Robert C. Allen
<u>Lectures and Readings</u>

lecture 1: The long run history of poverty and living standards

Robert C. Allen, “Poverty Lines in History, Theory, and Current International Practice,” Oxford University, Department of Economics, Working Paper 685, 2013.

Robert C. Allen, Jean-Pascal Bassino, Debin Ma, Christine Moll-Murata, and Jan Luiten van Zanden, “Wages, Prices, and Living Standards in China,1739-1925: in comparison with Europe, Japan, and India," *Economic History Review*, 2011, Vol. 64, pp. 8-38.

Robert C. Allen, *The British Industrial Revolution in Global Perspective*, Cambridge, Cambridge University Press, 2009, chapters 1-2.

lecture 2: globalization and economic growth in early modern Europe

Robert C. Allen, "Poverty and Progress in Early Modern Europe," *Economic History Review*, Vol. LVI, No. 3, August, 2003, pp. 403-443.

Robert C. Allen, *The British Industrial Revolution in Global Perspective*, Cambridge, Cambridge University Press, 2009, chapters 3-5.

Daron Acemoglu, Simon Johnson, and James Robinson, “The Rise of Europe: Atlantic Trade, Institutional Change and Economic Growth,” *American Economic Review*, Vol. 95, 2005, pp. 546-79.

lecture 3: Explaining the Industrial Revolution

Robert C. Allen, *The British Industrial Revolution in Global Perspective*, Cambridge, Cambridge University Press, 2009, chapters 6-11.

Joel Mokyr (2005). “The Intellectual Origins of Modern Economic Growth” *Journal of Economic History* 65: 285-351.

Robert C. Allen, “The British industrial revolution: A Schumpeterian interpretation.”

lecture 4: The roots of American economic supremacy

Robert C. Allen, “American Exceptionalism as a Problem in Global History,” *Journal of Economic History*, Vol. 74, No. 2, 2014, pp. 1-42.

Nelson, R. R., and G. Wright. “The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective.” *Journal of Economic Literature* 30, no. 4 (1992): 1931–64.

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POVERTY LINES IN HISTORY, THEORY, AND CURRENT INTERNATIONAL PRACTICE

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Poverty Lines in History, Theory, and Current International Practice

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Measuring the standard of living has been a longstanding problem for economists and historians. A direct approach is to calculate the purchasing power of wages. The real wage is the ratio of the nominal wage to a measure of the price level. A common short cut is to use the price of grain as the measure of prices, in which case, the real wage becomes a 'grain wage' indicating the quantity of grain that can be purchased with a day's labour (Braudel and Spooner 1967, van Zanden 1999). An attraction of this procedure is that it provides an absolute measure of the standard of living. However, people consume more than grain, so it is preferable to measure the price level as a weighted average of the prices of the goods that workers consume. The weights should reflect consumer spending patterns. A limitation of this approach, as usually practised, is that the resulting real wage can only be interpreted as an index of relative income levels and has no absolute interpretation.

In Allen (2001, 2007) and Allen et al (2011), attempts were made to provided an absolute interpretation of real wages even when inflation is measured with an index of consumer goods prices. These studies examined mainly the wages of men employed in the building industry. The worker's annual earnings were computed by multiplying the daily wage by the number of days worked in a year (often taken to be 250). The earnings were divided by the annual cost of maintaining a family at a specified poverty line. The ratio of annual earnings to the cost of annual subsistence equalled the 'welfare ratio' of the family (Blackorby and Donaldson 1978). When the ratio equalled one, the worker earned just enough to keep his family at subsistence. Values greater than one equalled a surplus over subsistence, while values less than one equalled a deficit. The implications of a deficit depended on how 'subsistence' was defined.

The subsistence wage was a cornerstone of the classical economists (Ricardo, Malthus, Marx). They regarded English labourers as the bottom rung of the income hierarchy with incomes 'at subsistence' since they were the main beneficiaries of the Old Poor Law, which provided income supplements to keep labourer's consumption at subsistence–and no higher. The empirical counterparts to the classic theories were the surveys of budgets collected in David Davies' *The Case of Labourers in Husbandry* (1795) and Sir Frederick Eden's *The State of the Poor* (1797). Davies' and Eden's descriptions of spending are not problem free. They were often incomplete, but by combining details from several budgets a comprehensive view of family incomes and expenditure and can be assembled. The two prove to be in balance, and the quantities and prices of the main items consumed are known, so the budgets can be assessed for nutritional adequacy and so forth.

Table 1 shows the 'respectability basket' put together from Eden's work. The name identifies this was the standard of living to which a labourer in the south of England aspired. The table shows the consumption pattern for a man for one year.[1] The food items can be reasonably well determined from descriptions like Eden's and Davies'. When the basket is evaluated for other parts of the world, the contents are varied to reflect local food availability. Thus, olive oil and wine replace butter and beer in the Mediterranean, and price of the usual common meat or bean is used in each locality. The non-food items are harder to pin down, and the apparel component is represented by only a single item–linen or cotton cloth. This simplification was introduced since the cost of the budget must be calculated for many places

[1]The particular representation in Table 1 is intended to be a medieval or early modern version of the budget in that it excludes the new goods (potatoes, sugar, tea) introduced from Asia and America. These exclusions were made so that the budget could be priced in the middle ages and in countries where these new goods were not consumed.

over centuries to measure real wages, and light cloth is the only item of dress whose price is consistently reported on this scale. Likewise, the rental cost of housing is represented by a 5% charge on the other items in the budget since the cost of housing cannot presently be measured for the times and places that interest historians.

Two features of the budget should be highlighted since they will be subjects of discussion in this paper. The first is the calorie content of the diet which works out to be 1940 kcalories per day. This appears to be a minimal standard and not atypical of the budgets in Eden and Davies. The second is the 'scaling factor' used to relate the family's subsistence cost to that of an adult male. On the assumption that a family consisted of a man, a woman, and two children, it was assumed that a family corresponded to three adult male equivalents, so the cost of the budget in Table 1 was multiplied by three to determine the annual subsistence cost of the family. There has been some discussion of the correctness of the value (Allen and Weisdorf 2011, Humphries 2012), and it is reassuring that detailed calculations by Floud et al. (2011, p. 46, 165-7) found that, indeed, the calorie requirement of the average person in England in the eighteenth and nineteenth centuries equalled 76% of the requirement of the average adult male, i.e. three adult males corresponded to four people in the overall population.

Figure 1 shows the welfare ratios for six cities in Eurasia when subsistence is calculated according to the respectability budget of Table 1. For labourers in London and Amsterdam, the results are in line with the views of the classical economists, for these workers earned only marginally more than subsistence. In the fifteenth century, workers in Florence and Vienna lived as well, but by the eighteenth century, their real wage had fallen to less than half of the respectability standard. Living standards were similarly low for wages in Delhi and Beijing.

What could the families do to make ends meet? Income could be increased if the man worked more or if the women and children earned money, but the chances of closing the gap were not good when the man earned less than half of the cost of the basket. In that case, spending economies would have to be made. These were possible because the respectability basket was, in fact, a high cost basket. Beer, meat, even bread were expensive sources of calories.

Costs could be cut by eliminating the expensive calories from the diet and by reducing the consumption of non-food items. Table 1 shows 'subsistence' baskets defined in this way. They are based on a diet in which most calories come from the cheapest available grain (oats in northwestern Europe, maize in the Americas and northern Italy, millet in northern India, sorghum in Beijing, and wheat flour today in many parts of the world), legumes are an important source of protein, butter or oil provides some fat, and meat or fish are rare luxuries. Diets along these lines, in fact, were common in many parts of the pre-industrial world.

For comparative purposes, a 'Northern' basket is also defined in Table 1. People in Northern Britain consumed an oat based diet in the eighteenth century (Dr. Johnson defined oats to be 'a grain, which in England is generally given to horses, but in Scotland supports the people.'), and that is an inspiration for the oat-based subsistence basket. However, many people in Northern Britain ate a more varied diet when they could afford it. Table 1 shows a stylized version. It is included since a diet based on coarse grain, potatoes, and milk is common in India and other poor places today.

Figure 2 shows the welfare ratios implied by the subsistence baskets. The geometry is similar to Figure 1, but the ratios are all higher since subsistence baskets cost less than respectability baskets. Workers in central and eastern Europe and in Asia ended up with subsistence ratios equal to about one in the eighteenth century. A man's earnings were just enough to keep the family at the level of income corresponding to the subsistence basket in Table 1. It is remarkable that the classical economists were wrong about the standard of living of the English labourer. His real income was, in fact, higher than that of workers in most of Eurasia. Indeed, in London in the eighteenth century labourers earned four times subsistence. English workers did not consume four times the oatmeal specified in Table 1; rather, they upgraded the quality of the food the consumed to the bread, beef, and beer of the respectability basket.

The welfare ratio using the respectability baskets was worked out in the 1990s, and since then great advances have been made in measuring food adequacy and poverty in developing countries. The United Nations Food and Agricultural Organization and the United States Department of Agriculture have established food security and insecurity lines and estimated the number of people in the world below them. The World Bank has established its \$1 per day poverty line and undertaken poverty assessments for many countries. These indicate national poverty lines that reflect national conditions and do not necessarily equal the \$1 per day standard.

The question explored in this paper is how these modern lines relate to the respectability and subsistence ratios. The indices are closely related. However, it is also discovered that the historical measures can be brought into closer alignment with the modern ones by raising the calories content of the basket from 1940 to 2100 and by increasing the scaling factor from three adult male equivalents per family to four. Given the assumptions about family size, this means the standard of 2100 calorie per day standard becomes the per capita norm rather than the norm per adult male equivalent. This change turns out to be warranted by activity levels in the past as well as by the aim of establishing consistency with modern measures. The first change increases the annual cost by about 5%, while the second increases it by one third

These themes will be developed by considering the food security lines and the poverty lines in turn.

<u>Food security lines</u>

Since 1996, the United Nations Food and Agricultural Organization (FAO) has published annually *The State of Food Insecurity in the World*. Since 1997, the US Department of Agriculture (USDA) has published a *Food Security Assessment* dealing with 70 developing countries. Both reports specify a per capita calorie consumption level that marks the division between security and insecurity. The USDA sets the frontier at approximately 2100 calories per day "depending on the region." (USDA 2010-20, p 1 n2) The FAO specifies country specific cut-offs that range from about 1750 calories per person per day to 1950 calories. The FAO figures are derived from a demographic model that relates calorie requirements to the population age distribution and physical activity levels. It is primarily differences in the former that account for the differences in calorie requirements.

Both reports specify higher calorie consumption than either the respectability or subsistence baskets. These set calorie consumption at 1940 calories per day, a figure seemingly at the upper end of the FAO range. There is an important difference, however, for the historical baskets apply this figure to an adult male rather than to the average person in the society. On the assumptions that a family had four members and equalled three adult male equivalents, the implied calorie consumption is 1455 calories per person per day (three quarters of 1940). As it happens, this corresponds to the average calorie intake of someone in the poorest decile of the Indian population (Suryanarayana 2009, p. 35). Setting the calorie intake at this level makes some sense in the case of the subsistence basket, which is intended to track to the minimal cost of survival. However, 1455 calories per person is arguably too low to provide the man with enough nutrition to do the labourer's job that generates the income in the numerator of the welfare ratio.

We can use the FAO's demographic model to set a more appropriate standard. The model requires the age structure of the males and females, and I have used values from the 1841 English census, which is the first to provide sufficient detail. The height of men and women at each age must also be specified. There is historical information about the heights of men, but the heights of women and children are less well established. As it happens, FAO (2008b, pp. 20-1) gives an example of its calculations, and the average height of men in that example is 166 centimetres, which was the average height of British men in 1841 (Floud et al. 1990, Cinnarella 2008). On the assumption that other heights were in proportion, I have applied the heights in the FAO example to England in 1841. One must also assume a Body Mass Index (BMI) for each age to compute weight from height. For adults, the FAO assumes the low value of 18.66 since the aim is to compute a minimum calorie requirement, and I follow their lead. Next, from these data, calorie requirements for basal metabolism for each age-sex group can be computed with equations developed by the World Health Organization and FAO.[2] Finally, total energy expenditure for each age-sex group is calculated by multiplying the calories required for basal metabolism by the physical activity level (PAL) of the group.

The physical activity level is computed by applying physical activity ratios (PAR) to an individual's annual time budget. The PAR is the ratio of energy expended in an activity to the energy required for basal metabolism in the same time period. The FAO (2001, pp. 36, 92-6) reports PAR's for a variety of domestic, agricultural, industrial, and recreational activities. These range from sleep (PAR = 1) to eating, chatting, or watching television (PAR = 1.4) to caring for children (PAR = 2.5) to planting maize (PAR = 4.1) to carrying wood (PAR = 6.6).

The PAL equals the fraction of the year spent sleeping multiplied by 1.0 plus the fraction spent watching television multiplied by 1.4 and so forth for all uses of time over the year. FAO (2001, p. 36) presents rough calculations for light, medium, and vigorous lifestyles. The corresponding PALs are 1.53, 1.76, and 2.25. (FAO, 36) No distinction is made in these examples between work days and non-work days, and length of the work day is shorter than the length of work days in the past or today in many less developed countries. Whether these features balance out is unclear.

Respectability and subsistence ratios have usually been calculated for building labourers and craftsmen. To determine the PAL for men doing these jobs, time budgets have been elaborated based on conditions in the past. The PAL for women is also need to compute the overall calorie requirement, so a corresponding time budget has been worked out for a

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[2]FAO (2008b, p. 18). The equation given for women age 18-29 is clearly erroneous. It should be noted that the equation given for women 18-29 is erroneous and was not used to compute the calorie requirements shown in the example on pp. 21 despite what it says there. From the example, I inferred the equation total energy expenditure = PAL *(451.5 + 15.688 * body mass in kilograms).

woman on the assumption that she was a spinner. The PAL for a woman who was mainly performing domestic tasks was similar.

The time budget for a building labourer is show in Table 2. Key parameters are taken from Voth (2000, pp. 118-33). In London in the mid-eighteenth century, people normally worked five days per week with Sunday and Monday being the days off. Consequently, it is assumed that the work year was 250 days, the number often adopted for welfare ratio calculations. The remaining 115 days were non-work days. Again, following Voth, I assume that people slept seven hours per night, and the work day was 11 hours. This is not as arduous as it appears since people spent 2.5 of the 11 hours eating breakfast, dinner, and tea. (Later in the evening, they ate a fourth meal during leisure time.)

Within this framework, I have allocated time among characteristic activities. Labourers were allotted several hours per day of strenuous activities like carrying wood and digging as well as the somewhat less strenuous tasks of cleaning, loading, and walking. Craftsmen were assumed to be carpenters and spent much of their time on the moderate activities of nailing and roofing, although some time was also spent sawing and carrying wood. Spinning was not a strenuous activity, since it was performed sitting down and did not involve heavy lifting. Indeed, spinning probably required no more energy than the daily routine of a women who earned no money. Both men and women were assumed to have devoted much of their leisure to non-strenuous activities like eating, drinking, playing cards, listening to sermons, etc. The most strenuous leisure activities were not overly energetic–personal care and cooking.

Tables 2-4 show the hours assumed to have been devoted to the various activities and the corresponding PARs. The implied annual PALs are similar to the FAO's calculated values. The PAL for the spinner (light work) is 1.74. The carpenter's PAL was 1.87 and the labourer's 2.16. Different assumptions would, of course, give different values, but the orders of magnitude are clear.

When the PAL values for the labourer and spinner are inserted in the demographic model based on English data for 1841, the average calorie requirement comes out at 2105 calories per person per year–almost precisely the USDA assumption[3]. (Had we used the carpenter's PAL instead of the labourer's, the calorie requirement would have been cut to 1990 per day.) The labourer himself is allocated 3160 calories per day averaged over non-working as well as working days. The spinner receives 2057 calories per day on average, and the children receive less. These calorie supplies are sufficient for their activities according to the FAO model.

In view of these results, it is reasonable to compute welfare ratios following the USDA model with a per capita calorie consumption of 2100. When the welfare ratios equal one, the budget is adequate for a labourer to earn the income to perform his job.

Raising the calorie content of the baskets to 2100 calories per person per day lowers welfare ratios everywhere but has no appreciable impact on relative rankings. Figure 3 shows the results. The patterns are the same as Figure 2, although the absolute values are smaller. Workers in northwestern Europe continued to earn several times subsistence throughout the period. The earnings of workers in central and southern Europe and Asia dropped below subsistence at the end of the eighteenth and beginning of the nineteenth centuries. These

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[3]The activity level of children must also be specified, and that has been set at 'strenuous.'

were, indeed, hard times. Either the labourers whose earnings are studied here were unmarried, so their wages did not have to support wives and children, or the other family members were put to work to bring family earnings up to subsistence.

World Bank Poverty Line

While one can, in principle, define a food security line with precision, the same is not true of a poverty line. The canonical poverty line is the World Bank's 'dollar a day' line, which is variously stated more precisely as \$1 per day in 1985 prices, \$1.08 in 1993 prices or \$1.25 per day in 2005 prices. These values themselves are overly precise; indeed, the original analysis suggested a range of \$.75 to \$1.00 per day, which was later truncated to simply a 'dollar a day.'

The World Bank Poverty Line was not set by the Bank's defining a poverty budget along the lines of 74(r)2.80439(e)3.74( )-0.146571(w)1.5(s)-1.2299anhe teboleth ir tubsistencenbayt ws 22n

[4]World Bank (1990, p.27). Strangely, Chen and Ravallion (2001, p. 285 n.6) specify the countries as 'Bangaladesh, China, India, Indonesia, Nepal, Pakistan, Tanzania, Thailand, Tunisia, and Zambia.' The data points for Egypt, Kenya, and Morocco lie among these ten and apparently support the dollar a day standard in the original study.

Likewise, updating the line over time raises analogous problems since inflation rates differ between countries and national prices indices differ from those relevant to the poor, so the effects are not captured by the evolution of the PPP exchange rates. These problems could all be avoided by defining poverty explicitly in terms of a basket of goods (allowing for local adjustment in response to food availability) that could be priced anywhere at any time.

While the World Bank refuses to propose a basket of goods to define the international poverty line, the various national poverty lines that form the basis of the dollar a day line were themselves based on their own baskets (or, in a few cases, on a sense of what that basket might have been). This is clear in the 2005 revision where most of the data come from poverty assessments using an explicit budgeting procedure. It was also true for the original $1 a day line, although the procedures were less standardized. The upshot is that the World Bank Poverty Line depends on the poverty line baskets of the poor countries in the dollar a day group. By examining their baskets, we can see what the dollar a day line means, and how it relates to the historical poverty lines we have discussed.

The Ravallion, Datt, van de Walle, Chan (1991, p. 34) data set included fifteen countries with poverty lines less than or equal to $1/day. It would be desirable to find the poverty line baskets of all of these countries, but that is not possible. In a few cases, lines were chosen with only a vague reference to the consumption of the poor. In his study of Pakistan, Naseem (1973, p. 321) noted that a satisfactory poverty line "would require a considerably detailed investigation" into nutrition requirements, geographical variation, and the structure of prices. "In the absence of a detailed investigation for the precise estimation of the poverty line, we have chosen two arbitrary benchmarks for the rural areas of Pakistan" as well as two higher benchmarks for urban areas. These lines were set with an eye towards the incomes of the poor–Naseem alluded to the Indian poverty line– but without an explicit budget.

Many poverty lines are taken from World Bank staff reports written in the 1980s, and many of these are either unavailable or provide too few details to be useful. In his study of the Dominican Republic, Musgrove (1984, p. 115, cf. 1986, p. 356) reported that "there has not yet been a detailed calculation establishing a minimum adequate budget," however, he did estimate a poverty line "based on the total spending and food spending of households in the second decile of total income, with an upward adjustment to compensate for their estimated short fall in caloric intake." Unfortunately, the resulting basket was not reported. The poverty line for Nepal was a modification of a Nepalese Planning Commission line that stipulated an average consumption of 2250 calories per person per day and assumed that food amounted to only 65% of consumption expenditure–a very low value (World Bank 1989, Vol. II, pp. 176-7). Further details are unavailable. Likewise the poverty line for China is based on two different Chinese government poverty lines, neither of which is spelled out in detail, or on relative poverty lines equal to 35% and 50% of average income. In the absence of information about the prices people actually paid for food, "we use several different expenditure-based poverty lines, including the official poverty line, without attempting to assign nutritional equivalence." (Ahmad and Wand 191, p. 236)

We are in better shape with poverty lines defined by independent social scientists as they provide more details of their methods. The food baskets for studies of Egypt, Tanzania, and Kenya are shown in Table 5. The Egyptian basket was intended to reflect the actual consumption pattern of the median household in a random sample drawn from 18 villages in Egypt in 1977, although the food quantities were all reduced in the same proportion so that the diet gave the calorie content corresponding to norms at the time. (Radwan and Lee 1986, pp.. 17, 82-3). The Tanzanian diet contained only four foods and was intended to be 'deliberately austere.' (Jamal 2001, p. 38). The Kenyan diet with only maize and beans took simplification to the extreme. "Using only two staple commodities to compute a basic subsistence diet for small-holders in Kenya is bound to underestimate the cost of a realistic minimum diet, which would also contain small amounts of more palatable and expensive foodstuffs, such as meat, vegetables, dairy products, and sugar." (Crawford and Thorbecke 1980, p. 317). It will be no surprise that the costs of these diets vary enormously although they are all treated equivalently in inferring the dollar a day poverty line.

The measurement of deprivation and poverty has been studied in India since the late colonial period, and it remains contentious (Sukhatme 1961, Deaton and Kozel 2005). In 1962 the Indian Planning Commission chose the value of 20 rupees per month (in 1960/1 prices) as the minimum consumption level that should be a target of the fifth Five Year Plan. The Commission did not explain how it reached this figure, but a strong possibility, suggested by Rudra (2005, p. 373-6), is that it was based on the research of P.V. Sukhatme. He was a leading Indian statistician who investigated food issues, he was head of the statistics division of the FAO from 1952-70, and he lectured on "The food and Nutrition Situation in India" at the annual sessions of the Indian Society of Agricultural Statistics in the 1950s and 1960s (Sukhatme 1965, p. vi). He published various estimates of low cost diets that met nutritional objectives (eg. Sukhatme 1961, p. 498). In 1965, he published an influential assessment of India's food needs. His 'minimal level'diet, evaluated in 1960/1 prices, cost 15.63 rupees per month (Sukhatme 1965, pp. 120-1). Low income rural households at the time devoted approximately 79% of their spending to food (National Sample Survey 138, Table 1.6.0). Applying this percentage to the cost of Sukhatme's diet implies a total monthly expenditure of 19.8 rupees. This calculation would justify the Planning Commission's choice.

