$Y_t = A_t H_t^{\alpha} N_t^{1-\alpha} \tag{4}$$

receiving no bequests. It follows that parents invest a fraction γ of their income in their children. Output in this economy comes from the standard production function :

where $0 < \alpha < 1$ and N is the number of workers. Each worker receives an income Y_t/N_t.

Each worker pays a share of his income to the government or landlords, receiving nothing in return. In addition, however, the government may tax the landlord class and redistribute this money to workers in the form of a Poor Law. It follows that the disposable income of workers is $(1-\tau)Y/N$ where τ is the net rate of tax and rent after subtracting Poor Law transfers. To analyze the evolution of useful knowledge A and human capital H it will be simpler, both for intuition and for drawing phase diagrams, to adopt the trick of using the inverse of human capital, M. The intuition

$$M \equiv \frac{1}{H} \tag{5}$$

of M is that it is an index of both ignorance and physical weakness ("misery").

that Malthus would define as "misery and vice" and we will refer to simply as "misery", remembering that it also refers to low levels of schooling and other outcomes of childhood

$$\begin{aligned}\Delta \log A_t &= \delta \log \tilde{A} - \delta \log A_{t-1} - \eta \log M_{t-1} \\ \Delta \log M_t &= \lambda \log \frac{N_t^{\alpha}}{\gamma(1-\tau)} - \lambda \log A_{t-1} - (\mu - \lambda\alpha) \log M_{t-1}\end{aligned} \tag{6}$$

deprivation. It follows that useful knowledge and malnutrition evolve according to the log-linear system of difference equations:

Assuming that population is more than a handful of people so that $N^{\alpha}_t > \gamma(1-\tau)$, only one coefficient of this system has a sign that is not immediately obvious: the $(\mu - \lambda\alpha)$ term multiplying $\log M_{t-1}$ in the malnutrition equation. If $\mu < \lambda\alpha$, the real wage at the technological minimum rises as population N or net taxes τ increase as (9) below shows. In addition, the malnutrition process is unstable: a rise in malnutrition lowers output and human capital investment, increasing malnutrition next period in a self-reinforcing process so long as population remains stable. We therefore assume that $(\mu - \lambda\alpha)$ is positive.

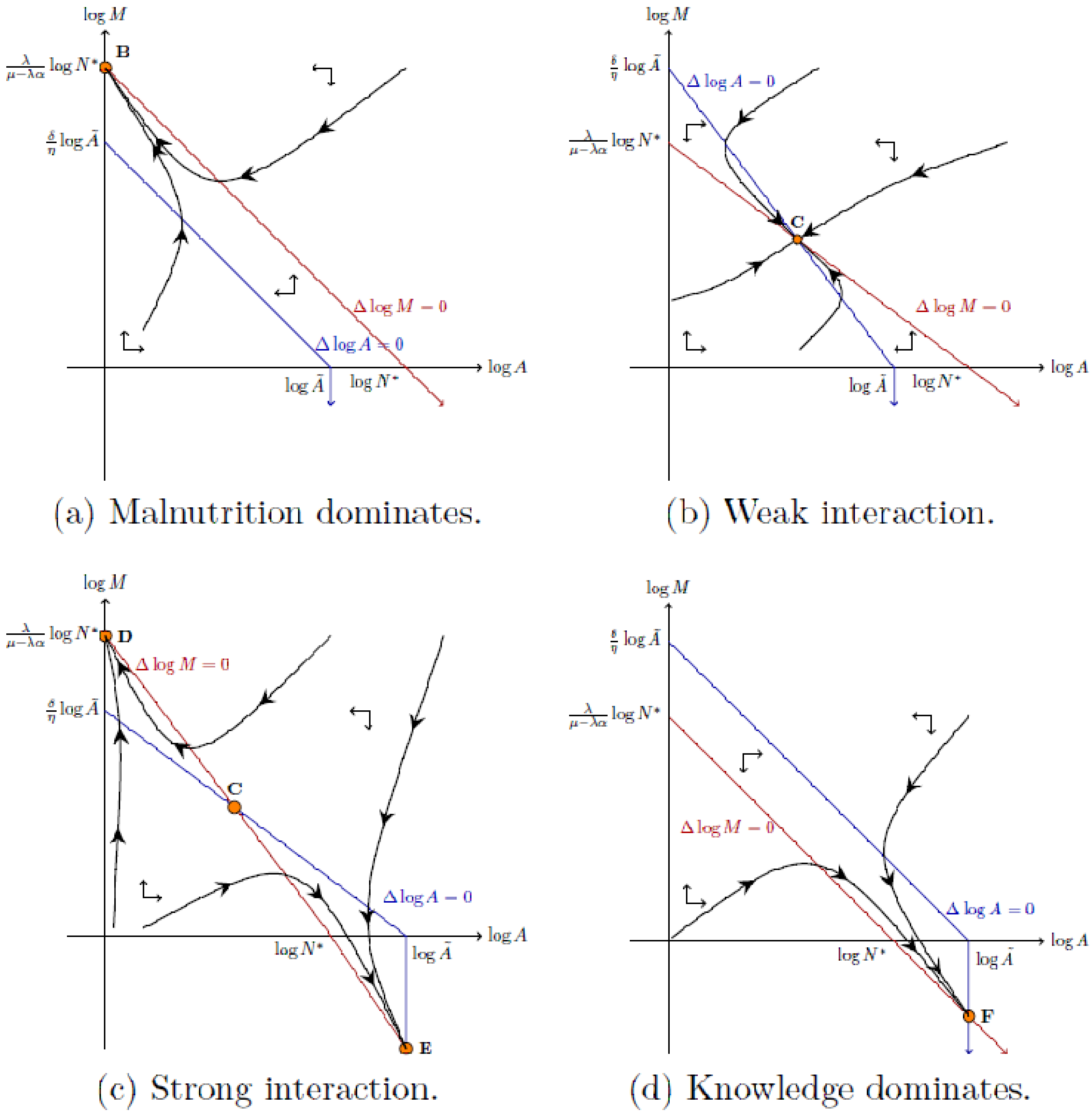

Figure 1: The four equilibria of the knowledge-misery system.