A weakness of this figure is that Sukhatme's diet contained more expensive foods than poor people consumed. Dandekar and Rath (1971, p. 7) observed that rural households with expenditures of 13 to 15 rupees per month in the NSS 1960/61 probably consumed about 2250 calories per person per day, which was adequate for the work they did. A more precise analysis of this group's spending shows that they consumed 2311 calories per day at a cost of 11.03 rupees for food and a total onthly.2312(s2(a)3.74(n)-0.295581( )-0.147792(t)-2.16-1.2312( )-0.12.1655

2004/5 national sample survey, and from this information we can work out a budget that would generate the 2005 Indian poverty line. Table 6 shows Sukhatme's 1965 budget, the budget assumed by Dandekar and Rath (1971, p. 7) and built into the World Bank Poverty Line, and the budget implicit in the 2005 poverty line.

To establish the relationship between the 'dollar a day' line and the historical subsistence baskets, we can compare the baskets directly as well as their cost. They differ in three important ways. The first is the calories supplied per day. All other things equal, more calories implies a higher costs. The second is the range of foods. Generally, the more calories are derived from foods other than the basic carbohydrate, the more expensive is the diet. The third is the proportion of the spending devoted to food. More spent on non-food items raises costs. The historical baskets have somewhat lower than average calorie contents. The respectability and northern baskets contain more goods than the subsistence basket and look more like the Egyptian and Sukhatme baskets than the Kenyan and Tanzanian baskets. The subsistence basket has many similarities to the Kenyan and Tanzanian baskets, as well as the Dandekar-Rath basket for India. The non-food shares of the historical baskets are lower than those of most of the modern baskets.

The baskets can also be compared in terms of their cost. Table 7 shows estimates of the cost of historical subsistence baskets evaluated with prices from online shopping in the United States conducted mainly at the end of 2012. Most prices come from Safeway for delivery in San Francisco, and a few nonfood items come from other suppliers. The dollar a day line was recalibrated as \$1.25 in 2005. If it is increased in line with the US consumer price index, it becomes \$1.47 at the end of 2012. Comparison with Table 7 shows that the rice, maize, and wheat flour baskets bracket this figure with a mean of \$1.58. Only the oatmeal basket at \$2.47 per day looks out of line with the international poverty line. This provides some validation for the historical baskets in terms of World Bank practise.

The correspondence between the subsistence baskets and the \$1 per day poverty line turns out to be looser when the subject is investigated over a longer time frame. Most of the relevant food and energy prices are available since 1980 in the US Bureau of Labor Statistics 'average retail food and energy prices' and the others can be inferred by extrapolating prices in Table 7. Figure 4 plots the cost of the various historical baskets valuing them with US prices. There was always a range in values with the wheat flour basket invariably the cheapest and the oatmeal basket the most expensive. In 1985 most baskets cost about \$1 per day and in 2005 they bracketed \$1.25 per day.

The modern poverty line baskets can be valued in US retail prices. Figure 5 shows the results for the Indian poverty lines. The Dandekar-Rath line lies between the cost of the maize and wheat flour subsistence baskets. The Sukhatme line, which is equivalent to the Indian Planning Commission 20 Rs line, and the 2005 line were both more expensive and greatly exceeded the 'dollar a day' standard as well as the other poverty lines.

The diversity in the value of different poverty lines is highlighted even more by Figure 6. The Egyptian line was extremely expensive and greatly exceeded the 'dollar a day' standard despite being in the original data set. Its exceptional cost is no surprise in view of its expensive foods and high non-food spending share. The Sukhatme-Planning Commission line and the 2005 line are the next most expensive. The various historical baskets and the Dandekar-Rath line, as well as the poverty lines for Kenya and Tanzania lie at the bottom.

The discrepancies among the poverty lines may reflect differences in the relative prices between countries. We can illustrate the problem with US and Indian prices in 2009 (Table 8). The prices received by farmers in the two countries were similar when converted at the market exchange rate of rupees to the dollars. Rice was the most expensive grain followed by wheat and then by maize and oats. In India, the ratios of the prices of processed consumer goods to the corresponding farm prices were small. Consumers paid only a 5% mark-up on rice, and wheat and maize flour cost 38% - 77% more per kilo. In the United States, on the other hand, the corresponding mark-ups were much greater, presumably reflecting higher wage rates, and the disconnect between retail and farm gate prices was enormous. Wheat flour sold at more than double the farm gate price of wheat, and rice at the retail level was almost five times as expensive as it was on the farm. Maize flour and oatmeal were marked up by factors of 17 and 24 over the farm gate prices of corn and oats. The effect of these mark-ups was to make maize and oats the most expensive products in US super markets whereas they were the cheapest products on the farm, and maize was one of the cheapest foods at any point along the food chain in India.

Did the differences in relative prices affect the rankings of the various baskets? Figures 7-9 value the baskets with Indian rural retail prices and then convert the results to US dollars using the World Bank's PPP exchange rates for private consumption. Figure 7 shows that the historical subsistence baskets based on wheat flour, rice, and maize all cost less than the 'dollar a day' standard (in contrast to Figure 4 where US retail prices were used). The significance of this is called into question, however, when the Indian poverty lines are expressed in US dollars. The Sukhatme-Planning Commission line is the highest but certainly on the low side of a 'dollar a day'. The Dandekar-Rath line is very low, indeed, being little different from the wheat historical basket. Figure 8 adds some of the other lines discussed. As in Figure 5, the Egyptian and Sukhatme-Planning Commission lines are the most expensive with the latter giving the best tracking of the 'dollar a day' standard. The 2005 Indian line was lower. Once again, the Dandekar-Rath line for India, the historical wheat subsistence basket and the poverty lines developed for Kenya and Tanzania cost less than a 'dollar a day' but were close to each other.

The question motivating these comparisons was the relationship between the historical baskets and modern poverty lines. The comparisons revealed a greater range in the value of modern poverty baskets than was anticipated. The comparisons depend in detail on the prices used to value the baskets, but the following were generally true: The respectability and northern baskets are on a par with the more expensive modern baskets like those of Egypt and those proposed by Sukhatme and in Tendulkar Commission for India. The subsistence basket has a cost like the baskets proposed for Tanzania or Kenya or the Dandekar-Rath poverty line for India.

An Inter-Temporal Price Issue

Table 7 raises a small mystery: For earlier periods in American history, a maize-based basket was used, and yet the wheat-based basket was clearly less expensive in 2011. Was the use of the maize basket in earlier years a mistake or had relative costs of the baskets changed? While the oat basket was never the cheapest in the Americas, its extremely high cost vis-à-vis wheat in 2011 raises the same question with respect to Northwestern Europe where an oat-based basket was used for historical calculations.

In fact, wheat emerged as the cheapest source of calories during or after the Industrial Revolution. Figure 10 shows the price paid per pound for oatmeal and wheat flour by Greenwich Hospital from 1748 to 1902. Before Waterloo, oats were always cheaper by a substantial margin, and this had been the relationship since the middle ages. From about

1815 to the 1870s, Greenwich Hospital paid similar prices for wheat flour and oat meal. From the 1880s onward, wheat flour was substantially cheaper and remains so. The fall in the price of wheat was a consequence of the global market in wheat that emerged in the nineteenth century and the immense exports originating from Australia, Russia, Argentina, and North America.

Maize remained the cheaper source of calories in the Americas later than oats in Europe. Figure 11 shows the retail price of wheat flour and corn meal in Boston from 1785 to 1930. Before the 1890s, corn meal was always cheaper. From 1890 to 1925, the prices were similar. After 1925, wheat dropped below maize. Its unfortunate that the Bureau of Labor Statistics stopped publishing Boston prices in 1930, so we cannot track the evolution since then. Certainly today, wheat flour is much cheaper than maize flour.

It was always clear that different subsistence baskets should be used in different parts of the world since the cheapest grain was different in different places. The implication of Figure 11 is that baskets are not constant over time. They should also be changed from time to time to reflect changes in relative food prices

Conclusion

This paper has explored the interface between historical real wage indices and modern food security and poverty lines in an effort to connect our understanding of the past to the present. Connection requires consistently defined indicators. In this case, the main issue is the deflator used to adjust income differences for differences in the prices of consumer goods.

Analysis of the logic and practice of food security lines suggests that we can improve the historical measures by raising the calorie content of the food basket to 2100 calories and interpreting the basket to apply to each person rather than to an adult male equivalent. These changes would bring the baskets into alignment with modern food security lines, as well as the nutritional assumptions underlying many poverty lines. Furthermore, explicit calculations indicate that this calorie standard is consistent with the energy requirements of people living in earlier times.

Analysis of the World Bank poverty line indicates that a subsistence basket based on 2100 calories per person is consistent with the 'dollar a day' line under many assumptions. The analysis does highlight many of the unsatisfactory features of the World Bank Poverty Line, however, that result from its method of construction. Perhaps the World Bank can learn a lesson from historians and settle on an explicit definition of poverty that can be applied across space and over time. Historical research indicates that this is practical. The benefits in terms of transparency and intelligibility would be large.

Table 1

Historical Baskets

		Respectability	Subsistence	Northern
bread	kg	182		
grain	kg		170	121
beans/peas	kg	34	20	
potatoes	kg			163
meat	kg	26	5	5
butter	kg	5.2	3	5
cheese	kg	5.2		3
eggs	kg	52		
milk	litres			220
beer	litres	182		120
sugar	kg			1.4755
tea	kg			1.4755
soap	kg	2.6	1.3	1.3
cloth	metres	5	3	3
candles	kg	2.6	1.3	1.3
lamp oil	litres	2.6	1.3	1.3
fuel	Mill BTU	5	2	2
calories/day		2103	2099	2101
food share				86%

note:
Grain– This diet assumes the grain was oats. Different quantities are used for other grains, eg maize (182), rice (187), millet (184), wheat flour (195).
subsistence–
Northern–65 kg of barley plus 56 kg of oatmeal

Table 2

Labourer’s Annual Time Budget

			days at work			days not at work	
labourer (male)							
	PAR		hours	PAR*hours		hours	PAR*hour
rest hours							
sleep	1		7	7		7	7
personal	2.3		1	2.3		1	2.3
eating	1.4		1	1.4		4	5.6
drinking	1.4		2	2.8		3	4.2
chores	2.3		2	4.6		2	4.6
misc	1.5		0	0		7	10.5
work hours							
digging (a	5.6		1.5	8.4		0	0
loading (m	3.2		2	6.4		0	0
cleaning e	4		2	8		0	0
carry woo	6.6		2	13.2		0	0
walking	2.3		1	2.3		0	0
eating	1.4		2.5	3.5		0	0
total hours =			24	59.9		24	34.2
work hrs/day =			11	2.495833			1.425
days/year =				250			115
				623.9583			163.875
PAL =				2.158447			

Table 3

Carpenter's Annual Time Budget

			days at work			days not at work	
carpenter							
	PAR		hours	PAR*hours		hours	PAR*hour:
not at work							
sleep	1		7	7		7	7
personal	2.3		1	2.3		1	2.3
eating	1.4		1	1.4		4	5.6
drinking	1.4		2	2.8		3	4.2
chores	2.3		2	4.6		2	4.6
misc	1.5		0	0		7	10.5
work							
nailing	3		4.5	13.5		0	0
roofing	2.9		2	5.8		0	0
sawing	6.7		0.5	3.35		0	0
carry woo(	6.6		0.5	3.3		0	0
walking	2.3		1	2.3		0	0
eating	1.4		2.5	3.5		0	0
			24	49.85		24	34.2
work hrs/day =			11	2.077083			1.425
				250			115
				519.2708			163.875
PAL =				1.871632			

			days at work			days not at work	
spinner (female)							
	PAR		hours	PAR*hours		hours	PAR*hour:
rest hours							
sleep	1		7	7		7	7
personal	2.3		1	2.3		1	2.3
eating	1.4		1	1.4		4	5.6
leisure	1.4		1	1.4		3	4.2
cooking	2.1		2	4.2		2	4.2
houseworl	2.8		1	2.8		7	19.6
work hours							
spinning	2.2		7.5	16.5		0	0
							0

Table 5

Some Modern Baskets underlying
the World Bank Poverty Line
(Kilograms per person per year)

	Egypt	Tanzania	Kenya
wheat	34.2		
maize	33.6	188.2	136.9
millet	1.1		
flour	44.7		
rice	22.7		
macaroni	54.2		
beans/pulses	20.9	37.6	58.7
meat	5.5		
poultry/fish	3.6		
eggs	3.4		
oil/fat/butter	7.8	5.4	
milk	3.4		
cheese	8.2		
potatoes	12.1		
onions	8.0		
tomatoes	13.7		
other veg/fruit	6.6		
sugar	14.8	11.47	
Kcal/day	2114	2200	1715
food share	60%	75%	75%

sources:
Egypt–Radwan and Lee (1986, p. 83)for food consumption per adult equivalent, p. 84 for ratio of food to total, and p. 86 for ratio of people to adult equivalents. The quantity of beans and pulses were increased in proportion to the calories derived from the consumption of cooked beans and falafel, the quantities of which are not reported.
Tanzania–Jamal (2001, p. 38). This appears to be a published version of the source cited by Ravallion, Datt, van de Walle, and Chan (1991).
Kenya–Crawford and Thorbecke (1980, p. 316) for diet per adult equivalent and p. 318 and 319n16 for the ratio of people to adult equivalents.

Table 6

Indian Poverty Line Budgets

	Sukhatme	Dendekar-Rath	Tendulkar (implicit)
grain	147.10	204.67	122.52
starchy roots	16.79		
legumes/pulses	37.96	20.09	9.80
milk	73.37	14.60	29.07
oil	6.57	2.33	7.32
meat etc	2.56	1.54	7.92
fish & eggs	6.94		
sugar	18.25	6.69	8.1
salt & spices			2.96
fruit & veg	50.01		61.64
other food		2.38	17.04
intoxicants			1.78
clothing		7.91	
fuel & light		1.52	
miscellaneous		[1.3 R.]	
Kcal/day		2311	1960
food share		79%	56%

Note: all food is kilograms/person/year. Clothing is metres of cloth, fuel & lighting is in millions of BTUs (derived from implicit consumption of kerosene). The 1.3 Rupees shown as ‘miscellaneous’ is the spending on miscellaneous items in NSS 138, Table 1.6.0 for 13-15 Rs. per person per month.

Table 7

The Cost of Subsistence Budgets in USA in 2011

Barebones subsistence at 30 jan 2011				Prices of Delivery to area code 94115, San Francisco, CA.							
www.safewway.com											
		oat	rice	maize	wheatflour	prices		oat	rice	maize	wheatflour
						$/unit					
wheat flour	kg				195	$1.10					$214.13
oat porridge	kg	170				$3.69		$626.91			
rice	kg		185			$1.96			$362.25		
Flour corn	kg			182		$2.43				$442.87	
red kidney beans	kg	20	20	20	20	$4.28		$85.56	$85.56	$85.56	$85.56
meat-beef roasting	kg	5	5	5	5	$7.70		$38.49	$38.49	$38.49	$38.49
butter, unsalted	kg	3				$9.68		$29.04	$0.00	$0.00	$0.00
vegetable oil	l		3	3	3	$2.46		$0.00	$7.38	$7.38	$7.38
soap	kg	1.3	1.3	1.3	1.3	$5.48		$7.12	$7.12	$7.12	$7.12
candles	kg	1.3	1.3	1.3	1.3	$3.27		$4.25	$4.25	$4.25	$4.25
oil (lighting) (veg o	l	1.3	1.3	1.3	1.3	$4.64		$6.03	$6.03	$6.03	$6.03
cotton cloth	sq m	3	3	3	3	$4.66		$13.99	$13.99	$13.99	$13.99
coal	mill BTUs	2	2	2	2	$23.21		$46.41	$46.41	$46.41	$46.41
charcoal	mill BTUs					$242.33		$0.00	$0.00	$0.00	$0.00
No 2 home heating	mill BTUs					$25.50					
total								$857.81	$571.48	$652.11	$423.37
rent allowance @5%								$42.89	$28.57	$32.61	$21.17
total per person ($)								$900.70	$600.06	$684.71	$444.54
cost per day ($)								$2.47	$1.64	$1.88	$1.22

Figure 1

Respectability Ratios

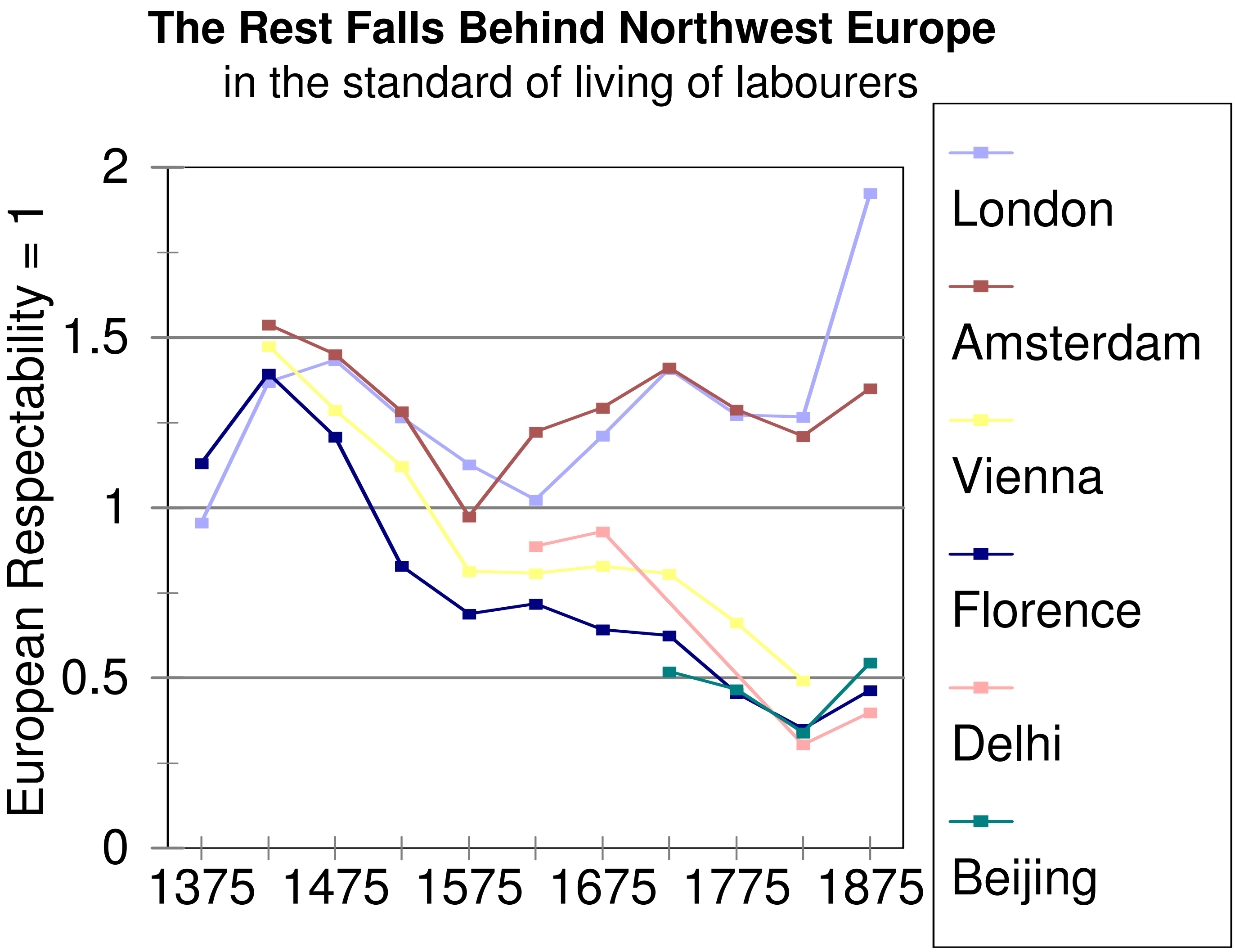


Figure 2

Subsistence Ratios

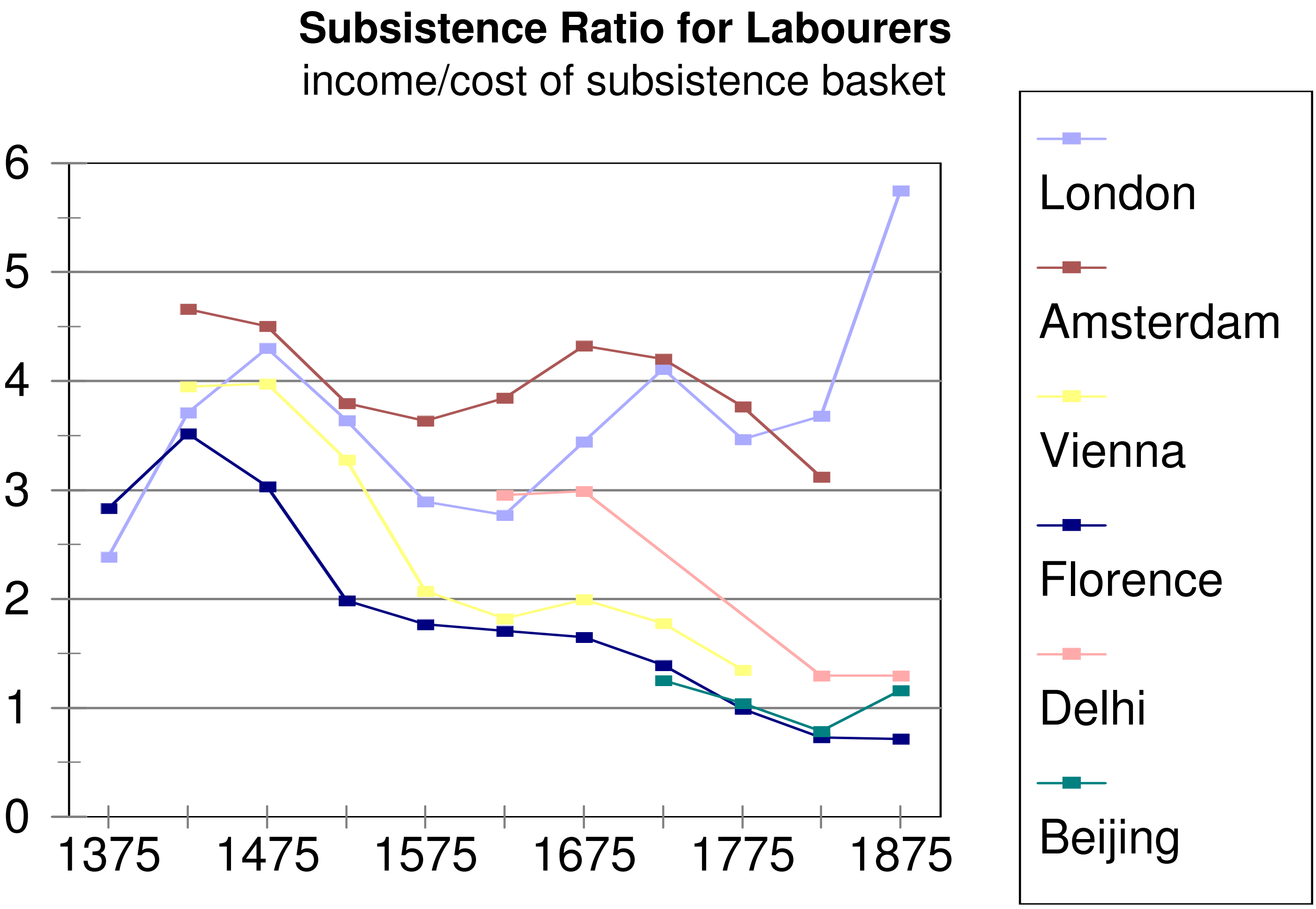


Figure 3

Subsistence Ratio (new basis)

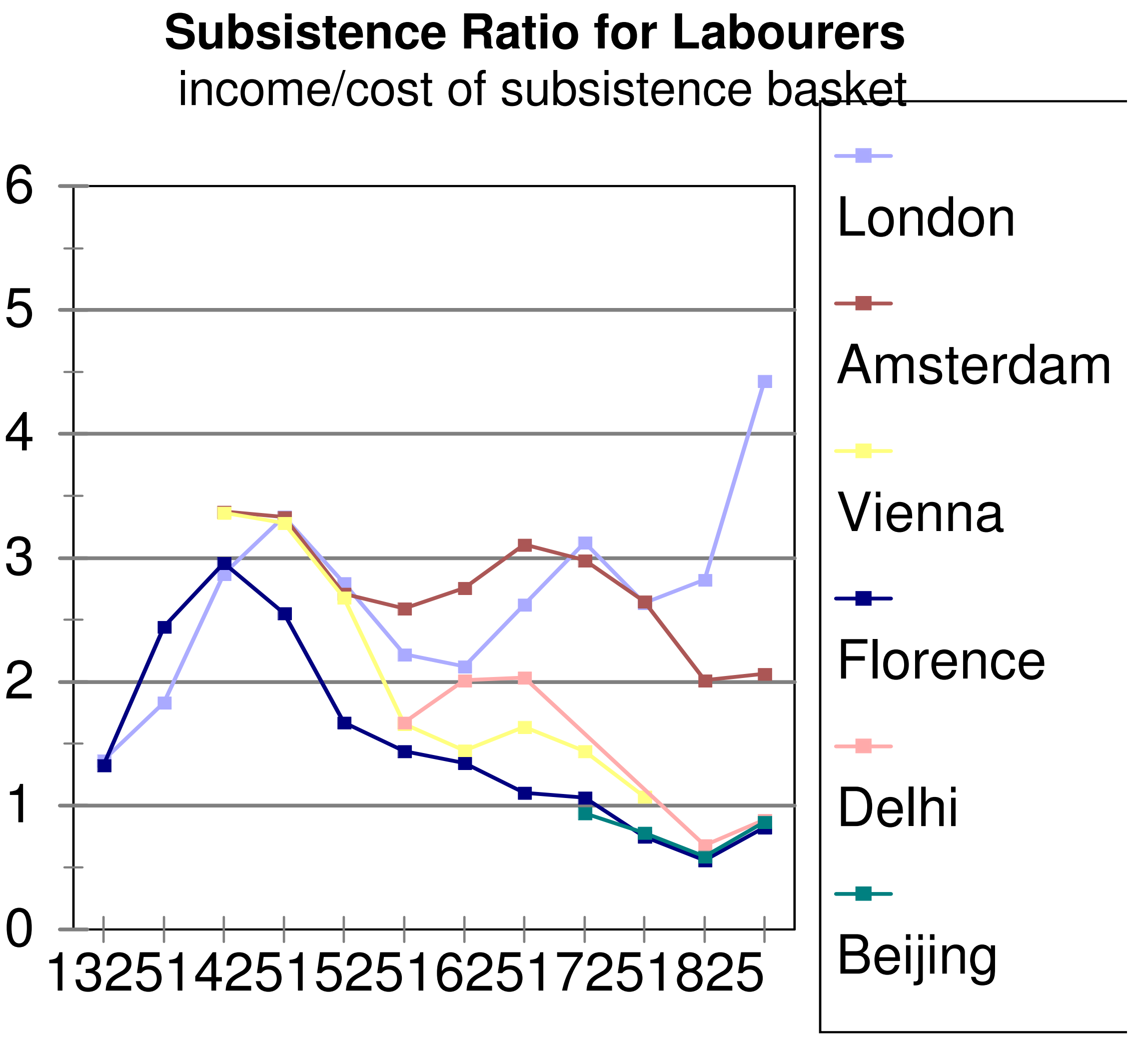


Figure 4

Historical Subsistence Baskets valued in US retail prices

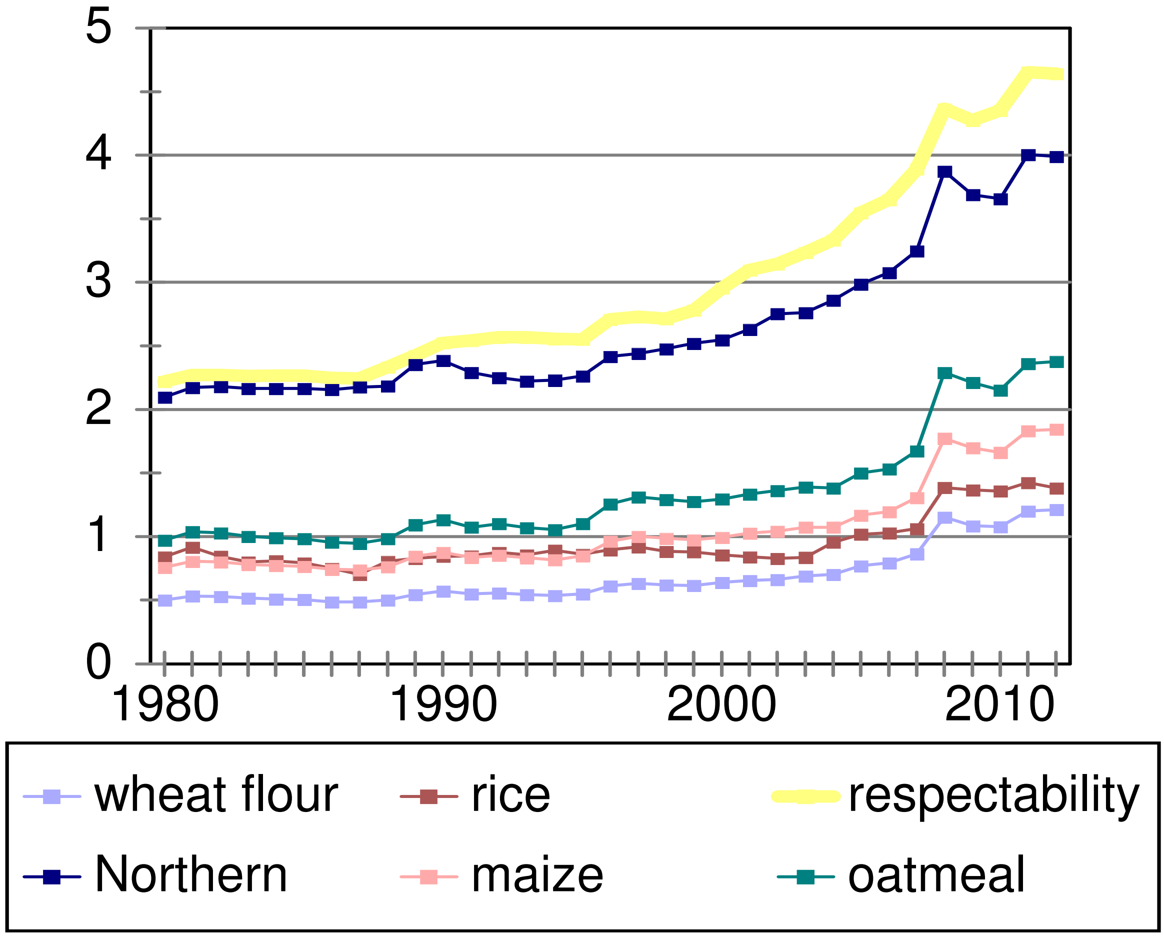
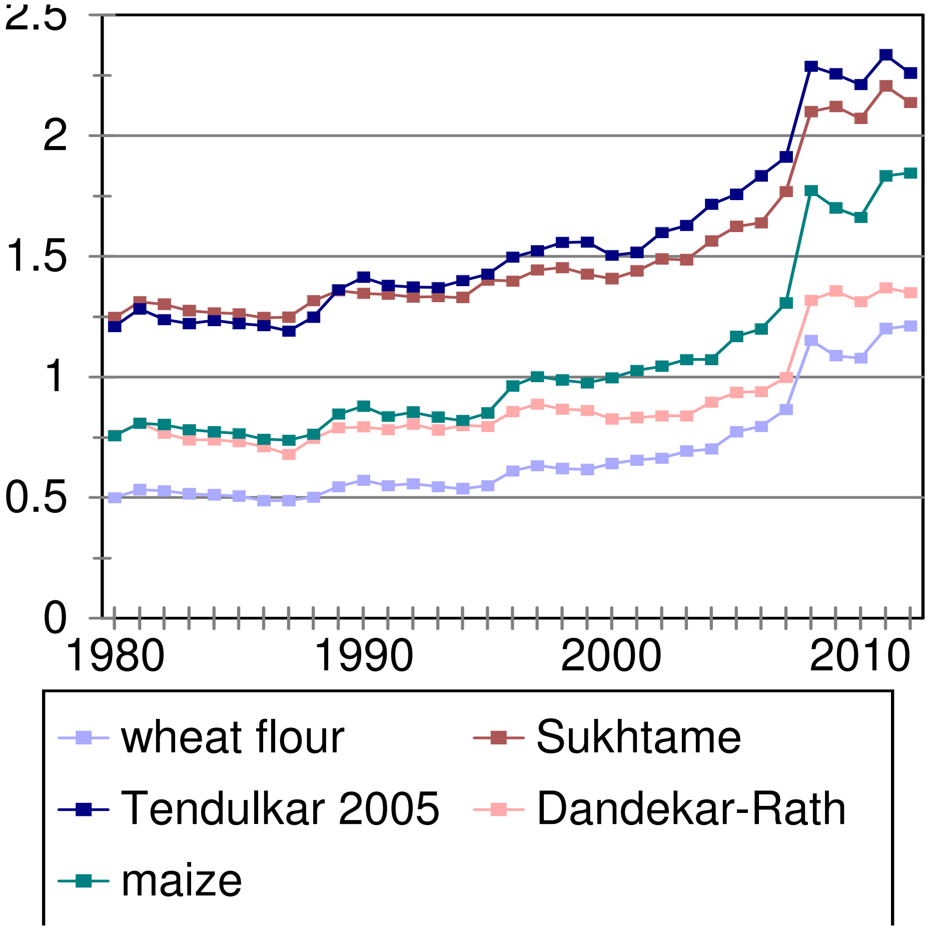


Figure 5

Indian Poverty Budgets valued in US retail prices



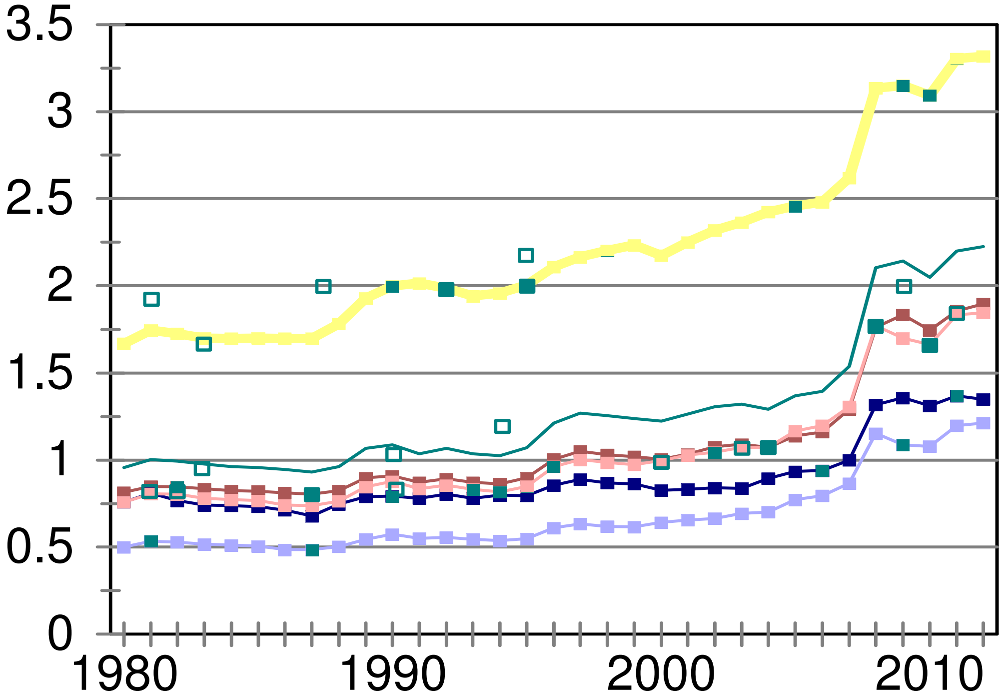
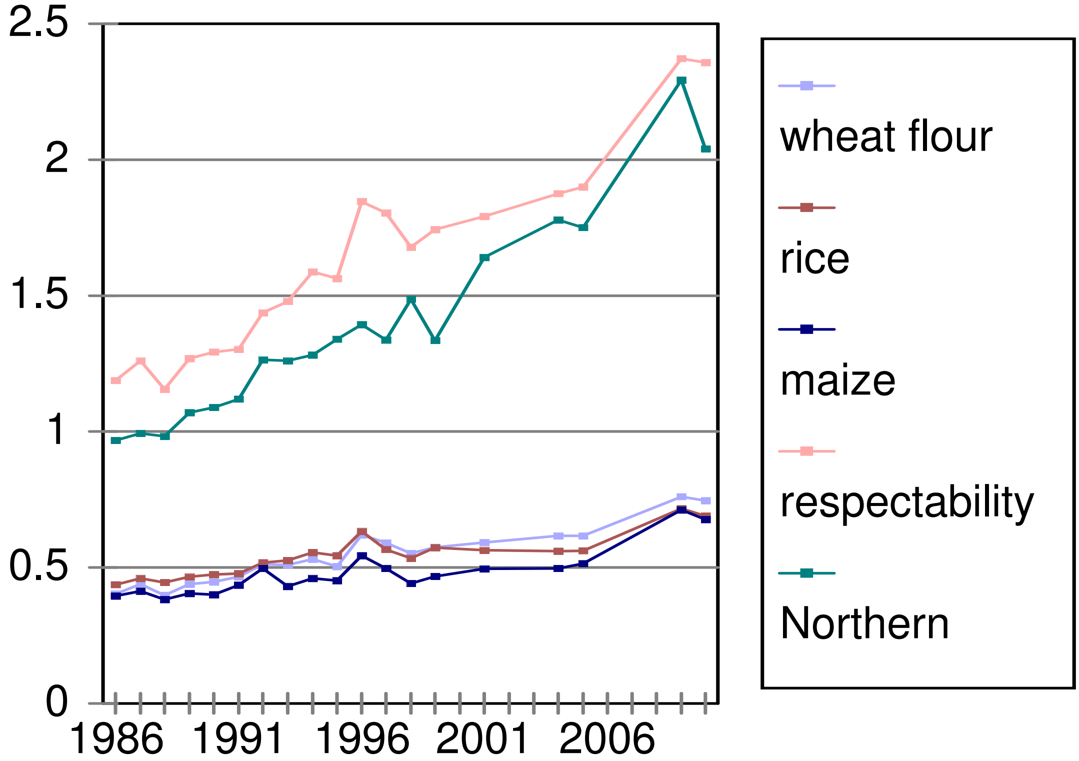

3.5
3
2.5
2
1.5
1
0.5
0
1980
1990
2000
2010

Figure 7

Historical Subsistence Baskets Valued in Rural Indian Prices



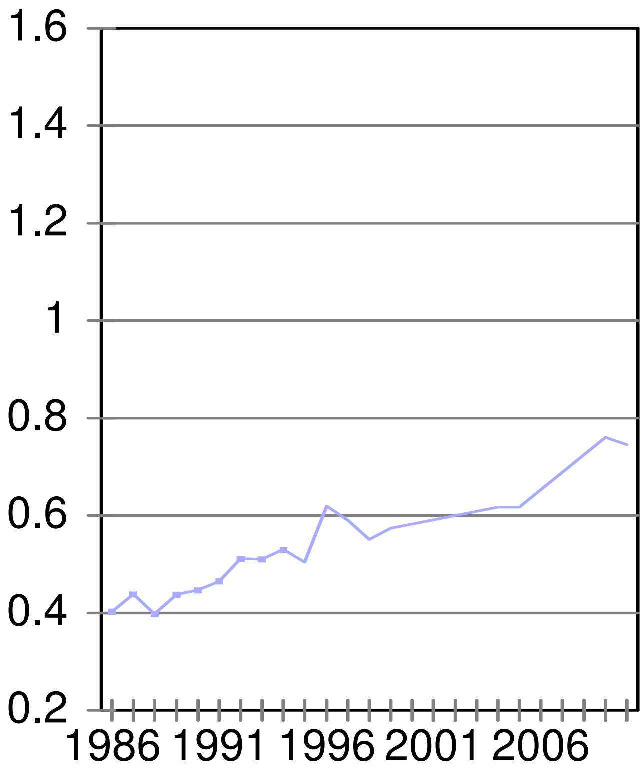
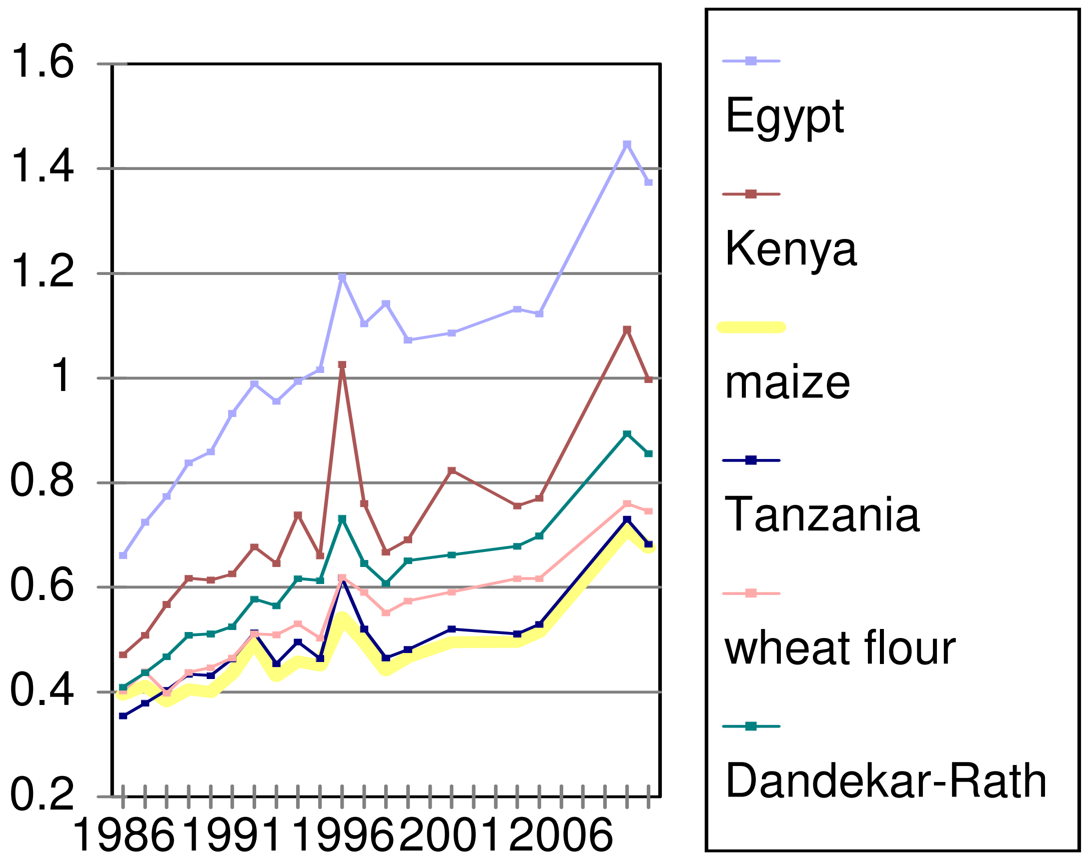
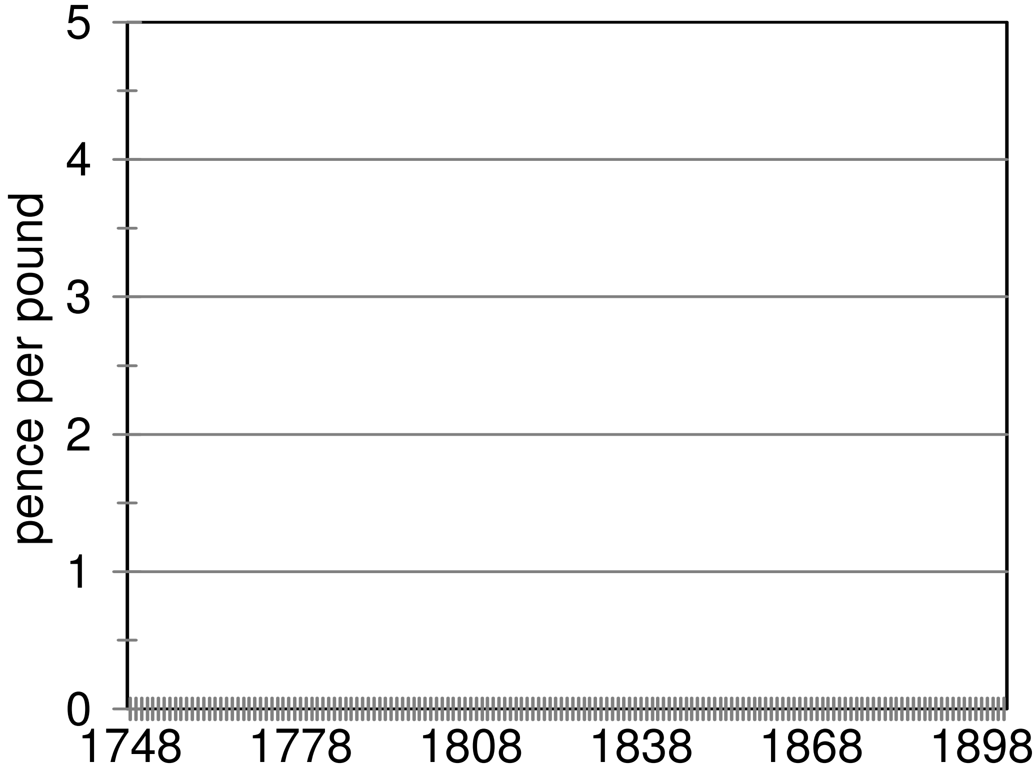
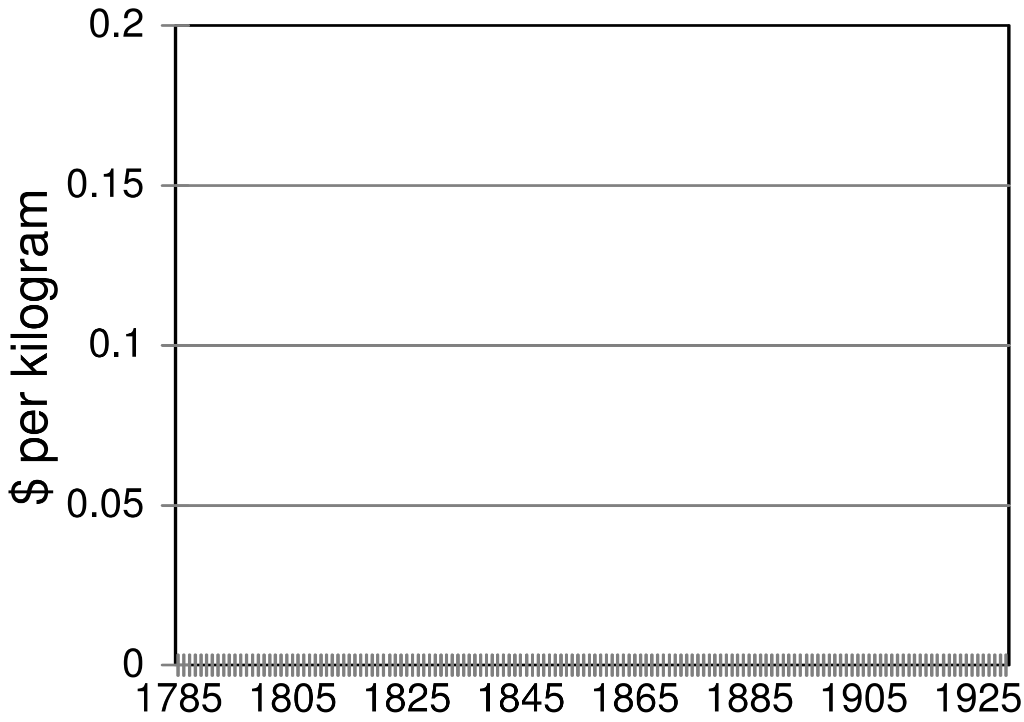