The isoclines of the system, between the minimum and maximum levels of technology, are:

$$\Delta \log A = 0 \qquad \log M = \frac{\delta}{\eta} \log \tilde{A} - \frac{\delta}{\eta} \log A$$

$$\Delta \log M = 0 \qquad \log M = \frac{\lambda}{\mu - \lambda\alpha} \log \frac{N_t^\alpha}{\gamma(1-\tau)} - \frac{\lambda}{\mu - \lambda\alpha} \log A \qquad (7)$$

The knowledge-misery system has four possible steady states depending on the relative position and slope of these isoclines.[9] In the phase diagrams we denote for simplicity $N^\alpha_t/(\gamma(1\text{-}\tau)) = N^*$.

In the first panel of Figure 1, the misery isocline lies everywhere above the knowledge isocline so that misery dominates. The only equilibrium is at point B, with the log of useful knowledge equal to its lower bound, which we have set at zero.

In the second and third panels the isoclines intersect at C = $\overline{\log A}$, $\overline{\log C}$, where:

$$\overline{\log A} = \frac{1}{\lambda\eta - \delta(\mu - \lambda\alpha)} \left[\lambda\eta \log \frac{N_t^\alpha}{\gamma(1-\tau)} - \delta(\mu - \lambda\alpha) \log \tilde{A}\right]$$

$$\overline{\log M} = \frac{\delta\lambda}{\delta(\mu - \lambda\alpha) - \lambda\eta} \left[\log \frac{N_t^\alpha}{\gamma(1-\tau)} - \log \tilde{A}\right] \qquad (8)$$

In the second panel, the own effect terms in (6) dominate the cross effect terms $\delta(\mu\text{-}\lambda\alpha) > \lambda\eta$ so the technology isocline is steeper. As a result, the intersection point C is globally stable.

In the third panel, cross effects dominate own effects $\delta(\mu\text{-}\lambda\alpha) < \lambda\eta$ so the misery curve is

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[9] There is also the case where the isoclines exactly coincide, making every point along them a steady state.

steeper. As a result, the intersection point C = ($\overline{\log A}$, $\overline{\log C}$) is a saddle point dividing the space into two basins of attraction, one converging on point D with technology at its lower bound, the other at point E where the malnutrition isocline cuts the upper bound of technology $\log \tilde{A}$.

Finally, in the last panel of Figure 1, the knowledge isocline lies everywhere above the malnutrition isocline, so the system converges to a steady state at point F where the malnutrition isocline cuts the upper bound of technology $\log \tilde{A}$.

Intuitively, the evolution of useful knowledge and malnutrition in (6) resembles an eco-system with two competing species: the growth of each species is retarded by the presence of the other. In the first panel of Figure 1, conditions are so favourable 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; with the converse holding in the fourth panel where knowledge dominates. In the second panel, the species have little impact on each other and both co-exist at positive levels, while in the third panel they have a strong impact on each other but the outcome depends on which population initially has a sufficiently large population to dominate the system.

Given our concern with the origins of the Industrial Revolution, we have focused on the applied technology and malnutrition as the driving forces of growth. However, the basic structure of (6) lends itself to other growth models.[10] To return to the Industrial Revolution, we now analyze how this simple model of knowledge and malnutrition can explain the differing experiences of two economies such as France and England and how differing levels of human capital affect an

[10]For instance we can start with a Solow model where capital accumulates through time, and add corruption or anarchy — the inverse of institutional quality—as a competing species: corruption retards the accumulation of capital, while rising income causes institutional quality to rise. Assuming the interaction between capital accumulation and corruption is sufficiently strong, we will end up in a system like panel 3 of Figure 1, where economies cluster around two steady states: either rich and clean, or poor and corrupt.

economy's ability to apply knowledge.

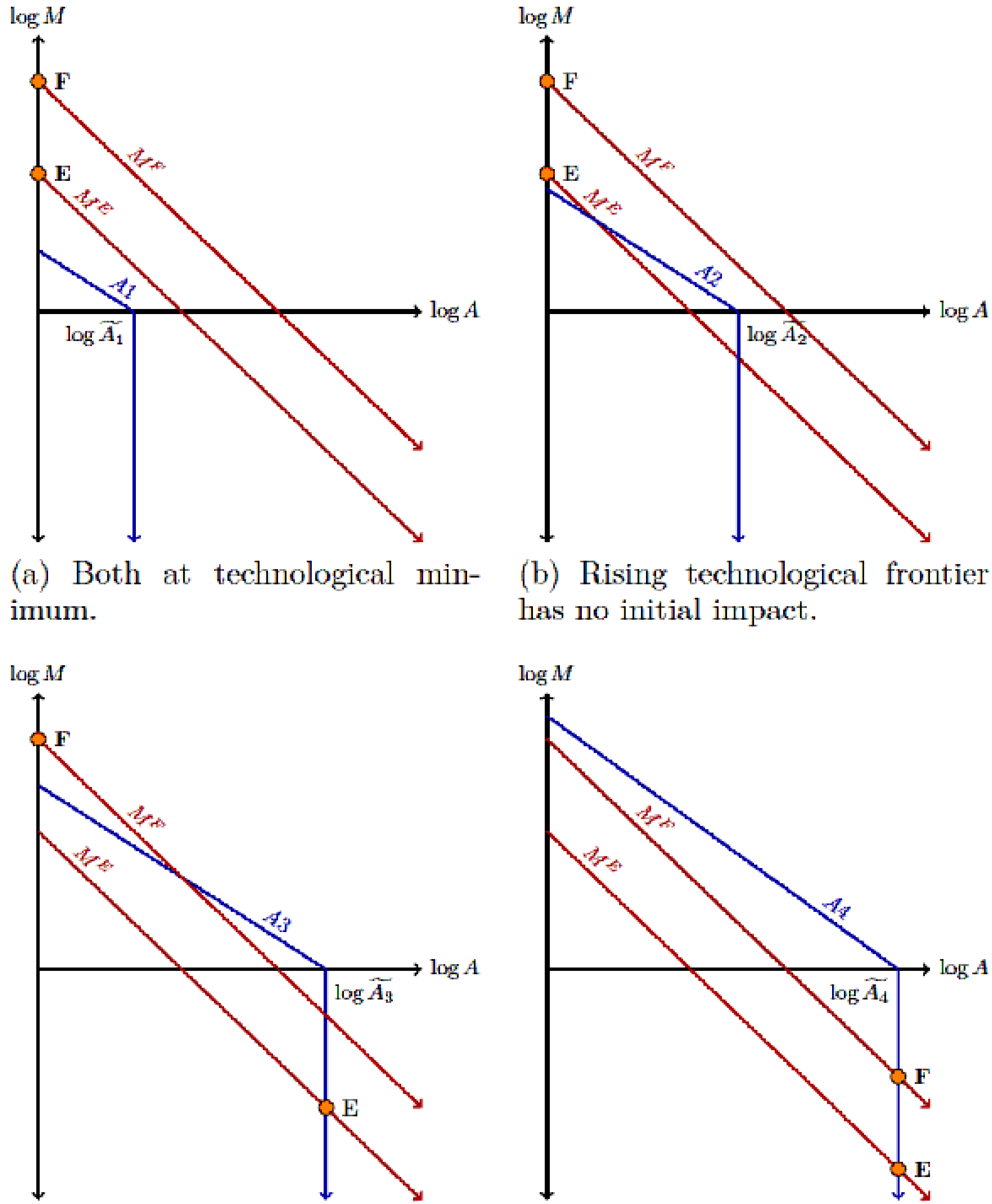
There are two economies that we shall call France and England. Each faces the same technological frontier A that rises through time, reflecting exogenous technological progress due to a change in useful knowledge. France and England differ in only one way: for a variety of reasons disposable income at the outset is higher in England than in France. The existence of a Poor Law in England but not in France implies that for the population at large (leaving out the landlords), $\tau_E < \tau_F$ where subscripts E and F denote England and France respectively.