1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
1986
1991
1996
2001
2006

Figure 9

Modern Poverty Budgets valued in Rural Indian Prices




5
4
3
2
1
0
pence per pound
1748
1778
1808
1838
1868
1898


0.2
0.15
0.1
0.05
0
$ per kilogram
1785
1805
1825
1845
1865
1885
1905
1925

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THE ECONOMIC HISTORY REVIEW

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Wages, prices, and living standards in China, 1738–1925: in comparison with Europe, Japan, and India[1]

By ROBERT C. ALLEN, JEAN-PASCAL BASSINO, DEBIN MA, CHRISTINE MOLL-MURATA, and JAN LUITEN VAN ZANDEN

This article develops data on the history of wages and prices in Beijing, Canton, and Suzhou/Shanghai in China from the eighteenth century to the twentieth, and compares them with leading cities in Europe, Japan, and India in terms of nominal wages, the cost of living, and the standard of living. In the eighteenth century, the real income of building workers in Asia was similar to that of workers in the backward parts of Europe but far behind that in the leading economies in north-western Europe. Real wages stagnated in China in the eighteenth and early nineteenth centuries and rose slowly in the late nineteenth and early twentieth, with little cumulative change for 200 years. The income disparities of the early twentieth century were due to long-run stagnation in China combined with industrialization in Japan and Europe.

> 'The difference between the money price of labour in China and Europe is still greater than that between the money price of subsistence; because the real recompence of labour is higher in Europe than in China'.
>
> Adam Smith, *Wealth of nations*[2]

The comparative standard of living of Asians and Europeans on the eve of the industrial revolution has become a controversial issue in economic history. The classical economists and many modern scholars have claimed that European living standards exceeded those in Asia long before the industrial revolution. Recently, this consensus has been questioned by revisionists, who have suggested that Asian living standards were on a par with those of Europe in the eighteenth

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[2] Smith, *Wealth of nations*, p. 189.

century and who have disputed the demographic and agrarian assumptions that underpin the traditional view.[3] The revisionists have not convinced everyone, however.[4]

One thing is clear about this debate, and that is the fragility of the evidence that has been brought to the issue. Most of the comparative studies relied on indirect comparisons based on scattered output, consumption, or demographic data. The few that attempted comparisons of direct income were largely based on scattered information about wages and prices in Asia.[5] Our knowledge of real incomes in Europe is broad and deep because since the mid-nineteenth century scholars have been compiling databases of wages and prices for European cities from the late middle ages into the nineteenth century when official statistics begin.

This article, by assembling and constructing systematic data on wages and prices from Imperial ministry records, merchant account books, and local gazetteers, is an attempt to fill that gap for China in the eighteenth and nineteenth centuries. These wage series, deflated by appropriate cost of living indices using reconstructed consumption baskets, are then compared to the Japanese, Indian, and European evidence to assess the relative levels of wage earners' real income at the two ends of Eurasia. The comparisons paint a less optimistic picture of Asian performance than the revisionists suggest.

Taking the hypothesis of Adam Smith at the head of this article as a point of departure, the present study compares the 'money price' of labour in China and Europe. For this purpose, wage rates are expressed in grams of silver earned per day in the two regions. Unminted silver measured in taels (one tael equalled 37 grams)[6] was a universal medium of exchange in China in this period. The terms on which silver coins exchanged defined the market exchange rate of European and Asian moneys. Next, the 'money price of subsistence' is compared. This is a more complicated problem since the subsistence foods were different in China and Europe. Fortunately, the different methods adopted to tackle this problem turn out to imply similar relative price levels. Once they are measured, the differences between European and Chinese money wages and costs of subsistence and the implications of those differences for the 'real recompence of labour' can be perceived.

The rest of the article is divided into six sections with a conclusion. The first two sections review a variety of Chinese wage data to establish the history of nominal wages from the eighteenth to the twentieth centuries. The focus is set on the histories of Canton, Beijing, and the nearby cities of Suzhou and Shanghai in the Yangzi Delta, because more information is available for these cities, and because they are comparable to the large cities in Europe and Japan for which we have similar information. In section III, nominal wages in China and Europe are compared to see if Smith was correct about the 'money price of labour'. Section IV

[3] For instance, Pomeranz, *Great divergence*; Parthasarathi, 'Rethinking wages'; Wong, *China transformed*; Lee and Wang, *One quarter of humanity*; Li, *Agricultural development*; Allen, 'Agricultural productivity'; idem (2004) 'Mr Lockyer meets the index number problem: the standard of living in Canton and London in 1704' [WWW document]. URL http://www.economics.ox.ac.uk/Members/robert.allen/Papers/Lockyer.pdf [accessed on 10 June 2009]; idem, 'Real wages in Europe and Asia'; Allen, Bengtsson, and Dribe, eds., *Living standards in the past*.

[4] For instance, Broadberry and Gupta, 'Early modern great divergence'; Allen, 'India in the great divergence'.

[5] Pomeranz, *Great divergence*; Lee and Wang, *One quarter of humanity*.

[6] The present study applies this average value; variation for the four most important varieties ranged between 36.54 and 37.58 grams. See Peng, *Zhongguo huobi shi*, p. 669, nn. 4–7.

turns to the 'price of subsistence' and develops consumer price indices to compare the cost of living across Eurasia. In section V, the authors compare Smithian price indices to Fisher Ideal Indices for broader consumer bundles and show that they yield similar results in a comparison of London and Beijing. In section VI, the real wage income in Canton, Beijing, and Suzhou/Shanghai from the mid-eighteenth century to the 1920s is estimated. Smith's belief about the 'real recompence of labour' is tested by comparing real wage income in these Chinese cities to their counterparts in other countries. For Japan, Chinese urban incomes are compared to a composite picture of Kyoto and Edo (modern Tokyo) in the eighteenth and early nineteenth centuries, and Tokyo for the late nineteenth and early twentieth centuries, based on Bassino and Ma's study 'Japanese unskilled wages'. Real wages in China are compared to those in India using the results in Allen's 'India in the great divergence'. The perspective on Asian performance is broadened by contrasting living standards there with those in London, Amsterdam, Leipzig, and Milan, as worked out by Allen in 'Great divergence'. The study concludes with a discussion of the significance of its findings for Adam Smith and the great divergence debate.

I

Before comparing living standards, the level and trend of nominal wages in China must be established. Since most European wages are recorded for urban labourers in the building industry, the present study concentrates on unskilled male workers in three large Chinese cities. No single source covers the whole period from the eighteenth century to the twentieth, so the wage history of China must be pieced together by combining disparate information.[7]

For Beijing, some wages for labourers on eighteenth-century government building projects are known, and wages for similar workers from the 1860s to the 1920s can be found. For Canton, wage data of unskilled port labour hired by European trading companies in the eighteenth century are available. For Suzhou, the daily earnings of men engaged as calenderers pressing cloth in the textile industry can be estimated. This series can be linked to the wages of spinners in cotton textile mills in Shanghai in the twentieth century. Indeed, a more complete picture of labour incomes in the Yangzi Delta can be developed by also assessing the earnings of male farm labourers, rural women spinning and weaving cotton cloth, and peasant households as a whole. By matching eighteenth-century wages for specific unskilled occupations in China with corresponding wages for the early twentieth century, the long-term history of Chinese wages can be reconstructed for comparison with European wages.

This wage survey begins with three sets of wage data for the eighteenth century that are reasonably continuous and well defined. The first set is the piece wage rates of the cotton calenderers inscribed on steles for crafts and commerce in Suzhou, the largest industrial and trading city in the Yangzi Delta during the eighteenth and nineteenth centuries. The case of cotton calenderers and their wage disputes has been the subject of numerous studies.[8] The calenderers' job was 'to

[7] For a survey of existing studies on wages and prices, see Kishimoto, *Shindai chūgoku*, pp. 11–46.

[8] Quan, 'Qingdai Suzhou de chuaibuye'; Terada, 'Sōshū tampogyō'; Santangelo, 'Urban society'; Xu, ed., *Jiangnan tubu shi*.

soften and polish cotton cloth after it had been pressed and rubbed'.[9] The inscribed data give us the guild-negotiated piece wage rates for the years of 1670, 1693, 1701, 1715, 1730, 1772, and 1795. As these are piece wages quoted in silver taels, there are no ambiguities about copper–silver exchange rates or additional food allowances. The major issue is the conversion of piece rates into daily wages, for which Xu's study on the early twentieth century was used, as explained in appendix I A. Overall, the daily wages thus derived come to 0.09944 and 0.1144 silver taels in 1730 and 1772 respectively.

In the eighteenth century, the calenderers were mostly migrants to Suzhou from the impoverished provinces of northern Jiangsu and Anhui. They 'had to be strong men, considering the especially tiring nature of their job: using their arms as levers on wooden supports while balancing, they had to rock a huge forked stone with a ground base onto cotton cloth wrapped around a wooden roller which rotated in a groove in the base of the stone'.[10] Calenderers were only a little above unskilled building labourers but probably below a fully skilled worker in the pay scale.

Our second source for private sector wages is the archives of the Dutch East Indies Company (VOC). Many VOC ships docked at Canton, which was the city where Europeans were allowed to trade with China in the eighteenth century. The VOC hired many Chinese workers to repair ships and move cargo. A recent study by van Dyke offers a detailed description of the workings of the provisioning system in Canton. From the VOC archives, 63 wage quotations spanning the eighteenth century can be obtained.[11] The wages fluctuated, but they clustered between 0.08 and 0.1 taels per day with no additional food allowances.

The third set of wage data comes from diverse sources. We begin with two government regulations. The first is the *Wuliao jiazhi zeli* (*Regulations and precedents on the prices of materials*) of 1769, which is a very detailed and systematic government report on the prices of building materials and the wages paid at construction projects, and an attempt to set these prices and wages for the future. According to the editorial introduction, it contained information about 1,557 administrative units described in a compilation of 220 chapters. The original compilation has not been preserved, but the editions for 15 provinces covering 945 districts are extant. Most of them contain the daily wages of unskilled and skilled craftsmen for each district; a few are more detailed and present wages for occupations such as master sawyers, carpenters, stonemasons, paint-makers and painters, tailors, plasterers, canopy makers, paperhangers, and cleaners (in Zhili). Occasionally additional food provisions and their monetary value are recorded, so that the total wage value can be calculated. Where no food provisions are mentioned, probably no food allowance was given, as these wage regulations were supposed to cover the entire labour cost of these public building projects.[12]

[9] Santangelo, 'Urban society', p. 109.

[10] Ibid., p. 109.

[11] See van Dyke, *Canton trade*, and Jörg, *Porcelain*, pp. 21–73, for the details of the organization of the VOC in Canton. We specifically used the files in the National Archives of the Netherlands, The Hague, Archives VOC, nos. 4373, 4376, 4378, 4381, 4382, 4386, 4388, 4390, 4392, 4395–4401, 4403, 4405, 4408, 4409.

[12] The introductory memorial to these regulations by the compiler Chen Hongmou, 'Wuliao jiazhi zonglue' ['General remarks on the prices of materials'], states that market prices and wages were investigated in the regions, and that the prices and wages quoted in these volumes were near to market prices at low market activity; see *Wuliao jiazhi zeli*, ch. 1, fol. 4b, availableao probabCaghW0,aURL0, ag

Table 1. *Nominal wages of workers in public construction, 1769–95, and in arms manufacture, 1813 (in taels per day)*

	Construction (unskilled)	*Construction (skilled)*	N =	*Arms manufacture (unskilled)*	*Population (millions in 1787)*
Manchuria and the north-western frontier					
Heilongjiang	0.100	0.191	2/6 (unskilled/skilled)		
Jilin	0.095	0.160	6		1.0***
Shengjing	0.057	0.100	13		
Xinjiang	0.097	0.110	3		0.5
North					
Rehe*	0.066	0.120	7		
Beijing*	0.077	0.141	24		
Tianjin/Baoding*	0.071	0.112	34		23.0****
Residual Zhili*	0.054	0.081	82	0.060****	
Gansu	0.044	0.054	48		15.2
Shanxi	0.054	0.073	85	0.040	13.2
Shaanxi	0.044	0.050	74	0.040	8.4
Shandong	0.045	0.061	50	0.040	22.6
Middle					
Henan	0.037	0.039	106	0.040	21.0
Jiangsu**	0.040	0.051	63	0.040	31.4
Zhejiang**	0.040	0.060	63	0.040	21.7
Hunan	0.039	0.050	10	0.040	16.2
Hubei				0.040	
Jiangxi				0.030	
Guizhou				0.040	
Sichuan	0.048	0.062	47	0.040	8.6
Yunnan	0.048	0.068	84	0.030	3.5
South					
Fujian (including Taiwan)	0.030	0.050	9	0.040	12.0
Guangdong	0.040	0.050	89	0.040	16.0
Guangxi				0.040	
Average (unweighted)	0.053	0.081			
Average (weighted by N)	0.047	0.065	901/905 (unskilled/skilled)		
Average (weighted by population)	0.044	0.060			214.5

Notes: *Part of the province of Zhili; **Yangzi Delta; ***whole of Manchuria; ****whole of Zhili. N: number of districts for which data are available.
Sources: For wages, see app. I; for population data: Wang, *Land taxation*, p. 87.

A virtue of the *Wuliao jiazhi zeli* is its comprehensive regional coverage of Chinese wages. For each province we calculated the unweighted average of the wage norms for labourers in all districts. Table 1 presents the results of these calculations for 21 regions. Zhili is divided into a number of sub-regions because of the large wage differences within this province. The total population of these

Shanxi, Shaanxi, Gansu, Jiangsu, Zhejiang, Guangdong, and Yunnan all carry the same introductory memorial dated 1769. Other editions have no preface, such as those for Hunan, which is a fragment, and 'Manchuria' (Shengjing/Jilin/Heilongjiang). The 1791 Sichuan and the 1795 Rehe editions are later compilations. No special edition was ever compiled for Xinjiang, but a few Xinjiang data are mentioned in the Gansu, Sichuan, and Rehe editions. Digitized datasets for the provinces Gansu, Zhili, Yunnan, Hunan, and Shanxi are available online in the 'Databases on materials, wages, and transport costs in public construction in the Qianlong era' [http://www.uni-tuebingen.de/sinologie/project/shp/databases.html]. See also Song and Moll-Murata, 'Notes', pp. 93–9.

regions in 1776 was about 214.5 million, or 73 per cent of the total population of China of about 293 million.[13]

The pattern that emerges from the *Wuliao jiazhi zeli* is that daily wages in parts of Manchuria (Heilongjiang and Jilin), the home territory of the ruling Manchu Dynasty, and the sparsely populated north-western frontier of Xinjiang, stand out as the highest, followed by areas in and near the capital city of Beijing. Average daily wages in the rest of China seem to have been fairly uniform, with the coastal Fujian province fetching the lowest, 0.030 taels for unskilled labourers.

A second government source is the so-called *Gongbu junqi zeli* (*Regulations and precedents on weapons and military equipment by the Ministry of Public Works*) of 1813, which contains more government wage regulations on an empire-wide scale. The *Gongbu junqi zeli* contains wages for master artisans and unskilled labour that produced military equipment. This dataset includes information for skilled and unskilled labourers.[14] This source shows again that, with the exception of Zhili where Beijing is situated, the norm for average daily wages of unskilled labourers in most provinces in 1813 was about 0.04 taels, very close to that in the 1769 regulations.

Extreme caution should be exercised in the interpretation of these government data. The *Wuliao jiazhi zeli* wage data collected at the county level often show identical wages across a vast number of counties within one province, with little distinction between the more and less urbanized ones. This poses the question whether these data reflect actual market conditions or rather government policies, which tended to favour the capital region as well as Manchuria, the home territory of the Qing rulers.[15]

To tackle the question of how accurately these government regulated wages approximate wages in the private sector of the economy, we place these wage series against a broader dataset of 264 scattered wage quotations from many sources and for different parts of China. The problem with these disparate wages from the private sector is a lack of the kind of detailed information available for the Suzhou calenderers and Canton VOC labourers. Also, there is a general lack of comparability due to the multiplicity of labour contracts, payment systems, and currency units. Employment contracts could last for a day, a month, or a year, and careful attention must be given to the number of days worked in a month or a year to reduce the payment information to a consistent daily rate. There are many cases for which food allowances were given in addition to cash payments. Possibly the most difficult issue of all is the quotation of wages in different currency units (copper coins, silver taels) with exchange values that were both highly localized and fluctuating over time. Studies not taking full cognizance of these problems can be very misleading.[16]

[13] Wang, *Land taxation*, p. 87.

[14] See You, 'Lun junqi zeli', p. 314. Wages of skilled craftsmen were 0.020 or 0.010 taels higher than those of unskilled labourers.

[15] The Qing government restricted the migration of Han Chinese to the land and resource rich, but labour-scarce region of Manchuria until the mid-nineteenth century.

[16] Vogel, 'Chinese central monetary policy', contains the most comprehensive collection of market exchange rates for various provinces in China for the seventeenth to nineteenth centuries, but these exchange rates do not apply to the case of the co-circulation of multiple versions of silver and copper cash within the same locality, an issue pointed out in Kuroda's recent study, 'Copper coins'. For a case of neglecting these complicated currency problems in the study of nominal and grain wages, see Chao, *Man and land*, pp. 218–20.

The most important official source for private wages consulted in the present study is the records of the imperial Ministry of Justice, which summarized judicial cases dealing with wage payment. A sample of 188 manufacturing and handicraft wages was obtained from Peng's compilation on craft history, which is based on judicial records from *c.* 1740 to 1820.[17] They are contained in the archival documents of the Ministry of Justice, *Qingdai xingbu chao'an* (*Copies of archival materials from the Qing Ministry of Justice*).[18] This represents a widespread sample which includes scattered wage data for different occupations, in different regions, using different means of payment (silver taels or copper coins), covering different time periods (per day, month, or year), and spread over a long period. The Ministry of Justice records also contain samples of agricultural wages. These are available in the work of Wei and Wu.[19]

The resulting large, if disparate, sample of wages covers many provinces, industries, and types of employment in eighteenth-century China. To extract basic patterns from this information, a wage function was estimated using all of the collected wages, including the VOC and government regulation wages. All wages were converted to daily wages in silver taels by means of Vogel's regional dataset of silver–copper conversion ratios.[20]

The following independent variables were defined: (1) regions: Manchuria, Zhili, the north (Shanxi, Shaanxi, Gansu, Shandong), the Yangzi Delta (Jiangsu and Zhejiang), the 'middle', and the south (see table 1 for the exact specification of the regions; Canton is also distinguished separately); (2) branches (agriculture, coal mining, the iron industry, construction, textiles, and other industries); (3) a time-trend with 1700 as the base year; (4) skill (a dummy for skilled labour was used; unskilled labourers were all agricultural workers, the unskilled labourers in construction and the 'helpers' in other industries); (5) regulation (data drawn from the two government documents *Wuliao jiazhi zeli* (1769) and *Gongbu junqi zeli* (1813) were identified by a dummy for 'regulation'). We also include a few additional government regulation data from *Suzhou zizhao ju zhi* (1686) and *Da Qing huidian shili* (for 1723 and 1736).[21]

The total number of observations was 327, relatively equally spread over the different regions and branches. There are only four observations for the late seventeenth century. Most observations cluster between the 1740s and the 1810s; no observations after 1820 were included.

[17] Peng, *Zhongguo jindai shougongye*, vol. 1, pp. 396–414.

[18] Ibid., vol. 1, p. 397, n. 2.

[19] Wei, 'Ming-Qing'; Wu, 'Qing'.

[20] Vogel, 'Chinese central monetary policy'. Another problem was how to convert monthly and annual wages into daily wages; a few observations of both daily and monthly or annual wages suggests conversion factors of about 15 (days/month) and 60 (days/year). The next step was to use these conversion factors and estimate dummies for monthly and annual wages in the wage regression. The dummies became close to zero when somewhat different conversion factors were used, namely 13 and 90. We used these conversion factors in the estimation of wage levels in the wage regressions shown in tab. 1; therefore, the dummies for monthly and annual wages have not been included.

[21] Wage data from *Suzhou zizhao ju zhi* (*Treatise on the Suzhou weaving offices*) for 1686, included in Peng, *Zhongguo jindai shougongye*, vol. 1, pp. 90–2, were also consulted, as well as wage data from *Da Qing huidian shili*, ch. 952, fos. 4b–5a, pp. 16,640–1. The complete wage dataset used in this study can be found at http://www.iisg.nl/hpw/data.php#china; it presents an overview of the different datasets, their compilers (Christine Moll-Murata, Debin Ma, and Paul van Dyke), and the linked Excel files.

Table 2. *Wage regressions for eighteenth-century China, standardized on the daily wage of an unskilled construction labourer in the Yangzi Delta in 1769 (in taels)*

	Coefficient	T-*value*
Constant	0.0456	4.00
Trend	−0.0000351	−0.348
Manchuria	0.0902	6.73
Zhili (including Beijing)	0.0441	4.36
North	0.0132	1.397
Middle	−0.0022	−0.026
South	−0.000593	−0.056
Canton	0.0379	3.55
Skilled	0.0295	4.79
Regulated	−0.0171	−2.21
Iron industry	0.0092	1.12
Coal mining	−0.0093	−0.83
Agriculture	−0.0072	−0.744
Textiles	0.0403	3.22
Other	−0.0147	−1.93
R^2	0.408	
F (14,312)	15.34*	
N	327	

Note: *Significant at the 1% level.

Table 2 presents the results of the wage regression. All independent variables except the time trend are dummies for regions, branches, and so on; the standard for comparison is the market wage of a construction labourer in the Yangzi Delta in 1700. The constant in the equation is his wage, which is estimated as 0.0456 taels. The regional pattern mirrors the results from the analysis of the *Wuliao jiazhi zeli*: wages in Manchuria and Zhili were (much) higher than in the rest of the country, whereas the differences between the Yangzi Delta and the rest of the rice region were very small. Most industry dummies were insignificant. Finally, the dummy for skill premium is significant; its level in regression is 63 per cent of the wage of an unskilled labourer in the Yangzi Delta.

To get a perspective on our wage regression, we plotted in figure 1 the wage rates of Suzhou and Canton against the predicted wages from our regression. Figure 1 shows that the baseline predicted wages, set as the constant plus the time trend in the wage regression (the rate equivalent to that of an unskilled labourer in the Yangzi Delta), is about half the level of Suzhou and Canton wages. While VOC and calenderers' wages were rising gently, wages in China in general were declining slowly, as indicated by the wage equation. This difference in trend is not significant for our purpose. Figure 1 also plots the predicted wages of Beijing which uses the dummy coefficients for Zhili from the wage regression.

These results make sense: large cities in Europe, the counterparts of Canton, Suzhou, and Beijing, had higher wages than small towns and rural districts in part because the cost of living was higher in the large cities and also because they had to recruit population from the countryside. This conjecture is in agreement with Pomeranz's description of the earnings of a Yangzi Delta farm worker employed by the year in the mid-eighteenth century. Pomeranz reckoned that the cash component of these earnings was two to five taels, and that the food allowance over a full

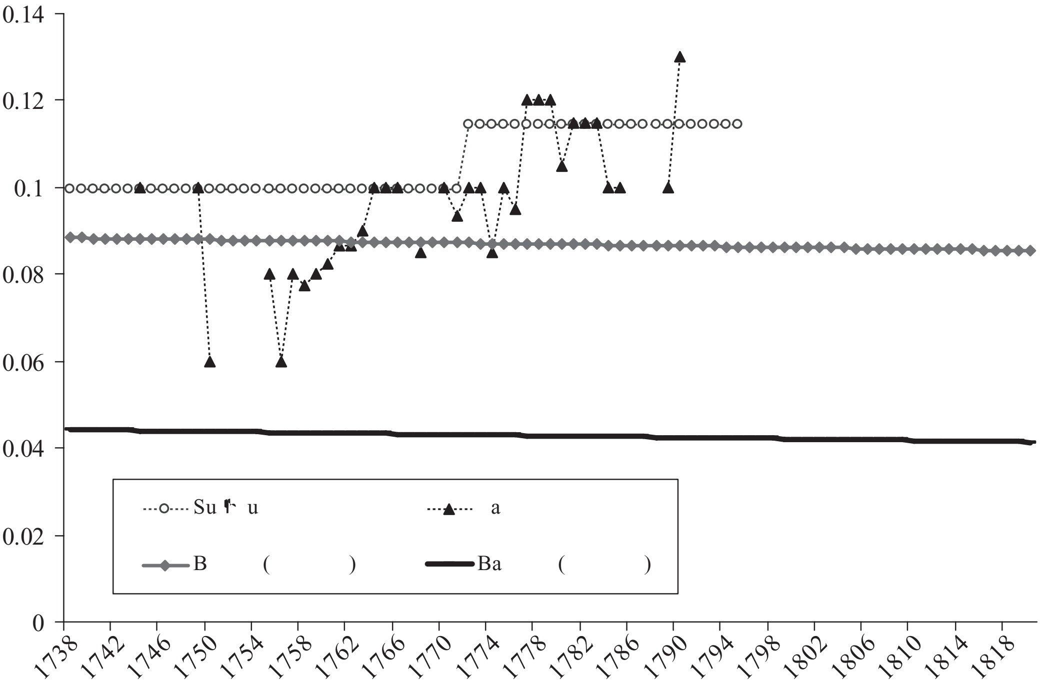


Figure 1. *Nominal wages in Beijing, Suzhou, and Canton (in silver taels)*
Source: See section I.

year was perhaps five *shi* of rice worth 8.4 taels, so the total earnings over the year were 10.4 to 13.4 taels. Dividing by 360 implies daily earnings of 0.035 to 0.045 taels per day, very close to the baseline wage level from our regression result.[22]

As the wage regression contains some wage data that might include additional food allowances, we have experimented with alternative regressions by adding 0.024 taels—roughly the cost of one kilogram of rice in Canton or millet in Beijing in the middle of the eighteenth century—to the daily earnings of those workers earning less than six taels per year (0.5 taels per month). The alternative regression leads to changes of little significance to the coefficients of most significance for this study.

The level of our baseline wage in figure 1 matches the empire-wide averages in the *Wuliao jiazhi zeli* and *Gongbu junqi zeli* in the official regulation data. This leads us to

[22] Pomeranz, *Great divergence*, pp. 319–20. The average of agricultural wages on daily contracts collected in our sample was 0.045 taels. Wages on daily contract were likely to be higher, as usually day labourers were more often employed during the planting and harvest seasons. It is unclear whether additional food was provided. A national level survey conducted by Chen in the 1930s, *Gesheng nonggong*, reveals the existence of both types of payment arrangements for daily wages, either with or without food payment, the latter being higher. However, in cases where there was food payment, the portion amounted to about 33 per cent of the total cash wage, much less than for the eighteenth- and nineteenth-century agricultural wages on annual contracts (Chen, *Gesheng nonggong*, p. 9). Li, *Agricultural development*, p. 94, also seems to indicate that seventeenth-century nominal wage levels may not be far apart from those of the eighteenth to nineteenth centuries. He discusses wage levels in agriculture and silk production in the Yangzi Delta, and estimates the average wage in rice cultivation at 0.06 taels per day, adding 'the official standard was 0.04 taels a day which is a bit low compared to the wages in some farms in Huzhou, Zhejiang province'.

believe that the government regulation wages may have been set as a wage floor for the market wages, which the government used for the purpose of cost-accounting. Both these sources also reveal higher wage levels for the capital region than the national average, which may be a reflection of possible governmental discrimination. If carefully interpreted, the regulated wage is more useful as a benchmark for a national wage floor than as an indication of regional wage patterns. For the subsequent analysis, the wage level for Beijing and Canton was set in 1700, based on the predicted values in the regression of 0.0897 and 0.0835 taels respectively, equal to the constant coefficients plus dummy coefficients for Zhili and Canton respectively. For Suzhou, 0.09 taels for 1700 were used, very close to the 0.0968 taels for the calenderers' wages. The national trend level was used for all these three series in the international comparison. Clearly, we view our wage series as more reliable in indicating long-term trends than short-term fluctuations.

Somewhat contrary to the claims that Lower Yangzi had the highest living standards, our dataset collected at this stage do not reveal a higher nominal wage for unskilled laborers in that region. While the implications of possible regional wage difference will be discussed later (in particular, see footnote 54), the rest of this study focuses on cross-national comparison of average wage income for unskilled labourers between China and Europe. On the assumption that these wages are complete payments for unskilled labourers in the three major urban centres, they most likely represent the upper bound estimates of our larger dataset. Thus, if the average level turns out to be lower than our nominal wages, then actual Chinese living standards would be even lower.

II

Jumping forward in time, the best available information on wages in Beijing, Canton, and Shanghai is for the early twentieth century. Our wage series for Beijing is anchored in the work of Sidney Gamble (1890–1968). Gamble was an American sociologist who lived in China in the 1920s and 1930s. He conducted a survey of workers in Beijing in 1921. This provided the weights for a consumer price index for Chinese capital for 1900–24, and that index, in turn, was used in a study of real wages for the period. Gamble and his associates also recorded wage series for unskilled construction workers in Beijing for the period 1862–1925 using the records of the Beijing guilds for construction workers. This is our source for unskilled wages in the capital.[23]

Gamble carried out another important study based on the account books of a fuel store in the rural area of Beijing. The information runs from 1807 to 1902 and is possibly the only consistent wage series for nineteenth-century China. The nineteenth-century wage payments were recorded in copper cash and were broken around the mid-nineteenth century due to the monetary debasement in the period of the Taiping Rebellion. Gamble does provide vital information on copper–silver rates in that area from which we derive a silver-based wage series for 1807–1902,

[23] This series is composed of two parts. The first part is the 1870–1900 copper cash wages (inclusive of food money) in Gamble, 'Daily wages', p. 66, which we converted to silver wages using copper–silver rates from Peng (*Zhongguo huobi shi*, p. 548). The second series is the 1900–24 series by Meng and Gamble, 'Wages, prices, and the standard of living', p. 100.

as shown in appendix I B. The level of the wage rates seems very low and is difficult to interpret in its own right, as Gamble indicated that workers received unrecorded food allowances.[24] We apply the trend (not the levels) of these silver wages to fill in the 1820–62 gap for the light it throws on the Taiping Rebellion and its aftermath.

Information on Cantonese wages is less comprehensive than that for Beijing. As noted above, estimates of wages in the eighteenth century have been derived mainly from VOC records and summarized in the wage regression. For the early twentieth century, the simple average of six series of union-regulated shows wage rates for unskilled labourers in the construction sector from 1912 to 1927 is used.[25] For the nineteenth century, various plausible wage data exist, but were not included in the analysis as they were incomplete and scattered.

Similarly, no systematic wage series for Suzhou in the nineteenth century was available. From the middle of the nineteenth century, Shanghai was emerging as China's predominant trading and industrial city under the treaty port system imposed by western imperialism. Setting out from wage notations for female cotton spinners in Shanghai between 1910 and 1934, we have calculated the wage levels of male unskilled labourers based on a wage survey of the 1930s.[26]

III

Adam Smith thought that the 'money price of labour' was higher in Europe than in China. To test that, Chinese and European wages must be compared. Building on our earlier studies of European daily wage rates earned by labourers in the building industry,[27] we have been careful to exclude wage quotations where the earnings included food or other payment in kind that could not be valued and added to the money wage. As with China, we have converted the European wages to grams of silver per day by using the market price (in units of account) at which silver coins of known weight and fineness could be purchased.

Figures 2 and 3 show the daily wage rates of unskilled workers in London, Amsterdam, Leipzig, Milan, Beijing, and Kyoto/Tokyo from the eighteenth century to the twentieth. Figure 2 shows the series from 1738 to 1870. For this period, Adam Smith was half right. Wages were, indeed, highest in London and lowest in Beijing, but the other series show that the world was more complex than Smith thought. The silver wage in Milan or Leipzig was not appreciably higher than the wage in Beijing, Canton, or Suzhou throughout the eighteenth century.[28] The statistics of other European and Chinese cities show that this similarity was general.

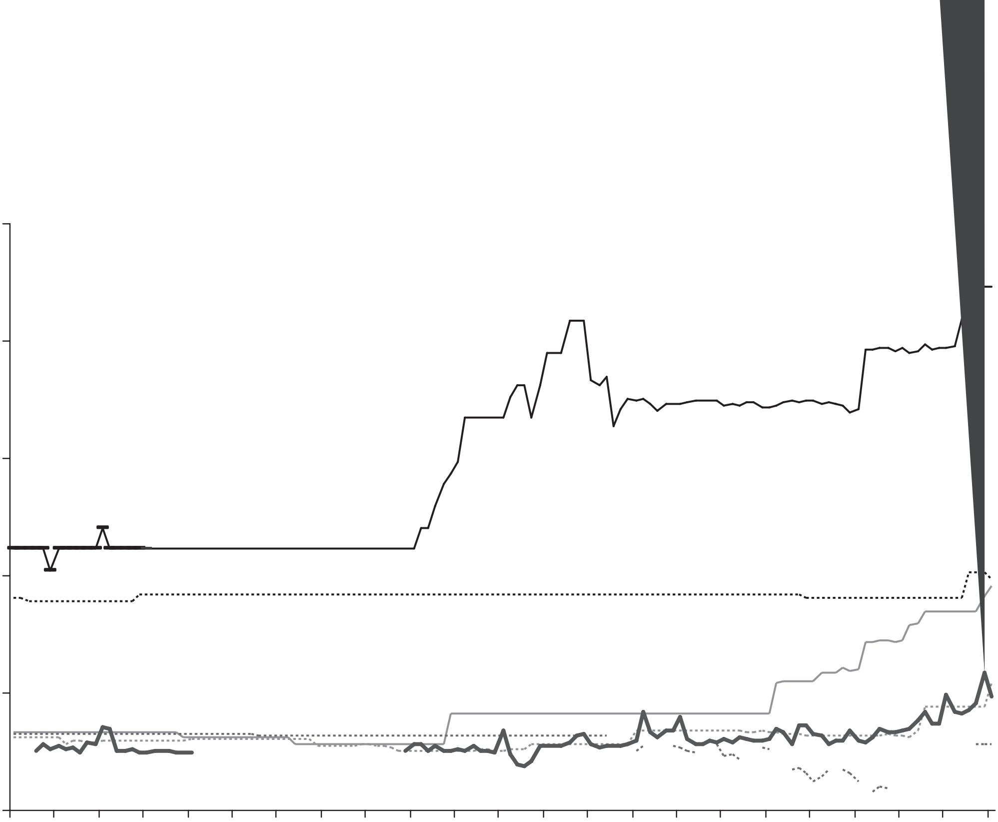
[24] Gamble, 'Daily wages', p. 41.

[25] Department of Peasantry and Labour, *Reports of statistics*, vol. 3, 'Wage tables in the construction sector'. Our wage series is the simple average of five types of unskilled labourers in the construction sector.

[26] We make use of the series by Rawski, *Economic growth*, p. 301, and the Bureau of Social Affairs, *Cost of living index*, pp. iii–iv. According to Yang, 'Shanghai gongren shenghuo', p. 250, female workers in 1927–8 were paid about 80% of the level of male workers.

[27] van Zanden, 'Wages and the standards of living'; Allen, 'Great divergence'.

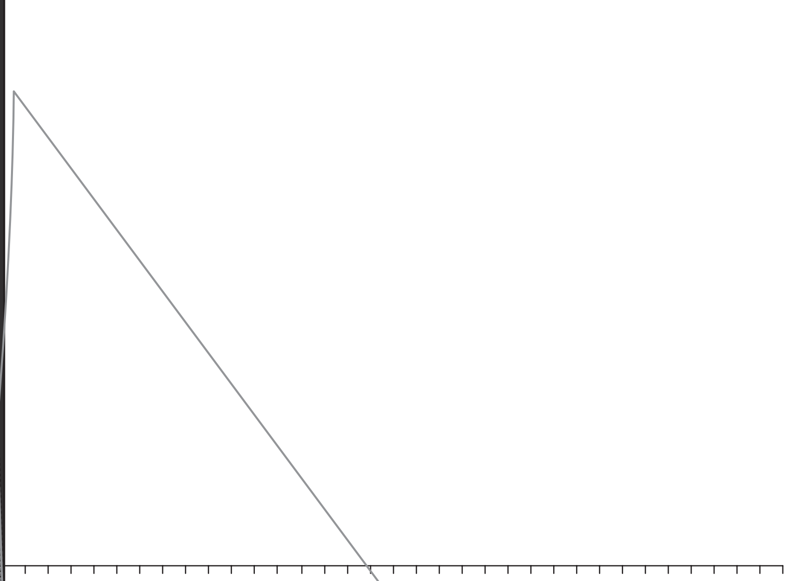
[28] As indicated earlier in section I and in fig. 1, the silver wages we used for Beijing, Canton, and Suzhou/ Shanghai are broadly equal. For reasons of easy visibility, we only plot the silver wage for the Beijing series on figs. 2 and 3. Complete price and wage series for figs. 2–6 can be downloaded from the websites at http:// www.iisg.nl/hpw/data.php and http://gpih.ucdavis.edu/Datafilelist.htm.



Amsterdam occupies a peculiar position in figure 2. Nominal wages there were remarkably constant for a century and a half. At the outset the Amsterdam wage was similar to the London wage. The same was true of Antwerp. Indeed, the Low Countries and the London region stand out from the rest of Europe for their high wages in the seventeenth and eighteenth centuries. These high wages were probably due to the active involvement of these regions in intercontinental commerce. However, this pattern changed as the nineteenth century advanced. The industrial revolution raised British wages above Dutch levels. Indeed, the early industrialization of Germany is seen in figure 2 as a rise in the Leipzig wage.

These developments intensified after 1870, as shown in figure 3. British wages continued to increase. By the First World War, German wages had caught up with the British level, and Dutch wages closed the gap as well. Italian wages were also growing, but the increase was muted compared to the industrial core of Europe. Outside Europe, Japanese wages before 1870 stayed largely flat, in keeping with the low Italian level. After 1890, Japanese wages, spurred by the industrialization drive in the Meiji era, began to rise, but continued to stay substantially below the rising trend of early twentieth-century European wages.

Chinese wages, in contrast, changed little over the entire period. There was some increase in the silver wage after 1870, but figure 3 emphasizes that the gain was of little importance from a global perspective. By the First World War, nominal wages in China were very much lower than wages in Europe generally.



[redacted]e Bassino and Ma, 'Japanese unskilled wages', pp. 231–3; for the rest, see section III, n. 31.

[redacted], Adam Smith's generalization about Chinese and European [redacted]ccurate at the time of the First World War than when he [redacted]

IV

[redacted]ith's second generalization? He remarked that 'the difference [redacted]f subsistence in China and in Europe is very great'.[29] This [redacted]be tested by computing price indices. We have tried many [redacted]weights, and the reassuring result is that our conclusions about [redacted]not depend in any important way on the choice of price index. [redacted]er problem is a difficult one, since diet and lifestyle were [redacted]different parts of Eurasia. How precisely does the real income [redacted]er who consumed beef, bread, and beer compare to that of a [redacted]ho ate rice and fish?

[redacted]nsidered in this section takes Adam Smith's comment as its [redacted]His generalization about price levels is expressed in terms of [redacted]ence'. We operationalize that by defining consumption baskets [redacted]are bones' minimum for survival (see tables 3–4). The baskets

[redacted]s, p. 189.

1873
1875
1877
1879
1881
1883
1885
1887

Table 3. *Subsistence lifestyle: baskets of goods in China*

	Suzhou/Canton			*Beijing*		
		Nutrients/day			*Nutrients/day*	
	Quantity per person per year	*Calories*	*Grams of protein*	*Quantity per person per annum*	*Calories*	*Grams of protein*
Rice	171 kg	1,677	47			
Sorghum				179 kg	1,667	55
Polenta						
Beans/peas	20 kg	187	14	20 kg	187	14
Meat/fish	3 kg	8	2	3 kg	21	2
Butter						
Oil	3 kg	67	0	3 kg	67	0
Soap	1.3 kg			1.3 kg		
Cotton	3 m			3 m		
Candles	1.3 kg			1.3 kg		
Lamp oil	1.3 kg			1.3 kg		
Fuel	3 M BTU			3 M BTU		
Total		1939	63		1,942	71

Note: For conversion of calories and proteins, see tab. A2. M: metres. M BTU: million BTU.
Sources: As explained in section IV.