At the technological minimum, where the system begins, workers in each economy i = E,F have log disposable income:

$$\log(1-\tau_i)\,w_i = \frac{1}{\mu - \lambda\alpha}\left[\log\gamma + \mu\log(1-\tau_i) - \alpha\mu\log N_i\right] \qquad (9)$$

In this pre-industrial world, if both economies are in a Malthusian equilibrium where births equal deaths, and they are subject to the same behavior parameters, they will have the same disposable income except for differences in τ. For English living standards to be above French ones, it could be the case that England had a higher death rate at each wage level (reflecting *lower* standards of hygiene or a worse morbidity regime or system of public health). In fact England's death rate was somewhat lower than France's. An alternative would be for it to exercise the "prudential check" and the decisive difference would then lay in the lower English marriage rate. A third alternative would be for the λ's to differ between the two countries, that is, for the British system of creating human capital to be more efficient than France's, for instance through its apprenticeship system working more effectively. We will return to this point below.

The incentive created by a poor law to lower population can be seen directly in the disposable income equation (9). If landlords are required to provide workers with a higher level of disposable income, they can increase poor law transfers by reducing net taxes and rents τ_i, or they can try to reduce N_i, by discouraging early marriage and so increase the marginal product of labour directly. We therefore expect that, in otherwise identical regions of France and England, the English requirement to provide a higher level of subsistence to workers implies that English regions would support lower populations: $N_E < N_F$. This means that the English misery isocline $\Delta \log M = 0$ will lie below the French one. In Figure 2 we denote the English and French misery isoclines by M_E and M_F respectively, and the equilibrium of each economy by E and F. We want to see how these change as the technological frontier $\tilde{A}$ gradually rises through time.



(a) Both at technological minimum.

(b) Rising technological frontier has no initial impact.

(c) England moves to technological frontier.

(d) France moves to technological frontier.

Figure 2: Impact of rising technological frontier $\tilde{A}$ on equilibrium in two economies with different misery isoclines.

Our starting point, in panel (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. As a result, both economies are at an equilibrium at the lower bound of knowledge. As time passes elite knowledge will rise, reflecting the accumulation of useful knowledge during the Scientific Revolution and its diffusion through the Enlightenment. This process will be the exogenous driving force behind the model. We will show that a process of interaction between misery and technological diffusion generated a process much like induced innovation: England is precocious, but its inventions disseminate to other poorer countries with a lag. In panel (b) the knowledge frontier has risen so that the knowledge isocline A_2 now intersects the English misery isocline. We suppose that misery and useful knowledge or capability strongly affect each other $\delta(\mu-\lambda\alpha) < \lambda\eta$ so that the misery isocline is steeper: when the opposite holds the evolution of the system is broadly similar as we will see below. While a steady state exists at the knowledge frontier, as in the third panel of Figure 1, because the English economy is starting in the basin of attraction of the low knowledge equilibrium, it stays at this point. The rising technological frontier has no impact on production technology because the level of human capital is too low to absorb it: the technological enlightenment has no impact down on the farm. This, then, can be seen as a world of Malthusian stagnation as assumed by Clark.

In the third panel of Figure 2, the continued gradual rise in scientific knowledge causes the technology isocline to move above the English misery isocline, but still to cut the French one from above. As a result, while France stays at the minimum technology Malthusian steady state at F, England jumps to the technological frontier at E. A small rise in the knowledge frontier causes a sudden divergence between the economies to occur. Because English human capital, for whatever reason, is slightly higher than French, England can start to apply technological knowledge to production, giving rise to a cumulative process of rising living standards, rising human capital, and rising production technology. A gradual rise in knowledge above a critical level causes England to experience an Industrial Revolution, while France appears mired in age-old backwardness.

This divergence is not permanent however. As the knowledge frontier $\log \tilde{A}$ continues to rise in the last panel of Figure 2, the technology isocline A_4 moves above the French misery isocline, causing France to converge to the same technological frontier as England. While technology in both economies is the same, living standards in England will be higher so long as it continues to enjoy higher transfers and a lower population. However, to the extent that rising living standards erode political support for a generous poor law, while urbanization removes social restrictions on early marriage, or to the extent that the British advantage in accumulating human capital is gradually dissolving, English and French living standards will converge.