Table 4. *Subsistence incomes: baskets of goods in Europe*

	Northern Europe			*Milan*		
		Nutrients/day			*Nutrients/day*	
	Quantity per person per year	*Calories*	*Grams of protein*	*Quantity per person per annum*	*Calories*	*Grams of protein*
Oats	155 kg	1,657	72			
Sorghum						
Polenta				165 kg	1,655	43
Beans/peas	20 kg	187	14	20 kg	187	14
Meat/fish	5 kg	34	3	5 kg	34	3
Butter	3 kg	60	0	3 kg	60	0
Oil						
Soap	1.3 kg			1.3 kg		
Cotton	3 m			3 m		
Candles	1.3 kg			1.3 kg		
Lamp oil	1.3 kg			1.3 kg		
Fuel	3 M BTU			3 M BTU		
Total		1,938	89		1,936	60

Notes: M: metres. M BTU: million BTU.
Sources: As explained in section IV.

provide 1,940 calories per day mainly from the cheapest available carbohydrate. In Shanghai, Canton, Japan, and Bengal that was rice; in Beijing it was sorghum; in Milan it was polenta; and in north-western Europe it was oats. The diet includes some beans and small quantities of meat or fish and butter or oil. Their quantities were suggested by Japanese consumption surveys of the 1920s and by the Chinese rural consumption survey in the 1930s carried out by the National Agricultural

Research Bureau (NARB).[30] Despite relying on the cheapest carbohydrates, these baskets provide at least the recommended daily intake of protein, although the amount varies from basket to basket. Polenta (closely followed by rice) is the least nutritious source of calories in this regard. Non-food items include some cloth and fuel. The magnitudes of the non-food items were also suggested by the Japanese and Chinese consumption surveys of the interwar period. It would have been hard for a person to survive on less than the cost of one of these baskets.

Having specified the consumption 'baskets' in tables 3–4, time series of the prices of the items shown are necessary, so that the cost of the baskets can be calculated across the eighteenth, nineteenth, and twentieth centuries. For Europe, the prices described in Allen's 'Great divergence' can be applied.[31] New databases were compiled for the Chinese cities under observation. For Beijing, we extended Gamble's retail prices for 1900–24 back to 1738.[32] Food prices were extended using wholesale agricultural prices for Zhili province compiled by Li.[33] The implicit assumption in these extrapolations was that the ratio of retail to wholesale prices remained constant. The details and the procedures for cloth and fuel are explained in appendix II. For Shanghai and Canton, twentieth-century retail prices were extracted from official sources.[34] For the eighteenth century, Wang's Yangzi Delta rice price series was used for Suzhou and Chen's series for Guangdong.[35] These are probably wholesale rather than retail prices. No allowance was made for retail mark-ups—a procedure which is again biased against our conclusions, for if rice prices in China were higher then living standards would have been even lower. The prices of other foods and fuel were taken from the costs incurred by European trading companies in provisioning their ships in Canton. These prices have been compared to the estimated prices for Beijing, and the agreement is close. For most of the eighteenth century, competition was intense in supplying these ships.[36]

The cost of the basket is Adam Smith's 'money price of subsistence', and its history is plotted in figure 4 for leading cities in China and Europe in the eighteenth and nineteenth centuries. The findings would have surprised Smith, for it contradicts his claim that China had cheaper subsistence than Europe. The silver cost of a 'bare bones' basket in Beijing or Suzhou was in the middle of the European range. A corollary is that the silver prices of grains, which dominate the cost of these indices, were similar across Eurasia. Another casualty of figure 4 is

[30] Department of Crop Reporting, Division of Agricultural Economics, The National Agricultural Research Bureau (NARB), China, Crop reports, vol. 5, issues 7 and 8; Rōdō undō shiryō iinkai, *Nihon rōdō*, p. 568. Alternative baskets constructed on the basis of these surveys can also be found in our earlier working paper, R. C. Allen, J.-P. Bassino, D. Ma, C. Moll-Murata, and J. L. van Zanden, 'Wages, prices, and living standards in China, Japan, and Europe, 1738–1925', Global Price and Income History Group working paper no. 1 (2005) [WWW document]. URL [http://gpih.ucdavis.edu/Papers.htm#1].

[31] The data are available on-line at http://www.nuffield.ox.ac.uk.

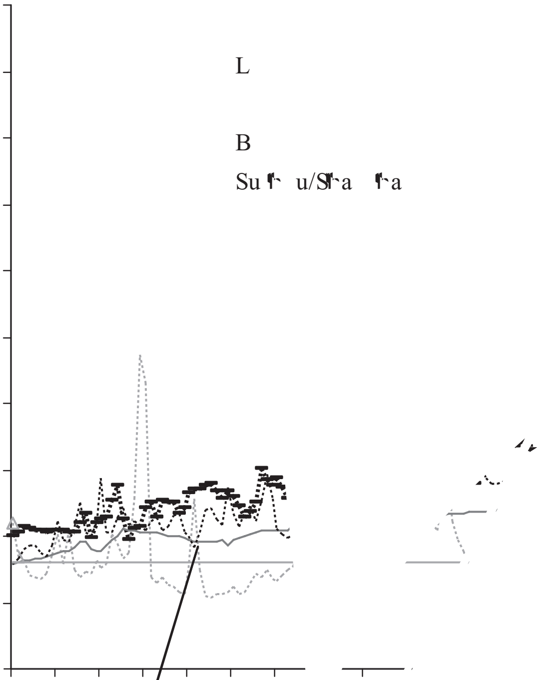
[32] Meng and Gamble, 'Wages'.

[33] Li, 'Integration'.

[34] The Canton data are based on *Reports of statistics* compiled by the Department of Peasantry and Labour, Kwangtung Government, China, in 1928; it covers the period 1912 to 1927. The Shanghai price is from Bureau of Social Affairs, *Cost of living index*, pp. 35–44.

[35] Wang, 'Secular trend', pp. 40–7; Chen, *Sichang jizhi*, pp. 147–9.

[36] See van Dyke, *Canton trade*.



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ope’.[37]

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In modern theory, the index number problem unfolds thus. Suppose an individual or family receives a particular income and faces particular prices. The income and prices determine the maximum level of utility (highest indifference curve) that the individual can reach. Now suppose that prices change. What proportional change in income would allow the individual to reach the original indifference curve in the new price situation? The price index is supposed to

Table 5. *Comparison of different basket costs around 1750*

	'Bare bones' basket		*'Respectable' basket*		*London prices (in grams of silver)*	*Beijing prices (in grams of silver)*
	Europe	*North China*	*Europe*	*North China*		
Oats/sorghum	155 kg	179 kg			0.76	0.48
Bread			182 kg	182 kg	1.28	0.95
Beans			40 kg	40 kg	0.5	0.84
Meat/fish	5 kg	3 kg	26 kg	31 kg	3.19	2.04
Cheese			5.2 kg		2.07	
Eggs			52 pieces	52 pieces	0.37	0.074
Butter	3 kg		5.2 kg		6.45	
Beer/rice wine			182 l	49 l	0.39	1.98
Oil/cooking		3 kg		5.2 kg		4
Soap	1.3 kg	1.3 kg	2.6 kg	2.6 kg	6.36	1.65
Linen/cotton	3 m	3 m	5 m	5 m	4.87	6.14
Candles	1.3 kg	1.3 kg	2.6 kg	2.6 kg	5.4	3.3
Lamp oil	1.3 kg	1.3 kg	2.6 kg	2.6 kg	2.8	3.3
Fuel	3 M BTU	3 M BTU	5 M BTU	5 M BTU	5.59	11.2
Total basket cost (grams of silver)	213	182.6	558.6	499.3		
Europe/Beijing ratio	'Bare bones' basket 1.17		'Respectable' basket 1.12		Geometric average 1.14	

Notes: M: metres. M BTU: million BTU.
Sources: See sections IV and V, and app. II.

have been supplied had it been produced in the European manner can be calculated. Likewise, the price of beer is unknown. For it, we substituted the quantity of rice wine (*sake*) that contained the same quantity of alcohol.[40] We estimated the price of rice wine using the Japanese relationship between the retail price of sake and the wholesale price of rice. In this way we proxied the missing prices needed to cost out a European basket in Beijing.

The European and Beijing baskets define Paasche and Laspeyres price indices. The final step in comparing the cost of living in London and Beijing is to compute the geometric average of the two, which is a Fisher Ideal Price index. This is a 'superlative' price index, which corresponds to a generalized Leontief expenditure function.[41] That representation of consumer preferences has the property that indifference curves are tangent to prices at both consumption patterns. In other words, the representative consumer whose behaviour is summarized by the price index would shift from an English to a Chinese spending pattern as prices shifted from the London to the Chinese configuration. Using this index number imposes the assumptions of modern theory on the reality of eighteenth-century behaviour—certainly a debatable procedure.

How does the Fisher Ideal Price index compare to the 'bare bones' indices? In fact, they are very similar. The relative cost of the European basket in London and Beijing was always close to the relative cost of the 'bare bones' baskets, which are equal to ratios of 1.12 and 1.17 respectively in table 5. Hence, their geometric average is also similar. Consequently, a superlative index number, in this case, gives

[40] 182 litres of beer at 4.5% alcohol contain as much alcohol as 41 litres of sake at 20%.
[41] Diewert, 'Exact and superlative index numbers'. The use of alternative consumption baskets for Canton and Japan based on comparable calories and protein contents also confirm the findings here; see Allen et al., 'Wages, prices, and living standards' (see above, n. 30).

the same result as a comparison of Smith's 'cost of subsistence'. Since the latter has so many intuitive interpretations, we use it as the axis of our discussion in the confidence that it is not misleading us when the index number problem is considered from other perspectives.

VI

The purchasing power of wages is usually measured by the ratio of the wage to the consumer price index. Our procedure elaborates that approach. In constructing the consumer price index, a notional budget was specified that represented the least costly way to survive (tables 3 and 4, however, do not include housing costs, so we increase them now by 5 per cent, which is a minimal allowance for rent). The budget was an annual budget for an adult male. If the man supported a family, the expenditures would have been higher, so that the cost of the budget (augmented by 5 per cent for rent) was multiplied by three to represent the annual budget of a family. This increase is roughly in line with the calorie norms for a man, a woman, and two young children.[42] On the income side, our income measure is the annual earnings that a worker could have gained if he worked full time for a year. We assume that one year's work consisted of 250 days—roughly full-time work allowing for holidays, illness, and slack periods. The earnings from full-time work provide a useful benchmark for comparing Europe and Asia and for defining the economic strategies of families. The ratio of estimated full-time earnings to the annual cost of the family budget is a real wage index.

Our real wage index has a particular interpretation since it answers a specific question, namely, whether a man working full time could support a family at the 'bare bones' level of consumption. Real wage indices of this sort are called 'welfare ratios'. When the welfare ratio equalled one, an unskilled labourer working full time could earn just enough to support his family at subsistence level. Higher values indicate some surplus, while values below one mean either that the family size had to be reduced or work effort had to be increased since there was little scope for reducing expenditure.

Figures 5 and 6 show welfare ratios for unskilled male workers from 1738 to 1923 in the European cities we discussed and the Chinese cities. Several features stand out. Firstly, as shown in figure 6, the Yangzi Delta is reputed to have had the most advanced economy of any Chinese province, but the real wage there was not noticeably higher than the real wage in Beijing or Canton, as we will see. Secondly, the Chinese cities were in a tie for last place with the Italian cities, which had the lowest standard of living in Europe, so an optimistic assessment of China's performance is difficult. Thirdly, the existing information about Beijing wages in the nineteenth century indicates that the real wage continued to slide until the Taiping Rebellion in mid-century, when it reached a life-threateningly low level. After authority was restored, living standards improved slowly into the early twentieth century. Fourthly, the most striking feature of figures 5 and 6 is the great lead in living standards enjoyed by workers in the rapidly growing parts of western Europe. The standard of living of workers in London was always much higher than

[42] Precisely, two children aged 1–3 and 4–6 respectively. For a discussion of food requirements for a notional family of four, see Allen, 'Great divergence', p. 426.

that of workers in Beijing or the Yangzi Delta. After the middle of the nineteenth century, London living standards began an upward trajectory and increased their lead over China. While workers in Amsterdam in the eighteenth century also lived better than their counterparts in Beijing, the Dutch economy faltered in the early nineteenth century.[43] By mid-century, however, growth resumed and real wages were climbing to new heights. At the same time, the rapid growth of the German economy was translating into rising real wages for workers in Leipzig. By the First World War, the standard of living of workers in the industrial core of western Europe had greatly increased over their counterparts in Beijing and Suzhou. The standard of living in China remained low and on a par with the regions of Europe untouched by the industrial revolution. Fifthly, the workers in north-western Europe with welfare ratios of four or more did not eat four times as much oatmeal as their 'bare bones' diet presupposes. Instead, they ate higher-quality food—beef, beer, and bread—that was a more expensive source of calories. In addition, they bought a wide range of non-food items. In the eighteenth century, these included the Asian imports and novel manufactures that comprised the 'consumer revolution' of that era. By the same token, workers in north-western Europe could afford the basket of goods shown in table 5, while workers in Asia could not, and had to subsist on the 'bare bones' baskets. After all, in regions of settled agriculture, the

[43] van Zanden and van Riel, *Strictures*, pp. 121–30, pp. 188–91.

least expensive way to get calories is to boil the cheapest grain into a gruel or porridge. In northern Britain, the poorest people ate oat porridge; in the Yangzi Delta, they ate wheat gruel.[44]

Figure 6 tests the generality of these conclusions by including all of the Asian welfare ratios for comparison. There was variation in experience, but that variety does not qualify the conclusion that Asian living standards were at the low end of the European range. The history of living standards in Japan, India, and Canton was very similar to that of Beijing or Suzhou. Real wages in Istanbul, as shown by Özmucur and Pamuk, were at a level as low as China's, so it may have characterized much of the non-industrializing world in the eighteenth century.[45] There is evidence of rising living standards across Asia after 1870, but the gains were not enough to catch up to the standard of mid-eighteenth-century London or Amsterdam, let alone the much higher standard of living enjoyed by workers in those cities in the early twentieth century.

Figure 6 broadens our comparison by inserting the welfare ratio of Oxford, with the view that London may be exceptional in terms of real wages among English towns. Indeed, real wages in Oxford were always lower than in London, although the gap narrowed from the late eighteenth century.[46] Nonetheless, at a welfare ratio between 2.50353.5(e)-227(ra)nmay53.5(e)-227-22.en 2330.8(w)9n-3139.8(y)79.8(.)]4(5 prosperous than Beijing. London (the capital and a major port) and other big cities were chosen because they are comparable to Beijing (the capital) and Canton (a major port), which are likely to be at the top of the wage scale in their country or region. Oxford, meanwhile, ranked much lower on the urban hierarchies compared with the cities in our study. Thus, the inclusion of Oxford as a robustness check assured us that our finding is not driven by the relative position of London.

A more important question is how representative wages are of labour incomes in China in general. Our knowledge of labour market conditions and the extent of regional migration seem to substantiate the view that wage rates may serve as a reasonable proxy for the average earnings of a particular socio-economic group as well as the marginal productivity of labour in the economy as a whole. The existence of a vibrant and active labour market, particularly for short-term or day labour, in early modern China (and Japan) is well documented, although the precise proportion remains elusive.[47] For the early twentieth century, which shared much of the institutional and economic continuities of the eighteenth and nineteenth centuries, large-scale household surveys reveal, for example, that between 30 and 50 per cent of rural households in the 1930s Wuxi county in the Yangzi Delta region hired day labourers during peak season, whereas the long-term labour market was extremely thin. Furthermore, those households whose main income derived from farm labour fetched an average income 20 per cent below the mean per capita income of all the Wuxi households. This income distance of 20 per cent from the mean shows that agricultural day labourers were at the lower end—but not a marginal fringe—of the income ladder.[48]

Secondly, at least for the commercialized regions near the major urban centres, evidence of a relatively high degree of integration of labour markets between urban and rural areas can be perceived. As noted earlier, most calenderers in Suzhou were migrant workers from the relatively impoverished rural Northern Jiangsu. Similarly for the Beijing wage series, Gamble's detailed study reminds us of the close linkage between urban and rural wages in the nineteenth century. Indeed, if labour market and regional labour migration in eighteenth-century China were as flexible as claimed by the revisionists, there is all the more reason to believe that the wage rates for unskilled labourers we measure are representative of labour earnings for a substantial part of the population at the relatively low end of income distribution.[49]

Our notional wage income can be directly compared with the labour income data cited by Pomeranz and Li when they in fact argue the reverse case, namely, that labouring people in the Yangzi Delta had a high standard of living. Pomeranz,

[47] The literature on the prevalence of labour employment and contracts in Ming and Qing China is voluminous. Examples of this literature can be seen in Pomeranz, *Great divergence*, pp. 81–2, and Huang, *Peasant family*, pp. 58–62. Wei, 'Ming-Qing', documents in detail the improved legal status of labourers towards the eighteenth century.

[48] For information on the labour market in north China and the Yangzi Delta, see Huang, *Peasant family*, p. 110. The Wuxi survey summary can be found in Kung, Lee, and Bai, 'Human capital', tabs. 1 and 2. For a nationwide survey of the labour market in the 1930s, see Chen, *Gesheng nonggong*. Similar labour market and income distribution can also be found in Tokugawa Japan. Bassino, Ma, and Saito, 'Level of real wages', calculate that the welfare ratios of the wage earnings of farm labourers were roughly equivalent to those of tenant cultivators who, in turn, were about 20% below those of the median class.

[49] For linkage between urban and rural wages, see Gamble, 'Daily wages', p. 67. See Pomeranz, *Great divergence*, ch. 2, for an argument on the flexibility of product and factor markets and labour migration in early modern China.

for instance, estimates that a male agricultural labourer employed full time over the course of a year would have realized about 12 taels. Using average prices for 1745–54, the 'bare bones' cost of maintaining a family was 22.59 taels, so the labourer was only earning 53 per cent of subsistence; in other words, the welfare ratio was 0.53. He could barely support himself, let alone a wife and children. A woman spinning and weaving cotton for 200 days per annum, which Li and Pomeranz both reckon was about the maximum possible, could earn 14.61 taels, a bit more than a man.[50] Again, this was less than the cost of maintaining a family. Husband and wife together, however, would have earned 26.61 taels, which was 1.18 times the cost of maintaining a family. A family could survive on that, so long as nothing went wrong, but the standard of living was far behind that in London or Amsterdam where the labourers earned four times the cost of a 'bare bones' standard of living in the middle of the eighteenth century.

So far, this comparison has focused on the wage income of unskilled labourers. However, the wage regression and the twentieth-century wages summarized by Gamble for Beijing all indicate that the ratio of skilled to unskilled wages was about the same in China as in north-western Europe. While future research is needed, this evidence suggests that our conclusions about comparative living standards could still hold true if the comparison were broadened to include all kinds of wage earners.[51]

VII

Our investigation of Asian and European wages and prices shows that the situation differed somewhat from Adam Smith's impressions. Money wages were in accord with his view: in China, they were certainly lower than wages in the advanced parts of western Europe in the eighteenth century and similar to those in the lagging parts of Europe. By the twentieth century, however, wages in all parts of Europe were higher than in China. Contrary to Smith, the cost of living was similar in China and in Europe in the eighteenth century.

The upshot of the wage and price comparisons is that living standards were low in China. In the eighteenth century, advanced cities like London and Amsterdam had a higher standard of living than Suzhou, Beijing, or Canton. The standard of living in the Chinese cities we have studied was on a par with the lagging parts of Europe, the Ottoman Empire, India, and Japan. By the twentieth century, enough progress had occurred in even the backward parts of Europe that their standards of living were beginning to creep above those in China. Wages seemed to have slipped in China in the eighteenth century. Still, most of the difference between Europe and China in 1913 was due to European advance rather than Chinese decline.

In spite of the above, a major surprise is our finding that unskilled labourers in major cities of China and Japan—poor as they were—had roughly the same standard of living as their counterparts in central and southern Europe for the

[50] Li, *Agricultural development*, pp. 149, 152. Pomeranz, *Great divergence*, pp. 318–19, offers two calculations pointing to slightly lower earnings. Li's calculation assumes women received 0.19 shi per bolt of cloth; Pomeranz's is slightly higher. They do not use precisely the same prices. We use average values for 1745–54.

[51] J. L. van Zanden, 'The skill premium and the "great divergence" ', paper presented at the conference 'Towards a global history of prices and wages' (Utrecht, 19–21 Aug. 2004) [WWW document]. URL http://www.iisg.nl/hpw/papers/vanzanden.pdf [accessed on 10 June 2009].

greater part of the eighteenth century. This calls into question the fundamental tenet of the large 'rise of the west' literature that sees western Europe—as a whole—surpassing the rest of the world in the early modern era. Our article suggests that it was only England and the Low Countries that pulled ahead of the rest. The rest, in this context, includes not only Asia but also much of Europe.[52]

In this regard, Adam Smith neglected regional variation and thereby over-generalized the comparison of Europe and China. But our findings also dispute the revisionists' claim that the advanced parts of China, such as the Yangzi Delta, were on a par with England on the eve of the industrial revolution, for we find real wages for unskilled labourers in the Yangzi Delta to have been no higher than those in Beijing or Canton. Clearly, our database on China could be greatly improved and we do not claim to have given the final answer to this question. Nevertheless, any newly discovered data would have to be very different from what is currently available in order to convince us that pre-industrial Chinese living standards were similar to those in the leading regions of Europe.[53] In this regard, Adam Smith's pessimism looks closer to the truth than the revisionists' optimism. Of course, establishing the existence of an income gap between north-western Europe and China in the early modern era only takes us halfway towards the resolution of the great divergence debate. The search for a causal explanation of the great divergence still looms large as a future research agenda.

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[52] For a coverage of welfare ratios of unskilled workers across 16 major urban centres of continental Europe in the early modern period, see Allen, 'Great divergence'.

[53] For the discussion of higher living standards in the Yangzi Delta, see Pomeranz, *Great divergence*, and Li, *Agricultural development*. Huang's comparative regional study, *Peasant family*, also makes a strong case that the Yangzi Delta overall had higher productivity levels and income than north China. Our findings of roughly comparable nominal and real wage levels in the three major Chinese urban centres do not necessarily preclude the possibility that broader measures of per capita income and living standards could still be higher in the Yangzi Delta. A recent study by Ma, 'Economic growth', shows that the per capita income of the two provinces in the Yangzi Delta in the 1930s were 55% higher than the Chinese national average. There is good reason to believe the regional income gap in China in the 1930s would have been larger than in the eighteenth century. While future empirical research is needed to construct a comprehensive regional wage profile for eighteenth- and nineteenth-century China, the magnitude of regional variation within China as discussed in these other studies pales in comparison with the gaps in average real wages in urban centres between China and England.