The connection between misery and technological progress

As noted we have used "misery" as the inverse of human capital and thus interacting with productivity and technological progress. It is this nexus we will now explore in some detail. As noted, there is little dispute that British wages were higher than France's. Most interpretations acknowledge England's lead in terms of living standards on the eve of the Industrial Revolution. Allen (2001: 428) reckons that the real wages of eighteenth-century construction workers in London were almost double those of their Parisian peers, while Maddison's national income data (2009) imply that Great Britain's edge over France in GDP per head rose from about 60 per cent in 1700 to 70 per cent in 1820. Skilled British construction workers were still being paid two-thirds more than their French colleagues in c. 1800, and unskilled British workers almost twice as much.[11]

If income per capita affects labor productivity (instead of just the other way around), we are in an efficiency -wage world, in which employers or tax payers find it in their interest to pay workers more than the lowest wage they would have to pay, because by paying a higher wage they increase their productivity. They 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. This happens when the nexus between productivity and wages occurs through improved physical capability of workers. An employer may want to pay his workers a higher wage to elicit more work out of them. If this efficiency wage elicits a personal loyalty to the employer and thus reduces the productivity effects of asymmetrical information, this would work fine, but if it works through a mechanism of improved worker strength and energy, 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 a attempt to prevent local free-riding on improved worker quality.

Physical and Demographic differences

The higher productivity of British workers has two separate dimensions. One is a physical one, the other is one of competence and skills. The physical dimensions of the argument are immediately supportive of our argument that workers in Britain were more productive than in France; much of the work carried out, even in an age of growing mechanization, demanded physical strength,

[11]Josiah Tucker, one of the best-informed and writers of his age, writing in the late 1750s, thought that "the English have better conveniences in their houses and affect to have more in quantity of clean, neat furniture and a greater variety such as carpets, screens, curtains, chamber bells ... than are to be found in any other country in Europe, Holland excepted" (Tucker, 1758, p. 26).

endurance, and stamina.

Robert Fogel (1991, pp. 44-8) has famously argued that British workers, by being better fed than their French colleagues, were capable of more work and estimated that the median French worker consumed about 2200 kcal per day, considerably less than a median English diet of about 2600 kcal. The more recent calculations in Harris et al (2010) are much the same: they refer to averages around 1800, and put the English mean at 2,456 kcal as opposed to the French mean of 2,000.[12] This estimate is resonant with Arthur Young's assessment.[13] A summary of these findings is presented in Table 1.

Table 1: Calories per head and per consuming unit in England and Wales, 1700-1850 and in France in 1800 and 1705

Year	kcals per capita	kcals per consuming unit
ENGLAND		
1700	2,229	2,951
1750	2,168	2,867
1800	2,456	3,271
1850	2,524	3,337
FRANCE		
1705	1,657	2,209
1800	2,000	2,667

Source: Harris *et al*. 2010: Tables 6 and 8; Toutain 1995; Fogel 2004: 9.

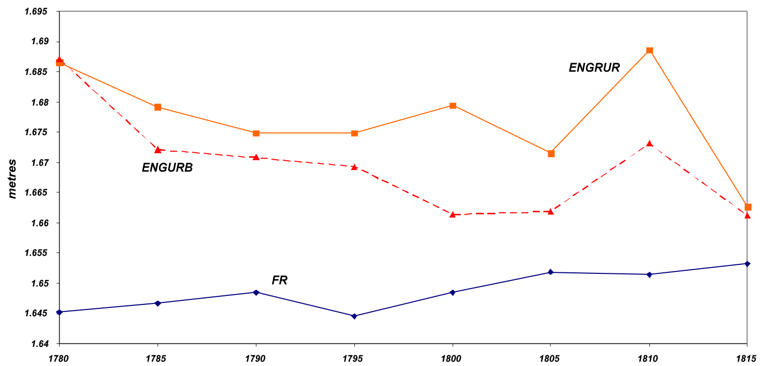
[12]Fogel (2004, p. 11) computes the energy "available for work" (after basal metabolic needs) and compares France's 600 kcal in 1785 with Britain's 858 in 1800, an advantage of 43 percent. Voth (1997) has shown that Fogel's figures for Britain actually still underestimate the calorific intake of the poorest of the British workers, and that the supply of energy available for work for the poorest ten percent of British work increases by a large factor. Fogel estimated that the lowest decile in England had only enough energy to work 1.10 hours of light work per day, or 0.18 of heavy work; Voth shows that once we account for a host of mitigating factors, these numbers rise to 12.68 and 2.11 respectively, a factor of eleven.

[13]Young wrote that "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-this also will I believe to be found to be correctly the case; and if the great superiority, not only of English husbandry, but also of those manufactures into which machines do not enter any more than in France, be well considered, this extension of these proportions will not be thought at all extravagant" (Young, 1793, Vol. II, p. 315–16). Earlier eighteenth century observers produced similar estimates; thus J.T. Desaguliers, who estimated in the 1740s that the strength of five Englishmen equaled that of a horse, as did the strength of seven Dutchmen or Frenchmen (Desaguliers (1734–44, Vol. 1, p. 254).

The impressionistic statements by Young and the somewhat heroic comparisons made by Fogel and his co-authors (based on agricultural output data) are reinforced by data on heights. Figure 1 below describes the average heights of French army recruits and English male convicts (Weir 1997: 191; Nicholas and Steckel 1991). Both sets of data refer to cohorts born between 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 and Ó Gráda 1996). We have added 1 cm. to the French heights to reflect the fact that they refer to recruits aged 20-21 years. The comparison suggests that the gap between French and English heights on the eve of the Industrial Revolution was considerable-about four centimetres. 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 Fogel 2004: 13; Heyberger 2007). The significant height advantage of English workers may have meant that they were physically stronger than their French counterparts. Modern physiological research documents the link between height and grip or muscle strength. For example, a recent study of Indian female laborers implies an elasticity of about two between height and grip strength (recorded in kilograms), while a study of champion weight lifters found that weight lifted "varied almost exactly with height squared", again suggesting an elasticity of two between height and strength (Koley et al., 2008; Koley et al. 2009; Ford et al. 2000).[14]

[14]If we take Fogel's (2004, p. 13) estimates for England and France for the late eighteenth century, English workers were about 3 percent taller than French ones, giving them a 6 percent additional strength.

Figure 1. English and French Adult Male Heights, Cohorts Born 1780-1815



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) reckons that every additional 1 cm. in height is associated with a gain in wage rates of "roughly 5-10 percent." Gao and Smyth (2009), using contemporary urban Chinese wage data, find that each additional centimeter of adult height is associated with wage gains of nearly 5 per cent for males and 11 per cent for females. If a similar relationship between heights and productivity held two centuries ago, then the 4 cm. gap in heights gap between Englishmen and Frenchmen at the time implied a gap of 20-30 per cent in wage rates. This would account for a significant proportion-though 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 link between physical characteristics and wages also implies that even unskilled English workers generated more output per period worked than their French counterparts. Did they? A comparative look at piece rates and day rates in French and English agriculture, along the lines separately pursued by Gregory Clark for England and George Grantham for France two decades ago (Clark 1987; 1989; 1991; Grantham 1991; 1992; Mokyr 1991), can be used to impute hourly productivity. A summary of the available data suggests considerable productivity advantages for Britain in the harvesting of wheat. Clark (1991, p. 449) estimated the cost of reaping wheat from scattered but plentiful evidence in the reports prepared for the Board of Agriculture in the 1800s. The average of the forty-four observations found by Clark is 2.9 man-days per acre (or 7.2 days per hectare).[15] This indicates a considerable advantage over France: in Grantham's regions around this time the cost measured in man-days ranged from 9.3 man-days per hectare in the relatively advanced Nord to 16.3 man-days per hectare in economically backward Brittany (compare Table 2A below). The average cost, weighted by output share, was 12.9 man-days per hectare (Grantham 1992, p. 362). Even with considerable margins of error, it seems reasonable that a 79 percent productivity advantage for British workers reflects a real difference in the quality of labor.

Wages differed not just between England and France; they also differed significantly *within* both countries (as is also implied by the big difference between Allen's wages in Strasbourg (6.75

[15]Clark's estimate are consistent with data collected by Arthur Young on his agricultural tours of England over three decades earlier. Dividing the median costs of reaping an acre of wheat (60d) by the median harvest wage (20d-22d per diem) on both Young's southern and northern circuits yields a rate just short of three days per acre (Young 1771: IV, 293-96; 1772). Given that piece-workers earned more than 'the weekly pay of the country' (1771: IV, 296), this calculation probably biases our estimate of the productivity of harvest labour downwards. Young would probably not have objected to a rate of 7 man-days per hectare. For an analysis of Young's surveys of English agriculture, see Allen and Ó Gráda, 1988.

g. silver in 1780) and Paris (9.64g. for the same). Indeed, in 1767-70 agricultural wages in southern English counties such as Hertfordshire (at 7s. 6d. per week), Cambridgeshire (7s. 4d.), or Norfolk (8s.) were distinctly higher than in northern counties on the verge of industrialization such as Lancashire (6s. 6d.) or the West Riding of Yorkshire (6s.) (Hunt 1986a: 965; Hunt 1986b: 60-1). However, the gaps between wages in the regions of France were much greater (Chanut et al. 1995). Crébouw's analysis of official surveys conducted in the 1790s and 1800s suggests that interregional wage gaps across France were then considerable.[16] While in the *départements* of Eure or Seine-Inférieure in c. 1790 a worker might have earned enough to buy a quintal of wheat in what he or she earned in 6 to 6.5 days, in the Breton départements of Morbihan or Ile-et-Vilaine it would have taken double that (Crébouw 1986: 740). In 1840, when data by *département* become available, agricultural wages in Breton départements were only sixty per cent the national average, whereas in the *départements* surrounding Paris they were one-quarter above the national average.

The internal variation within France and the fact that data by *département* is available and lends itself to statistical analysis can be utilized to test our hypothesis. Some of Grantham's estimates are summarized in Tables 2[A] and 2[B]. They show that, calculated in terms of man-days per hectare, labor productivity in c. 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 are provided by Aron et al. (1972, pp. 92-93).

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[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 centre… The north — with its combination of high wages, steady employment, and low grain prices — seems clearly privileged (Crébouw 1986: 733-39; our translation).

TABLE 2 (A). HARVEST AND THRESHING COSTS IN MAN-DAYS PER ACRE: WHEAT c. 1800							
Region	*Pre-harvest (light)*	*Pre-harvest (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
Note: Threshing costs estimated by multiplying yield by man-days per hectolitre							

TABLE 2 [B]. Cost per hectare and per hectolitre: wheat in man-days c. 1800				
	Cost per hectare		Cost per hectolitre	
Region	*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
North	45.5	40.7	2.34	2.62

Source: Table 2(a); Grantham 1993: 483

As an alternative anthropometric measure, we also use their estimates of the proportion of "small" recruits by département. In both cases regional height is taken to be the arithmetic mean of the estimates for the relevant *départements*. Table 3 reports the results of correlating these heights data to Grantham's measures of labour requirements in the seven farming regions identified by him. The correlations between height and measures of productivity are very high. They would be higher still if Brittany (where productivity was high relative to height) was excluded. The implied elasticities are huge, but we have not controlled for likely differences due to soil quality (other than the distinction between "light" and "stiff" soils), capital equipment, or other forms of human capital. Moreover, the estimates are biased because we have not allowed for the obvious persistence in both variables, meaning that high wages in the past may have "caused" greater stature in the present.

Table 3:Correlations between height and measures of labour productivity				
	Average height		Percentage 'small'	
	Light	Stiff	Light	Stiff
Pre-harvest	-.846	-.812	.847	.810
Hectare	-.780	-.732	.817	.771
Hectolitre	-.851	-.885	.857	.891
Sources: Grantham 1993; Aron et al. 1972: 86-87, 92-93.				

More detailed departmental data on France in the nineteenth century indicate a strong correlation between height (and other measures of physical well-being) and productivity or wage. As Table 4 shows, estimates relating wages and agricultural productivity (measured as wheat yield per ha divided by man days per ha.) in 1852 show that the two are not only highly correlated (r = .400) but that they are by and large determined by the same variables: both are clearly positively influence by factors determining physical well being and by literacy.