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APPENDIX I: NOTES ON THE SOURCES FOR CHINESE WAGES, 1686–1902

A. Cotton calenderers' wages

In the seventeenth to nineteenth centuries, most calenderers in Suzhou were migrant workers from impoverished regions in Northern Jiangsu or Anhui. They usually worked under a contract system, renting capital and place of work from cotton cloth merchants. Although forbidden by the government to form their own guilds, they often went on strike for higher wages, hence the documentation of these negotiated wage rates in the stele records.

Information on the daily productivity quoted in Xu's study can be applied for converting the piece rates into daily wages. According to Xu, a calenderer could press one bolt of cloth in about 40 minutes.[54] In a day of about 11 working hours, he could press about 12 bolts of cloth. For conversion, we use 11 bolts of cloth pressed per day to adjust it roughly to a 10-hour working day. However, the calenderers would have to hand in 20 per cent as payment for rental and other expenses. Deducting the 20 per cent from the final wage, we converted the piece wage of 0.0113 taels (in 1730) and 0.013 taels (in 1772 and 1795) per bolt of cloth into 0.0994 and 0.1144 taels per day respectively. The daily productivity data in Xu's study are based on suburban Shanghai in the early twentieth century, but Xu explicitly states that both technology and organization then had changed little from the early modern period.[55]

Despite their footnote, Yan et al. derived their copper–silver series based on the standard rate of one *tiao* being equal to 1,000 cash. Our copper–silver exchange rate series in the second column is similarly derived, with the standard of one *tiao* equal to 1,000 cash. In order to derive the accurate wage rate in silver tael, the third column of table A1 is the silver wage converted from the first two volumes further divided by two. The wage rate thus derived seems extraordinarily low. However, as indicated by Gamble, workers were also given additional food.[62] As shown in section II, we use only the trend (not the level) for this study.

Table A1. *Gamble's rural Beijing wage series in copper cash and silver taels, 1807–1902*

Year	*Copper wages in cash (wen)*	*Copper cash per silver tael*	*Silver wages in taels (= col.1/ (col.2x2)*	*Year*	*Copper wages in cash (wen)*	*Copper cash per silver tael*	*Silver wages in taels (= col. 1/(col. 2x2)*
1807	81	979	0.041	1860	255		
1808	83	1,020	0.041	1865	265	5,180	0.026
1812	81	1,078	0.038	1870	287	5,576	0.026
1813	80	1,067	0.037	1871	333	5,892	0.028
1816	87	1,129	0.039	1872	355	6,170	0.029
1817	80	1,123	0.036	1873	382	6,383	0.03
1818	89	1,106	0.04	1874	388	6,611	0.029
1819	87	1,183	0.037	1875	389	6,681	0.029
1820	95	1,159	0.041	1876	370	7,446	0.025
1822	99	1,203	0.041	1877	368	8,325	0.022
1824	83	1,208	0.034	1878	348	8,314	0.021
1825	88	1,192	0.037	1879	375	8,342	0.022
1827	88	1,265	0.035	1880	410	8,510	0.024
1829	95	1,294	0.037	1881	401	8,341	0.024
1830	96	1,329	0.036	1883	387	7,154	0.027
1831	92	1,346	0.034	1884	356	6,722	0.026
1832	89	1,347	0.033	1885	395	7,573	0.026
1835	94	1,251	0.038	1886	402	6,950	0.029
1836	85	1,378	0.031	1887	395	7,024	0.028
1837	96	1,488	0.032	1888	361	7,883	0.023
1838	91	1,553	0.029	1889	421	7,314	0.029
1841	98	1,382	0.035	1890	393	7,254	0.027
1842	100	1,439	0.035	1891	390	7,627	0.026
1845	86	1,823	0.024	1892	372	7,651	0.024
1846	96	2,010	0.024	1893	410	7,212	0.028
1847	87	2,013	0.022	1894	443	6,722	0.033
1848	68	2,049	0.017	1896	448	6,501	0.034
1849	80	2,046	0.02	1900	422	5,312	0.04
1850	94	1,997	0.024	1901	462	5,758	0.04
1852	93	2,018	0.023	1902	470	6,079	0.039
1853	93	2,205	0.021				
1854	90	2,723	0.017				
1856	110	4,970	0.011				
1857	105	3,935	0.013				
1858	130	4,970	0.013				

[62] Gamble, 'Daily wages', p. 41.

APPENDIX II: NOTES ON THE SOURCES FOR CHINESE PRICES

Our series of prices for Beijing begins with Meng and Gamble's study of wages and prices in Beijing between 1900 and 1924.[63] For that period they collected the retail prices of most elements of the basket detailed in table 4. We abstracted the following series: wheat flour, *lao mi* (old, blackened rice), bean flour, millet, corn flour, pork, sweet oil, peanut oil, foreign cloth, and coal balls. 'Sweet oil' was treated as 'edible oil' in our scheme and 'peanut oil' as 'lamp oil'. Coal balls were

Two things can be said in favour of these extrapolations. First, most of the long-term agricultural time series inflate at the same rate, so the values projected back into the eighteenth century do not depend critically on which price series is used for the extrapolation. Second, the extrapolations can be checked by comparing the values we obtain in the eighteenth century for prices listed in the VOC records for Canton. Since the extrapolated prices are similar to prices paid then, this gives us some confidence in the procedure.

The price series of cotton cloth is based on several sources. First, the Beijing retail price of foreign cloth was projected back to 1871 using Feuerwerker's series of the price of cotton cloth imported into China.[68] Imported cloth was measured in pieces which were usually 40 yards long by one yard wide (360 square feet). Meng and Gamble's price was the price per 100 feet. We interpret that to mean 100 linear feet from a bolt of cloth, which we assume was three feet wide—a typical width. On those assumptions, the retail price per square foot of foreign cloth in Beijing was about 50 per cent more than the price at which it was landed. This is not an unreasonable mark-up.

In his detailed discussion of eighteenth-century cloth prices and weaving incomes, Pomeranz estimated the price of cloth in a low price scenario at 0.5 taels per bolt.[69] On this assumption, 300 square feet of cloth were worth 4.59 taels, and we interpret this as the eighteenth-century counterpart to Meng and Gamble's price for a 100-foot length of a piece of cloth three feet wide. Following Pomeranz, we assume that cloth prices remained constant over the eighteenth century.[70]

For the years between 1800 and 1870, we were guided by the history of cloth prices in Indonesia. A series of the price paid for cotton cloth in Java from 1815 to 1871 shows that from 1815 to 1824, the price was 4.89 grams of silver per square metre, which compares to a Chinese price of 5.12 grams per square metre for the eighteenth century. This correspondence is reassuring since cotton cloth was traded across Asia, so we would not expect extreme differences in its price. Starting in the 1830s, the price in Java dropped fairly quickly to a value of about 2.5 grams of silver per square metre and stayed at that level until 1871.[71] That low price is similar to the value of cloth imported into China—2.36 grams of silver per square metre in 1871. On the assumption that cloth prices in China followed the same temporal pattern as those in Java, the eighteenth-century price derived from Pomeranz was continued to 1830, and then interpolated linearly between 1830 and 1871.

The price of energy was also combined from diverse sources. For 1739–69, we used the data implied by charcoal prices in Zhili province in the 1769 *Wuliao jiazhi zeli*, and for 1816, the price implied by the price of coal in Beijing given by Timkovski.[72] From 1900 onwards, the cost of energy was based on the price of coal balls. One of the striking features of this scattered information is that it gives a fairly constant price for energy. In view of that constancy, the values for the missing years were interpolated.

[68] Feuerwerker, 'Handicraft', p. 344.
[69] Pomeranz, *Great divergence*, p. 319, decided that a cloth of 16 *chi* in length cost 0.4 taels. According to Li, *Agricultural development*, p. xvii, a bolt of 20 *chi* had 3.63 square yards. Hence, the price of cloth was 0.5 taels per bolt.
[70] Pomeranz, *Great divergence*, p. 323.
[71] See Korthals Altes, 'Prices', for cloth prices in Java.
[72] Timkovski, *Voyage*, p. 200.

Since no Chinese alcohol prices were available, the present study used the Japanese data, which show that one litre of sake equalled 1.31 kg of rice.[73] This ratio is applied to Beijing and Canton, assuming that the technology for processing rice wine was similar in China and Japan.

Table A2. *Caloric and protein contents*

	Unit (metric)	*Calories per unit*	*Grams of protein per unit*
Bread	kg	2,450	100
Beans/peas (Europe)	litre	1,125	71
Beans (Asia)	kg	3,383	213
Meat	kg	2,500	200
Butter	kg	7,268	7
Cheese	kg	3,750	214
Eggs	pieces	79	6.25
Beer	litre	426	3
Soy beans	kg	4,460	365
Rice	kg	3,620	75
Wheat flour	kg	3,390	137
Barley	kg	3,450	105
Millet	kg	3,780	110
Buckwheat	kg	3,430	133
Corn flour	kg	3,610	69
Fresh fish	kg	1,301	192
Edible oil	litre	8,840	1
Alcohol (20°)	litre	1,340	5

Sources: The caloric and protein content are based on Allen, 'Great divergence', p. 421, for bread, beans/peas consumed in Europe (fresh with pods, measured in litres), meat, butter, cheese, eggs, and beer. For other items, we relied on US Department of Agriculture (USDA) National Nutrient Database for Standard Reference [http://www.nal.usda.gov/fnic/foodcomp/search/] [accessed 11 Jan. 2010].

[73] On the basis of sake and glutinous rice price data in Osaka in the period in 1824–54 reported in Bunko, ed., *Kinsei Nihon*, tab. 8, pp. 113–17.

The Rise of Europe: Atlantic Trade, Institutional Change, and Economic Growth

By DARON ACEMOGLU, SIMON JOHNSON, AND JAMES ROBINSON*

The rise of Western Europe after 1500 is due largely to growth in countries with access to the Atlantic Ocean and with substantial trade with the New World, Africa, and Asia via the Atlantic. This trade and the associated colonialism affected Europe not only directly, but also indirectly by inducing institutional change. Where "initial" political institutions (those established before 1500) placed significant checks on the monarchy, the growth of Atlantic trade strengthened merchant groups by constraining the power of the monarchy, and helped merchants obtain changes in institutions to protect property rights. These changes were central to subsequent economic growth. (*JEL* F10, N13, O10, P10)

The world we live in was shaped by the rapid economic growth that took place in nineteenth-century Western Europe. The origins of this growth and the associated Industrial Revolution are generally considered to lie in the economic, political, and social development of Western Europe over the preceding centuries. In fact, between 1500 and 1800, Western Europe experienced a historically unprecedented period of sustained growth, perhaps the "First Great Divergence" (i.e., the first major sustained divergence in income per capita across different regions of the world), making this area substantially richer than Asia and Eastern Europe. There is little agreement, however, on why this growth took place in Western Europe and why it started in the sixteenth century.

This paper establishes the patterns of economic growth in Western Europe during this era, develops a hypothesis on the origins of the rise of (Western) Europe and provides historical and econometric evidence supporting some of the implications of this hypothesis.

We document that the differential growth of Western Europe during the sixteenth, seventeenth, eighteenth, and early nineteenth centuries is almost entirely accounted for by the growth of nations with access to the Atlantic Ocean, and of *Atlantic traders.* Throughout the paper, the term Atlantic trader refers to Britain, France, the Netherlands, Portugal, and Spain, the nations most directly involved in trade and colonialism in the New World and Asia. *Atlantic trade,* in turn, means trade with the New World, as well as trade with Asia via the Atlantic, and includes colonialism- and slavery-related activities.[1] The differential growth of Atlantic traders suggests a close link between Atlantic trade and the First Great Divergence. In fact, it appears that the rise of Europe between 1500 and 1850 is largely the rise of Atlantic

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[1] Atlantic trade opportunities became available only during the late fifteenth century, thanks to the discovery of the New World and the passage to Asia around the Cape of Good Hope. These discoveries resulted from a series of innovations in ship technology, primarily pioneered by the Portuguese, that changed the rigging and hull design of ships and developed knowledge of oceanic navigation.

Portugal, and to a large extent France, where the crown was able to closely control the expansion of trade. Consequently, in these countries, it was the monarchy and groups allied with it that were the main beneficiaries of the early profits from Atlantic trade and plunder, and groups favoring changes in political institutions did not become powerful enough to induce them. Our hypothesis, therefore, predicts an important interaction between initial institutions and Atlantic trade, which is the pattern we find in the data.

The major premise presented in this paper is consistent with the emphasis of a number of historians, including, among others, Ralph Davis (1973a), Jan de Vries (1984), Paul Bairoch (1988), Fernand Braudel (1992), and de Vries and Ad van der Woude (1997). Although this historical literature emphasizes the differential growth of Atlantic ports and Atlantic nations, to the best of our knowledge, there are no other studies documenting the quantitative importance of Atlantic traders and Atlantic ports, or showing that the differential growth of Western Europe is accounted for largely by the growth of Atlantic traders.

On the theoretical side, our hypothesis builds on the notion that institutional change, even when socially beneficial, will be resisted by social groups that stand to lose economic rents or political power. Consequently, the process of institutional change involves significant conflict between different groups—in the European context, between the monarchy and its allies, versus commercial interests outside the royal circle.[6] Our historical account can also be viewed as a marriage between the Marxist thesis linking the rise of the bourgeoisie and the de

and Andrei Shleifer, 1993). Distinct from these approaches, however, we offer an explanation, based on the interaction between Atlantic trade and medieval political institutions, of why strong private property rights emerged in Western Europe, especially in Britain and the Netherlands, starting in the sixteenth century. Although some scholars have noted the important role of overseas merchants in particular instances of political change during this period (most notably Robert Brenner, 2003, and Steven Pincus, 2002, in the British case), we are not aware of a theory along the lines developed in this paper.

The paper is organized as follows. Section I documents the key premise of the paper, and shows that the pattern seen in Figures 1 and 2 is robust. Section II develops our hypothesis for the rise of Europe and the role played by Atlantic trade in this process, and provides historical evidence supporting our interpretation. Sections III and IV provide evidence on some implications of our hypothesis (Section III shows that the evolution of European institutions is closely linked to Atlantic trade, and Section IV documents an important interaction between initial institutions and Atlantic trade in European economic growth). Section V concludes. The Appendix summarizes the construction of the variables used in the empirical analysis, and further detail can be found in Acemoglu et al. (2002b).

I. Atlantic Trade and the Rise of Europe

A. *Data*

TABLE 4—ROBUSTNESS CHECKS

	Panel, 1300–1850, controlling for religion (1)	Panel, 1300 to 1850, controlling for wars (2)	Panel, 1300 to 1850, controlling for Roman heritage (3)	Panel, 1300 to 1850, controlling for latitude (4)	Panel, 1500–1820, controlling for religion (5)	Panel, 1500 to 1820, controlling for wars (6)	Panel, 1500 to 1820, controlling for Roman heritage (7)	Panel, 1500 to 1820, controlling for latitude (8)
	Using Atlantic trader dummy measure of potential for Atlantic trade							
	Panel A: Dependent variable is level of urbanization				Panel B: Dependent variable is log GDP per capita			
p-value for Western Europe × year dummies, 1600–1850	[0.67]	[0.42]	[0.49]	[0.09]	[0.24]	[0.91]	[0.15]	[0.85]
Atlantic trader dummy × volume of Atlantic trade	0.013 (0.002)	0.011 (0.003)	0.011 (0.003)	0.011 (0.002)	0.089 (0.013)	0.070 (0.017)	0.125 (0.017)	0.078 (0.015)
p-value for Protestant × year	[0.07]				[0.00]			
Wars per year in preceding century		−0.0006 (0.008)				0.075 (0.029)		
p-value for Roman heritage × year			[0.89]				[0.00]	
p-value for latitude × year				[0.11]				[0.00]
R-squared	0.89	0.89	0.89	0.89	0.97	0.95	0.97	0.97
Number of observations	192	176	192	192	96	88	96	96
	Using Atlantic coastline-to-area measure of potential for Atlantic trade							
	Panel C: Dependent variable is level of urbanization				Panel D: Dependent variable is log GDP per capita			
p-value for Western Europe × year dummies, 1600–1850	[0.19]	[0.23]	[0.39]	[0.09]	[0.99]	[0.98]	[0.71]	[0.81]
Coastline-to-area × volume of Atlantic trade	0.79 (0.08)	0.76 (0.08)	0.75 (0.07)	0.78 (0.07)	2.78 (0.54)	3.33 (0.56)	3.32 (0.54)	2.96 (0.56)
p-value for Protestant × year	[0.51]				[0.05]			
Wars per year in preceding century		0.0082 (0.007)				0.033 (0.026)		
p-value for Roman heritage × year			[0.77]				[0.32]	
p-value for latitude × year				[0.52]				[0.38]
R-squared	0.93	0.93	0.92	0.93	0.97	0.96	0.97	0.97
Number of observations	192	176	192	192	96	88	96	96

Notes: Standard errors are in parentheses. Weighted panel regressions with full set of country and year dummies. Weights are total population of country in each year from McEvedy and Jones (1978). Dependent variable in panels A and C is level of urbanization (percent of population living in towns with more than 5,000 population). Urbanization in Europe is from Bairoch et al. (1988). Dependent variable in panels B and D is log GDP per capita, from Maddison (2001). Panels A and B use the Atlantic trader dummy as the measure of potential for Atlantic trade (one for Britain, France, Spain, Portugal, and the Netherlands; zero for all others). Panels C and D use the ratio of Atlantic coastline to area. Volume of Atlantic Trade is the log average number of voyages per year. Protestant is a dummy for whether country was majority Protestant in 1600. Protestant × year is the Protestant dummy interacted with year dummies for 1600 and after. Wars per year are in preceding century through 1700, 1700–1750 for 1750, 1750–1800 for 1800, and 1800–1850 for 1850. Roman heritage is dummy for whether country was in the Roman Empire; this is interacted with year dummies for 1600 and after. Latitude is distance from the equator for capital city of this country today; this is interacted with year dummies for 1600 and after. For more detailed data definitions and sources, see Appendix, Table 1.

we use the Atlantic trader dummy for our potential Atlantic trade measure (panel B), there is a significant effect from these religion times year interactions. Nevertheless, this has little impact on the pattern of differential growth between Western and Eastern Europe, or between Atlantic and non-Atlantic traders. Moreover, the quantitative effects of Protestantism on economic growth are smaller than those of Atlantic trade.[14]

Many social scientists view war-making as an important factor in the process of state building and subsequent economic development (e.g., Otto Hintze, 1975; Paul Kennedy, 1987; Charles Tilly, 1990). Incidence of wars might also proxy for the importance of interstate competition, which many historians, including Jones (1981) and Hall (1985), have emphasized. To assess the importance of wars, in columns 2 and 6 we include a variable which is the average number of years at war during the previous period (a century or

[14] The poi t est mates (ı t ort d) mpl th t P otes

TABLE 5—GROWTH OF ATLANTIC PORTS
Dependent variable is log city population

	Balanced panel, 1300–1850, weighted	Balanced panel, 1300–1850, unweighted	Balanced panel, 1300–1850, weighted	Balanced panel, 1300–1850, unweighted	Balanced panel, 1300–1850, weighted, without London and Amsterdam	Balanced panel, 1300–1850, weighted, with full set of country × year interactions	Balanced panel, weighted 1300–1850, with Asia	Balanced panel, weighted 1300–1850, with Mediterranean and Atlantic ports
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: Flexible specification							
	Atlantic port		Potential Atlantic port		Atlantic port			
p-value for Western Europe × year dummies, 1600–1850	[0.34]	[0.05]	[0.30]	[0.16]	[0.28]	[0.30]	[0.41]	[0.32]
Atlantic port × 1500	−0.04	−0.05	0.027	0.048	−0.008	−0.072	−0.03	−0.05
	(0.19)	(0.20)	(0.17)	(0.16)	(0.20)	(0.20)	(0.20)	(0.19)
Atlantic port × 1600	0.36	0.46	0.41	0.43	0.41	0.36	0.36	0.40
	(0.16)	(0.20)	(0.14)	(0.16)	(0.17)	(0.17)	(0.16)	(0.16)
Atlantic port × 1700	0.71	0.62	0.76	0.76	0.297	0.47	0.71	0.74
	(0.14)	(0.20)	(0.13)	(0.16)	(0.17)	(0.17)	(0.15)	(0.15)
Atlantic port × 1750	0.70	0.71	0.79	0.89	0.26	0.46	0.7	0.72
	(0.14)	(0.20)	(0.13)	(0.16)	(0.16)	(0.16)	(0.15)	(0.14)
Atlantic port × 1800	0.79	0.92	0.95	1.10	0.32	0.57	0.799	0.84
	(0.14)	(0.20)	(0.12)	(0.16)	(0.15)	(0.15)	(0.14)	(0.14)
Atlantic port × 1850	1.09	1.00	1.19	1.23	0.48	0.46	1.09	1.10
	(0.13)	(0.20)	(0.12)	(0.16)	(0.14)	(0.14)	(0.14)	(0.13)
p-value for Mediterranean port × year dummies, 1500–1850								[0.19]
R-squared	0.92	0.79	0.92	0.80	0.89	0.95	0.94	0.92
Number of observations	1544	1544	1544	1544	1528	1544	1624	1544
	Panel B: Structured specification							
p-value for Western Europe × year dummies, 1600–1850	[0.23]	[0.04]	[0.23]	[0.10]	[0.31]	[0.33]	[0.30]	[0.20]
Volume of Atlantic trade × Atlantic port	0.17	0.16	0.17	0.16	0.065	0.078	0.17	0.17
	(0.02)	(0.02)	(0.017)	(0.024)	(0.019)	(0.018)	(0.018)	(0.017)
p-value for Mediterranean Port × year dummies, 1500–1850								[0.14]
R-squared	0.92	0.79	0.92	0.79	0.89	0.95	0.94	0.92
Number of observations	1544	1544	1544	1544	1528	1544	1624	1544

Notes: Dependent variable is log city population, from Bairoch et al. (1988). Weighted regressions use current level of city population in each year as weights. All columns report balanced panel regressions for 1300, 1400, 1500, 1600, 1700, 1750, 1800, and 1850, using only cities for which we have data in all eight time periods. The Atlantic port dummy equals one for a city used as an Atlantic port. Potential Atlantic ports are all ports that could have been used for Atlantic trade and include Atlantic ports plus ports in Belgium, Germany, and Ireland (there are no potential Atlantic ports in Denmark or Norway in our balanced panel). Volume of Atlantic trade is log average voyages per year; this is multiplied by the Atlantic port dummy (or by the potential Atlantic port dummy); the coefficient on this interaction term is multiplied by 100. Year dummies are included for all years from 1400. Western Europe × year dummies are included for all years from 1600. For a list of Atlantic ports and potential Atlantic ports, see the Appendix of Acemoglu et al. (2002b).