Table 4: Regressing 1852 wages in France on measures of labor quality.(t-stats in parentheses)

dependent variable	Wage, 1852	Wage, 1852	Wage, 1852	Wage, 1852	Wage, 1852
Constant	-20.39 (-5.32)	111.7 (12.83)	-1.316.5 (-2.45	-1,445.0 (-3.76)	102.3 (13.02)
Height	1,322.2 (5.73)		873.1 2.65	954.2 (4.11)	
Literacy		.867 (5.41)	.438 (1.96)		.799 (5.34)
urban				.880 (3.96)	.932 (4.63)
goitre					-6.418 (-2.24)
n	86	85	85	86	81
adjusted R^2	0.272	0.252	0.303	0.380	0.455

dependent variable	agricultural productivity 1852	agricultural productivity 1852	agricultural productivity 1852	agricultural productivity 1852	agricultural productivity 1852
Constant	-10.72 (-5.49)	.241 (5.85)	-3.99 (-1.53)	-10.12 (-4.76)	.233 (5.55)
Height	6.76 (5.75)		2.59 (1.62)	6.39 (4.97)	
Literacy		.0052 (6.88)	.00395 (3.63)		.00546 (6.84)
urban				.00088 (0.72)	
goitre					-.0348 (-2.40)
n	86	85	85	86	81
adjusted R^2	.274	.356	.368	.270	.453

A somewhat different and more indirect measure of the physical quality of British labor can be inferred from demographic variables. An obvious measure is life expectancy. If life expectancy was significantly longer, this reflects 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 if these had a better chance to survive. According to the Cambridge Group family reconstitutions expectation of life 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: 295). In France in the 1740s e_0 was about 25 years; between 1750 and 1789 it averaged 28.1 years. The data are reproduced in Table 5.[17] Most of the gap between English and French e_0's on the eve of the

[17] Moreover, in 1750 the proportions of the population living in cities with at least ten thousand inhabitants were 16.7 per cent in England and 9.1 per cent in France; in 1800 they were 20.3 and 8.8 per cent (de Vries 1984: 39). Given lower urban life expectancies, the gap between life spans in rural England and France must have been even higher than reflected in Table 7.

Industrial Revolution was due to the much higher survival rates of English infants and children, but the gap for adults exists as well even if it is smaller.

Table 5: Life Expectancies in Eighteenth century England and France

	e_0		e_1		e_{25}	
	England and Wales	France	England and Wales	France	England and Wales	France
1740–49	37.3	24.8	46.2	34.0	34.5	31.3
1750–59	42.1	27.9	50.5	37.4	36.6	33.7
1760–69	39.0	27.7	47.2	37.4	34.4	33.8
1770–79	39.4	28.9	47.3	38.6	35.3	34.9
1780–89	39.2	27.8	47.4	37.4	33.9	33.5

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 Harris et al. (2010) emphasize the link between inadequate food consumption-hunger-and "premature death." Fogel's energy accounting study (2004: 9-11) of the nutritional status of the French and the English offers corroborative evidence that in the late eighteenth century the English were better fed. The amount of energy available for work per capita in his estimate (measured in kcals) was about one-third higher in England than in France: 600 kcals in France in 1785, against 812 kcals in England in 1750 and 858 kcals in 1800. Moreover, Fogel claims that a higher share of England's calories came from animal sources, adding to the relative quality of its diet. Even in England diets were not quite adequate, but they were significantly better than in France: at the end of the eighteenth century fewer than one English worker in five but more than one French worker in three (19 and 37 per cent, respectively) consumed enough calories even for a full day's light work.

On the other hand, if infant mortality rates were lower because British women tended to breast-feed their babies more than French ones, the long-run effects on adult health may be harder to discern.[18] Yet they may have been present: some modern evidence suggests that longer breast-feeding may be associated with more rapid development and better health at adult ages (http://www.bpni.org/information_sheets/IS-9.pdf). Another possibility is the decline in smallpox, which may have been faster in Britain due to the more successful application of pre-Jenner inoculation techniques (Rusnock 2002, p. 90), especially after the adoption of improved methods by Robert Sutton in the 1760s. There is still an ongoing debate to what extent smallpox had a scarring effect and to what extent it reduced stature and health among British children, but there seems little dispute that there were "unquantifiable secondary complications and potentially fatal illnesses" from smallpox (Mercer, 1985, p. 307). Childhood disease contributed, no doubt, to terminal height and thus to adult productivity. Many of the French children who survived to adulthood were probably scarred by sickness. Modern data finds a "strong inverse relationship between postneonatal (one month to one year) mortality, interpreted as a measure of the disease and nutritional burden in childhood, and the mean height of those children as adults" across ten European countries and the U.S. (Bozzoli, Deaton, and Quintana-Domeque, 2009). A greater degree of permanent scarring in eighteenth-century France than England is plausible. At the same time, with sufficiently high

[18]British mothers were reported by some contemporaries to breast-feed their babies more than their continental neighbors, and this has been argued to be a main reason for their lower marital fertility and infant mortality. The Prussian von Archenholz ([1785], 1797, p. 327) noted that "English women of quality often suckled their own children; they do not consider the name nor the duties of a mother disgraceful." Modern experts seem to have accepted this view (Fildes, 1986, p. 106; McLaren, 1990, p. 163).

mortality rates it is possible that selection dominated scarring and that the surviving population in the high-risk group turned out to be taller and healthier than in the other.

In a Malthusian framework, the issue of why all this was taking place cannot only be resolved by the British practicing some form of preventive check that reduced their fertility rates for any wage level below the French levels. After all, a higher life expectancy in the absence of continuous productivity growth would entail a lower equilibrium wage ceteris paribus, but a more powerful preventive check could compensate for the impact of lower mortality. The findings of the Cambridge Group for England and the INED enquête, led by Louis Henry, for France demonstrate that such was the case. In the late seventeenth and eighteenth centuries France's crude birth rate was higher than England's. Englishmen and Englishwomen were less inclined to marry and, when they did they were more inclined to have smaller families. The proportion never-married before 1750 was substantially higher in England than in France, although by 1750, these positions are reversed (fig. 4). Yet a main form of preventive control was lower marital fertility at any marriage, consistent with higher breast-feeding practices in Britain noted above.

Cognitive Effects and Skill Differences

Were British workers more productive because they were smarter than French workers? Recent work establishing correlations between height and various cognitive abilities would point in this direction. This has nothing to do with any inherent genetic 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 and iron deficiency in infancy and early childhood with weakened cognitive development (e.g. Scrimshaw and Gordon 1969; 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 as the determining factor. 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.[19] The anecdotal evidence linking Britain to beef eating in the eighteenth century is abundant. Henry Fielding, in his famous poem on roast beef, made a point similar to ours about the effect of beef on the mind and the body.[20] While he lamented that in his own age (1731) "we have learnt from all-vapouring France/ To eat their ragouts as well as to dance," in fact many other travelers commented on the beef-eating habits of the British.[21]

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[19]Interestingly enough, these studies find that this difference depended on the consumption of meat, but not for dairy products, which may be important in view of the anecdotal evidence that the British ate a great deal of meat in the era before the Industrial Revolution. In his recent book, Craig Muldrew (2011, p. 153) reports that British adult laborers consumed about 0.7 lbs of meat a day around 1770. This compared favorably with Toutain's estimates of France's per capita meat consumption of 0.1 - 0.13 lbs per capita on the eve of the French Revolution. In Germany, too, meat consumption was low. The comparison is biased, but given the high inequality of income distribution on the Continent, it is not clear of a per capita estimate is all that much downward biased in comparison with an adult male laborer. See Blum (1974), pp. 413–15.

[20] "When mighty Roast Beef was the Englishman's food,
It ennobled our brains and enriched our blood.
Our soldiers were brave and our courtiers were good
Oh! the Roast Beef of old England,
And old English Roast Beef!"

[21] Thus B.L. de Muralt, a Swiss traveler, in 1726: "The pleasures of the table in this happy nation consist chiefly in a variety of puddings... and roast beef which is a favorite dish as well at the King's table as at Tradesman. 'T is common to see one of these piece weigh from twenty to thirty pounds...This may be said to be (as it were) the emblem of Prosperity and Plenty of the English" (Muralt, 1726, pp. 39-40). In 1748 Per Kalm, a Swede, similarly remarked that he does not believe that any Englishman "who is his own master, has ever eaten a meal without meat" (Kalm, 1892, p. 15). Contemporary opinion also explained why. In 1736, an anonymous writer explained that "we have of late years increased in the Breeding Live-Stock of all kinds and the great supply of the Northern parts and Wales have glutted the London markets with meat far beyond its consumption and therefore lowered the price ...to be in the reach of the common people" (Anonymous, 1736, p. 23).

Recent research on heights and income in advanced economies (Case and Paxson 2008; Deaton and Arora 2009) has highlighted this work with richer and more systematic databases. That literature links the failure to reach one's potential height to failure to reach one's cognitive potential, and thereby to lower wages or income in adulthood (Weidner Williams, 1988; Bozzoli, Deaton, and Quintana-Domeque, 2009).[22] We are, of course, unable to measure average IQ rates for eighteenth century societies. What we know, however, is that IQ is strongly affected by nutritional intake, both quantitatively and qualitatively, that it is associated with measured height, and that height (the output) and nutrition (the input) differed between France and Britain. There is also an argument, made most strongly by Garrett Jones, that IQ correlates strongly with income per capita (Jones and Schneider, 2008, 2010). 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. All we are saying is 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.

Recent research on numeracy strongly supports our hypothesis. Baten, Crayen and Voth (2010) argue that using an index of age-heaping, reflecting numeracy, they can demonstrate a direct link from nutrition to cognitive ability. The idea of age heaping as a measure of numeracy was introduced into economic history by Mokyr (1983) and Mokyr and Ó Gráda (1985), but Baten, Crayen and Voth are able to establish that the high food prices in Britain during the French and Napoleonic Wars led to nutritional deficiencies that resulted in some kind of cognitive insult and which can be measured by their lack of numeracy decades afterward. The limitations of age heaping

[22] See also for example Eppig et al. (2010) on the link between the prevalence of infectious disease and IQ across countries.

techniques are such that a direct comparison between France and Britain could be misleading: too much depends on exactly how the question on age is posed and who makes the determination. Yet it seems clear that nutritional variables determine both height and numeracy (which they show to be strongly correlated), and thus can be said to impact both physical and cognitive development as a function of nutrition. The Baten, Crayen and Voth study is the only one that establishes unambiguously a connection between nutrition and cognitive development for a historical environment, although in the view of much contemporary evidence, this cannot be said to be a surprise.

Were British workers also better endowed with human capital? This is much more difficult to document. Standard measures of schooling and literacy rates are quite hard to compare, as they are measured using different techniques and at different times. Reis (2005) estimates mail adult literacy in Britain at ca. 1800 at 60 percent for males and 40 for females, slightly below Northern France (71 and 41 percent respectively) but above Southern France (44 and 17 percent). It is, however, open to question whether literacy at this early stage of the Industrial Revolution may have mattered a lot; highly literate regions in the Lutheran Baltic region remained late in their industrialization process (Sandberg, 1979). Mitch (1999) has specifically argued that Britain by the early nineteenth century was, if anything, overeducated. The main point we want to make here is that the standard human capital measures do not really reflect much advantage to Britain and do not explain its precocity.

Instead, we want to focus on a different form of human capital, namely the idea of *competence*. The basic idea is that technology, much like the performing arts, is an *implementable* form of culture; much like music and theatre it takes one person to write the original, but if it is to be successful it needs to be "performed" — that is, carried out by skilled individuals, whose skills, however, do not necessarily include comparable creativity and originality. Britain and France both could count on a considerable supply of original genius, but Britain had an advantage in skilled artisans. This was surely something that historians and contemporaries were convinced of.[23] 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 by Hollister-Short, 1976, p. 159). The idea that the British were above all good imitators thanks to their skilled labor force was reiterated by none less than David Hume, 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" (Hume, [1777], 1985, p. 328). Other such quotes can be found (Mokyr, 2009, pp. 107–08) and clearly it became something of a consensus amongst British economists to attribute the country's technological leadership to its advantage in skills.[24] But is there systematic evidence to back up contemporary observations?

One piece of evidence that suggests that Britain collected some kind of rent from her higher level of skills is that the mercantilist policy makers of the eighteenth century felt that the exportation of machinery and the emigration of artisans endangered these rents. The laws that prohibited the emigration of artisans and the exportation of machinery were first passed in 1696, and repeatedly amended in the eighteenth century. They remained on the books till 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

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

[24] Alfred Marshall in his *Industry and Trade* (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 snd far more truly than it could have been anywhere else."

to inspect large cargoes (Jeremy, 1981, p. 41). By the nineteenth century the laws were weakened and after 1815 barely enforced at all. All the same, they reflect a clear-cut view of what 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 (Harris, 1998).

How substantial was the migration of British technicians to Europe? Exact numbers are very hard to come by. It is quite clear, however, that it was not itself caused by the Industrial Revolution but preceded it, implying that the advantage that Britain enjoyed in the area of technical competence predated its technological achievements. John Holker, an English mechanic and political refugee in France, set up a textile manufacturing plant in 1752 in St. Sever, a Rouen suburb. He recruited many of his skilled workers in Britain, despite the risks to a Jacobite refugee. These skilled British workers would then be used to train French workers. In 1754, this firm employed no fewer than 20 skilled British artisans (Henderson, 1954, p. 16). The set-up was optimized to spread this knowledge: English workers were allocated among French workers so that skills could be disseminated in the most effective fashion (Harris, 1998, p. 60).[25] Holker had little doubt industrial improvements were derived above all from superior workers, and stressed that this superiority derived from British workers living in relative comfort, being well-fed, and working in freedom (ibid., p. 68). Of course, machinery was part of the British advantage, but, 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 (ibid., p. 413).

[25]Holker suggested to his French employers than preference should be given to English Catholic workers, whose loyalty to the British State might be lower, and suggested the French government concentrate on unmarried workers so they could be paired off with French women.

Of course, the Industrial Revolution strengthened this connection and after 1815 a very large number of British technicians found their way to the Continent, where they installed, maintained, and managed new equipment. The paradigmatic figure here was Aaron Manby (1776-1850) who set up a large engineering works in Charenton together with one Daniel Wilson in 1822 and were employing 200-250 Englishmen there in the mid-1820s (Henderson, 1954, p. 54), with the French providing only the manual labor. Evidence that the laws prohibiting this flow was in any way effective is sparse, but these laws did result in a Parliamentary investigation, which has yielded a rich if anecdotal and impressionistic body of evidence supporting the higher quality of British labor.[26] Thus it was maintained, much like Arthur Young's observation, that an English engineer, turner, or iron founder, working in France, will 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).[27] The great inventor and mechanical genius Bryan Donkin noted that a worker in the paper industry who might have made 18-20 s. a week in Britain, was hired at 50s. in France. Clearly, the much higher wages secured by skilled British workmen on the Continent is a reflection of the different scarcities. As late as 1820s, one 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

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[26]An engineer named Alexander Galloway felt that a person of similar qualifications would make 22 s. in Paris and 36 s 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 (ibid., p. 7) that a French blacksmith would make in France 4 francs a day, while an English smith in Paris would make 10– 11francs.

[27]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).

six hours as theirs in twelve (*ibid*., p. 580).[28] Philip Taylor, an engineer, pointed out that in Wurzburg, 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" (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).[29] 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.[30] How large were the flows? Mr. Alexander estimated that in the years 1822 and 1823 alone, 16,000 artisans moved from England to France (p. 108); this seems exaggerated, but a year later Galloway estimated the stock of English workers in France at 15,000-20,000 workers (Great Britain, 1825, pp. 37, 43).[31]

The higher competence of British workers is thus confirmed by the flows of immigrants, as well as by the reverse flow of 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 can

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[28]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."

[29]The witness attributed this difference to the comparative lack of dexterity among Belgian workmen, and their "nonchalance."

[30]Withers 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."

[31]It is true, of course, as Robert Fox has observed (1984, p. 142–3) that the French learned quickly and that as soon as local workmen had acquired the basic skills, the senior British operative became more of a rarity. Yet in 1841 a witness testified that in Liege Mr Cockerill, who had 2,000 men in his employ, "many of them Scotch and English" (Great Britain, 1841, p. 20). Another 1841 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 (ibid., 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" (ibid., p. 53).

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 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; Jacob Mayer, who worked for a time at Sheffield before opening a cast-steel mill near Cologne, and quite a few others (Henderson, 1954, ch. IV). Yet this of course may not solve the problem of British precocity as much as push it back.

Can we understand why Britain had this higher endowment of competence? The obvious answer is that this human capital was produced within the system by existing human capital. But the intergenerational transfers that created competence-intensive human capital were far from guaranteed. The vast bulk of artisans were trained as apprentices by other artisans. As Lane (1996, p. 76) has noted, "the untheoretical method of learning by observing a skilled practitioner was ... in genral use for centuries."[32] Was the British system better at doing so than other European economies? In her recent book on childhood labor and training, Jane Humphries stresses that apprenticeship in Britain was an outward looking institution that allowed boys to advance themselves and displayed a "resilience to entropy" (2010, p. 273). Unlike much of the Continent, the institution in Britain was not normally enforced and monitored by a guild with coercive powers. 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 if the contract itself was woefully incomplete (Humphries, 2003; 2010, pp. 282–83). It is also quite clear that apprenticeship was resorted to because it worked, not because of coercion. The 1563 Statute that formally prohibited craftsmen to carry out their trade without completing their apprenticeship was not uniformly

[32]For a very similar statement, see De Munck and Soly, 2007, pp. 6, 14.

enforced, and after its repeal in 1814, apprenticeship remained the main form for an English lad to acquire a professional training.[33] 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). Clearly this system of producing human capital was adaptive and worked well. 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 (Mokyr, 2008).[34] This institutional structure represents 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. Comparing human capital formation in Britain in a systematic way to that of other countries is still a research project awaiting to be done. But recent work in the area points out the nefarious effects of politics on how human capital was formed in France. The post-Napoleonic reaction restored religion and classical study to school curricula and regarded applications to production as revolutionary and subversive ideas, a policy especially vigorously applied in the industrial North (Jacob, 2011).

To summarize: the view put forward here as an alternative to the Allen theory is thus quite consonant with a notion that reconciles the seemingly inconsistent theories that pose "institutions" as opposed to "human capital" as the main engines of growth.[35] Instead, our view is that a variety of

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[33] London's carpenters and tailors, for instance, did not enforce the Statute of Apprentices: the corporation of the City of London passed regulations releasing masters from the need to insist on formally trained apprentices, since "the City masters could not permit the enforcement of regulations that might damage their trade" (Schwarz, 1992, p. 219).

[34] Yet, as Humphries emphasizes, the Poor Law contributed substantially to the accumulation of human capital, through the funding of pauper apprenticeships. Contrary to common belief, for much of the eighteenth century these apprenticeships provided real human capital to the children of the destitute who otherwise would have remained unskilled.

[35] See the critique of institutions as a critical variable in Glaeser et al., 2004.

institutions, including the Poor Law and the successful functioning of institutions that trained workers, led to a considerably higher *quality* of the labor force (both physically and in terms of competence) in Britain than on the Continent. This difference in quality implied higher real wages in Britain, but these wages were a *symptom* of these deeper factors rather than a primary *causal factor* themselves. Better institutions were not an alternative to higher human capital, but an input into it.

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