Column 7 adds Asian cities from Tertius Chandler (1987), so now West European cities are being compared to both East European and Asian cities. The results are similar, but also show the differential growth of all West European cities relative to Asian cities.[19]

Is there something special about ports, or is it Atlantic ports that are behaving differently after 1500? To answer this question, Figure 4B and column 8 show that Mediterranean ports grew at similar rates to inland European cities; what we find is not a general port effect but an *Atlantic port effect.*

Was the urban and economic expansion of Atlantic nations driven solely by the growth of Atlantic ports? Figure 5A shows the expansion of Iberian (Spanish and Portuguese) Atlantic ports, other Iberian cities, and West European inland cities. Almost all of the differential growth of Spain and Portugal comes from Atlantic ports. In fact, non-Atlantic parts of Spain and Portugal grew more slowly than West Eu-

[19] We also investigated the importance of the same controls used in Table 4 for country-level growth. The results, which [illegible] et al. (2002b), show that th[illegible] attern [illegible]

opposition, intervened in the election of treasurer for the Virginia Company, saying, "Choose the devil if you will, but not Sir Edwin Sandys" (Rabb, 1998, p. 349). Similarly, for the Glorious Revolution, Pincus (2002, pp. 32–33) provides evidence that "the merchant community poured money into William of Orange's coffers in 1688"—perhaps around £800,000 (about £500,000 in 1600 prices), enough to pay for a sizable army.

The Netherlands.—Dutch merchants always had considerable autonomy and access to profitable trade opportunities. Nevertheless, prior to the Dutch Revolt, the Netherlands (in fact, the entire Duchy of Burgundy) was part of the Habsburg Empire, and the political power of Dutch merchants was limited. The Habsburg monarchy consistently attempted to increase its political dominance over and fiscal revenues from the Netherlands (W. Fritschy et al., 2001). The critical improvement in Dutch political institutions was therefore the establishment of the independent Dutch Republic, with political dominance and economic security for merchants, including both the established wealthy regents and the new merchants immigrating from Antwerp and Germany.[28]

Dutch politics was shaped by the conflict between Dutch merchants and the Habsburg monarchy starting in the fifteenth century, and before then by the conflict between merchants and the Duke of Burgundy. By 1493 Maximilian of Habsburg had reversed the Grand Privilege of 1477, which gave the states general the right to gather on their own initiative and curbed the right of the ruler to raise taxes. After 1552, war with France and England increased the Habsburgs' fiscal needs and led them to impose a large tax burden on the Netherlands. Growing fiscal and religious resentment in 1572 led to a series of uprisings, mostly orchestrated by commercial interests (see Jonathan I. Israel, 1995). These culminated in a war of independence, which began with the Revolt in the 1570s and did not end until 1648, punctuated by Philip II diverting resources to intervene in France after 1590, the successful Dutch offensives of 1591–1597 under the command of Maurice of Nassau, the embargoes against Dutch trade with Spain and Portugal in 1585–1590, 1598–1609, and 1621–1647, and the Twelve Years Truce from 1609 to 1621.

The major turning point came in the 1590s when important changes in Dutch military and commercial strategy became evident. New military tactics made it possible for the Dutch to hold their own against experienced Spanish infantry (Geoffrey Parker, 1988, pp. 19–20). This was combined with a fiscal and financial "revolution" that allowed states, particularly Holland, both to increase their tax revenues and borrow against future taxes in order to finance the war effort (Fritschy, 2003). At the same time, the Dutch took the critical strategic step of seeking direct access to Asian and American trade centers. This both enriched a generation of Dutch merchants and undermined Spanish and Portuguese revenues sufficiently to induce Philip III to offer peace. By 1605 it was clear to a Spanish royal councillor, the Count of Olivares, that victory would go to "whoever is left with the last escudo" (Parker, 1977, p. 238).

Merchants were naturally the primary political and economic force on the side of independence. De Vries and van der Woude (1997) argue that "urban economic interests ultimately believed it advantageous to escape the Habsburg imperial framework" (p. 369). They also note that, in the case of Amsterdam, the "[Habsburgs'] opponents included most of the city's international merchants ... . [I]n 1578 a new Amsterdam city council threw the city's lot in with the Prince of Orange ... among the merchants returning from ... exile were [those whose families] and several generations of their descendents would long dominate the city" (1997, p. 365).

Commercial interests involved in the Atlantic were particularly important in the shaping of the conflict (see, for example, Israel, 1982, 1995; Herman van der Wee, 1993, pp. 272–73). In 1609, in an attempt to prevent the creation of the Dutch West India Company, Philip III offered peace and independence in return for a Dutch withdrawal from both the West and East Indies. But these terms were "simply not feasible politically because many regents and elite merchants had invested heavily in the [Dutch East India Company]" (Israel, 1995, p. 402).

[28] By the year 1600, a third of the population of Amsterdam was immigrants (Israel, 1995, p. 309). In 1631, there were 685 citizens of Amsterdam with wealth over 25,000 florins. Only half of them were native Hollanders (Parker, 1977, p. 251).

Portugal, Spain, and Switzerland. Bulgaria, Greece, Romania, and Yugoslavia had their Roman traditions eradicated by a long period of Ottoman rule. If they are also coded with Roman heritage, the effect of this variable is weakened further.

Wars.—George Childs Kohn (1999) lists the dates of every European war from about AD 1000, and a brief explanation of participants, duration, intensity, and outcome. We calculate the average number of years of war in a time interval before each date in our dataset: for the preceding 100 years through 1700 and for the preceding 50 years for 1750, 1800, and 1850, excluding purely civil wars and colonial wars outside Europe. Alternative codings such as dropping "minor" wars does not affect our main results. Kohn (1999) does not provide reliable information on the wars of Finland and Greece during this period, so we drop these countries from regressions involving the "wars per year" variable.

Constraint on Executive.—This variable is coded using the method of Polity IV as described in footnote 32. Our primary source in this exercise is the historical encyclopedia of Langer (1972), supplemented with Stearns (2001). Acemoglu et al. (2002b) provide more details on our coding, the full series, and robustness checks with some reasonable alternatives. We also checked our results using the three codings of institutions in De Long and Shleifer (1993), which are somewhat different from ours, for example awarding a much better score to feudal systems than does coding based on the Polity criteria. Using their measures leads to very similar results to those reported in the text.

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Progress and poverty in early modern Europe[1]

By ROBERT C. ALLEN

At the end of the middle ages, the urban, manufacturing core of Europe was on the Mediterranean with an important offshoot in Flanders. The Netherlands were thinly populated,[2] and England was an agrarian periphery. By 1800 the situation was largely reversed. First the Netherlands and then Britain emerged as commercial and manufacturing powerhouses with the largest urban economies in Europe. Italy and Spain slipped behind. Only present-day Belgium managed to remain near the leaders, perhaps because of its proximity to the Netherlands.

Explaining this reversal in fortunes has been a central problem of social science, and the literature includes many conflicting hypotheses. This article attempts to give an integrated assessment of six: population, enclosure, empire, representative government, technology, and literacy.

Population can function in two ways to explain social and economic change in early modern Europe. First, changes in the land-labour ratio can explain differences in real wages and land rents. These, in turn, may affect other aspects of economic life such as the extent of serfdom or proto-industrialization. Second, different demographic regimes may affect development by changing population growth and income levels. Hajnal has identified differences in marriage patterns which suggest that western Europe exhibited Malthus's preventive check, while eastern Europe may have been an example of the positive check model. Historians of the 'European miracle' have argued that just such a difference accounts for Europe's lead over Asia.[3] Perhaps it explains the advance of north-western Europe as well?[4]

Modernization of traditional rural society is a long-standing explanation of the lead of north-western Europe. The enclosure movement in England is the inspiration for this theory. Liberals have emphasized that enclosure replaced communal property with private property, which they regard as more 'efficient' since it aligned the interests of farmers and landlords more tightly with the results of their decisions.[5] Marxists have emphasized

[1] I am grateful to the Social Sciences and Humanities Research Council of Canada for supporting this research through its research grants program and the Team for Advanced Research on Globalization, Education, and Technology.

[2] Van anden, '"Revolt of the early modernists"', has argued that the Netherlands was already advanced in 1500, and that view is supported by its relatively high agricultural productivity and urbanization: see below, tab. 1, figs. 2, 6-8.

[3] Hajnal, 'European marriage patterns'; Jones, *European miracle*; Blaut, *Colonizer's model*, pp. 128-35.

[4] Weir, 'Life under pressure'.

[5] North and Thomas, *Rise of the western world*; Hardin, *Managing the commons*.

that the three-tiered social structure—landlords, tenant farmers, and landless labourers—that emerged in the eighteenth century and that seemed to accompany enclosure was a 'capitalist' arrangement that forced farmers to innovate since high productivity was the only way to pay their landlords and their workers.[6]

Both the English and the Dutch were winners in the early modern scramble for empire, and that success is the inspiration for the imperial theory of economic development. Marx developed this theme as well as the agrarian argument. The role of empire as a source of capital and a market for manufactures has since been emphasized by 'world system theorists' including Wallerstein, Arrighi, and Frank.[7] Acemoglu and his co-authors also emphasize the importance of Asian and American trade, as does Inikori.[8]

Eighteenth-century liberals contrasted the absolutism of France with England's 'mixed monarchy' and the constitution of the Dutch Republic. Representative institutions were alleged to be economically superior, as evidenced by lower interest rates in England and the Netherlands compared with France. These arguments have been restated by recent theorists such as North and Weingast and De Long and Schleifer, who allege that absolutist kings expropriated property and raised taxes in ways that discouraged business enterprise.[9] Eckland and Tollinson have proposed complementary explanations in terms of rent seeking.[10]

Theorists have long emphasized that continuous technological progress is the only basis for sustained economic growth.[11] The relationship between the scientific revolution of the seventeenth century and the industrial revolution has often been discussed, and has been probed recently by Jacob and Mokyr, who argue that north-western Europe benefited from an 'industrial enlightenment' (in Mokyr's phrase) and England, in particular, from a distinctive scientific culture that led to economic advance.[12] But is it possible to measure technological performance and assess its contribution to economic growth?

A final candidate which might explain success was the spread of literacy. When Gutenberg invented movable type in the mid-fifteenth century, less than 10 per cent of adult Europeans could sign their names. By 1800, the proportion was higher everywhere, and it exceeded half in the economic leaders. Much recent theorizing has emphasized the importance of education and human capital accumulation for economic growth, so it makes sense to probe its importance in earlier years. Was a literate population the seed bed for economic expansion?

[6] See, for instance, Brenner, 'Agrarian class structure', and the spirited debate in Aston and Philpin, eds., *The Brenner debate*.

[7] Wallerstein, *Modern world system*; Arrighi, *Long twentieth century*; Frank, *World accumulation*; *idem*, *ReOrient*.

[8] Acemoglu et al., 'Rise of Europe'; Inikori, *Africans and the industrial revolution*.

[9] North and Weingast, 'Constitutions and commitment'; De Long and Schleifer, 'Princes and merchants'.

[10] Eckland and Tollinson, *Politicized economies*.

[11] Jones, *Introduction to economic growth*.

[12] Jacob, *Scientific culture*; Mokyr, *Gifts of Athena*.

The importance of these developments has been debated extensively, usually in terms of internal coherence. The enclosure argument, for instance, has been called into question by historians who have denied that enclosure led to much growth in agricultural productivity.[13] The empire argument has been attacked on the grounds that the extra-European markets were too small to matter, and that the same was true of the profits earned on slavery and colonial trade.[14] The representative government argument has been disputed by those who assert that France did not have particularly high interest rates or taxes. Recent research has downplayed the importance of technological progress and literacy in explaining the British industrial revolution.

This article takes a different approach to assessment by estimating a five-equation simultaneous equation model of European development. The model explains five variables—the population, the wage rate, urbanization, agricultural productivity, and the proto-industrial revolution. It is estimated with an aggregate dataset for Europe from 1300 to 1800.[15] The units of observation are countries at intervals of approximately a century. The countries are defined in terms of their boundaries in 1945 and include England and Wales, Belgium, France, the Netherlands, Spain, Italy, Germany, Poland, and Austria/Hungary/Czechoslovakia. The years include 1300, 1400, 1500, 1600, 1700, 1750, and 1800, although observations in 1300 are available only for England and Italy, and the Netherlands does not enter the dataset until 1500.

A very serious issue is whether countries are appropriate units of analysis—in particular, whether they were homogeneous enough. Was there an 'English' or an 'Italian' wage, for instance? In many respects, the countries were internally heterogeneous, and are represented here with averages. However, if world empires or agrarian institutions were powerful enough to remake societies, their effects should show up in the average experience of the countries concerned. And they do.

A second question is whether the same model fits all countries; in particular, does a single, five-equation model summarize the variety of

[13] Comparisons of open and enclosed villages and of large and small farms find that England's unique rural institutions made little contribution to productivity: Allen, *Enclosure*; Clark, 'Commons sense'. Likewise, studies of share cropping in southern Europe and the Meseta in Spain find it to have been more efficient than liberals and marxists have thought: Hayami and Otsuka, *Economics of contract choice*; Hoffman, *Growth in traditional society*; Nugent and Sanchez, 'Efficiency of the Meseta'; Simpson, *Spanish agriculture*. International comparisons also call into question the importance of 'modern' institutions. The open-field farmers of north-eastern France achieved wheat yields that were on a par with those of farmers of enclosed land in England: O'Brien and Keyder, *Economic growth*; Allen and Ó Gráda, 'On the road again'. Moreover, the farmers who accomplished the Dutch agricultural revolution were mainly owner-occupiers rather than the capitalist tenants of great estates: De Vries, *Dutch rural economy*.

[14] The debate is enormous. Relevant works showing the diversity of approaches include Williams, *Capitalism and slavery*; Wallerstein, *Modern world system*, I and II; Frank, *World accumulation*; Findlay, '"Triangular trade"'; Darity, '"Original sin"'; Engerman, 'Slave trade'; Thomas and Bean, 'Fishers of men'; O'Brien, 'European economic development'; *idem*, 'Imperialism'; O'Brien and Engerman, 'Exports'; O'Brien and Prados, 'Costs and benefits'. Morgan, *Slavery*, is a survey of some important aspects, and Inikori, *Africans and the industrial revolution*, and Ormrod, *Rise of commercial empires*, are the most recent contributions.

[15] The data are tabulated in app. I.

development experiences seen in early modern Europe, or do we need specific, different models for each country to capture the divergent paths of development on the continent? The surprising answer is that one model does fit all, and it indicates why some countries were more successful than others.

I

It is possible to distinguish the successful economies from the unsuccessful by three indicators—real wages, economic structure, and agricultural productivity. These require discussion since they are the axes around which the present analysis is constructed.

Income is fundamental and is best measured by the real wage.[16] Figure 1 plots real wages for leading European cities and highlights the differences in performance between regions. In the fifteenth century, wages in north-western Europe were already higher than elsewhere on the continent, but the advantage was comparatively small. A large gap emerged by 1750—not because of advance in the north but rather because real wages collapsed in central and southern Europe. Figure 1 shows the drop for Valencia and Vienna. Similar declines occurred in other cities in France, Spain, Italy, Germany, Austria, and Poland. Conversely, the real wage in London showed ups and downs, but the trend was stable in the long run. Wages in other English towns fell like those on the continent between 1450 and 1650, but then began to converge up to the London level. Real wages in Antwerp and Amsterdam showed little variation from 1500 to 1800.[17] Roughly speaking, real wages were constant in the leading cities of north-western Europe between 1500 and 1750, but they halved elsewhere on the continent.

Concentration on the real wage also links economic success in early modern Europe to one of the great divides of human history—the escape from the Malthusian trap. Europe took its first steps in that direction between 1500 and 1800. Previously, if an economic expansion raised the standard of living of the majority of the population, their good fortune was unsustainable since the better living conditions induced an increase in population that eventually drove the standard of living back to its

[16] Maddison, *World economy*, has estimated GDP per head for many countries in the early modern period, and some of his estimates concur with the usual view. Thus, he shows Italy to have had the highest income in Europe in 1500, but with little growth from then until 1820. Likewise, between 1500 and 1820 he finds considerable growth in the Dutch Republic and the UK, which were the two richest economies at the time. More problematic reconstructions include Spain, which, according to Maddison's figures, was a rapidly growing economy in that period. Discrepancies such as this emphasize that estimates of GDP for the early modern period must be treated with great caution. Even for the early nineteenth century, the calculation of GDP per head is fraught with difficulties. Thus, Maddison, *Monitoring*, and Prados, 'International comparisons', agree that Britain had the highest income in Europe in 1820, but they disagree significantly about the income of the US—Maddison putting it below Britain's, while Prados puts it above. The differences in ranking reflect difficulties in deflation, for which there are no simple solutions.

[17] Allen, 'Great divergence'.

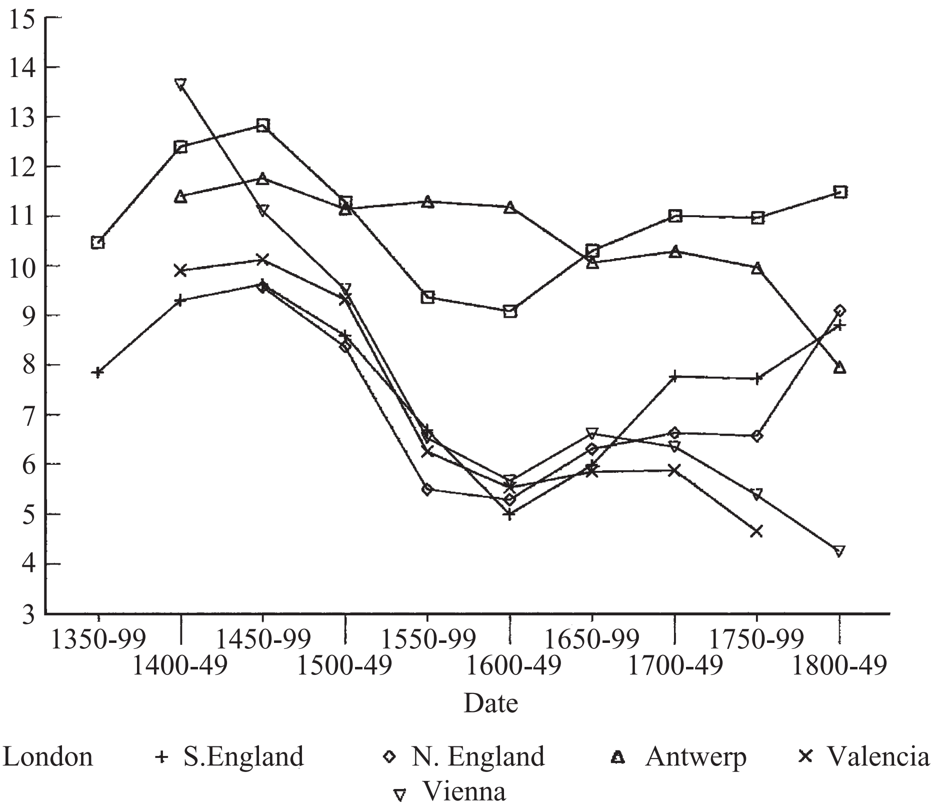

Figure 1. *Real wages, 1350-1850*
Source: Amounts are in Strasbourg prices of 1750-9 from Allen, 'Great divergence'.

earlier value.[18] The economic expansions of the Dutch and English, however, were sustained for centuries without serious falls in the standard of living. This was not because fertility was restrained; on the contrary, these countries had the most rapidly growing populations in Europe. The secret of their success was maintaining even more rapid growth in their economies.[19] The problem of combining economic growth and stable living standards was solved for the first time by vigorous economic expansion rather than by demographic restraint.

The economies that achieved high wages in 1750 were also the ones that experienced the most rapid structural change. Table 1 shows the distribution of the population in major European countries in 1500 and 1800. At the end of the middle ages, Italy, Spain, and present-day Belgium were the leading economies, and they had the smallest proportions of their populations in agriculture and the most extensive degree of urbanization. Elsewhere, about three-quarters of the population was

[18] Abel, *Agricultural fluctuations*; Le Roy Ladurie, *Peasants*; Postan, 'Agrarian evidence'; Wrigley and Schofield, *Population history*.
[19] North and Thomas, *Rise of the western world*.

Table 1. *Distribution of the population by sector, 1500-1800*

	1500	% Rural		1800	% Rural	
	Urban	*Non-agric*	*Agric*	*Urban*	*Non-agric*	*Agric*
Greatest transformation						
England	7	18	74	29	36	35
Significant modernization						
Netherlands	30	14	56	34	25	41
Belgium	28	14	58	22	29	49
Slight evolution						
Germany	8	18	73	9	29	62
France	9	18	73	13	28	59
Austria/Hungary	5	19	76	8	35	57
Poland	6	19	75	5	39	56
Little change						
Italy	22	16	62	22	20	58
Spain	19	16	65	20	16	64

Notes and sources: The procedures and estimates used in Wrigley, 'Urban growth', are generalized to the countries shown here. Total population and urban population are taken from McEvedy and Jones, *Atlas*, and from Bairoch, *La Population*. Census data from the nineteenth century are used to divide the rural population into agricultural and non-agricultural components in 1800. The comparable division in 1500 is made on the assumption that 80% of the rural population at that time was agricultural. Intervening years are linearly interpolated. For details, see Allen, 'Economic structure'.

agricultural—a proportion similar to that in most of the less developed countries early in the twentieth century—and the urban population was correspondingly small.

In analysing changes in the early modern period, it is useful to distinguish four groups. England was undoubtedly the most successful economy, with a drop in the agricultural population to 35 per cent of the whole and a rise in both the urban and 'rural non-agricultural' shares. The latter corresponds to the 'proto-industrial revolution', which involved the expansion of manufacturing (particularly textiles) in small villages organized in the putting-out system.[20] Belgium and the Netherlands experienced a similar transformation, with agriculture declining to a point where it employed 49 per cent and 41 per cent of the population, respectively, in 1800. Spain and Italy showed little change in economic structure, and, indeed, much of the growth in north-western Europe was at their expense as key industries such as woollen textiles relocated from the south to the north. Finally, France, Germany, Austria, and Poland experienced only modest structural transformation. The small decline in the agricultural share was reflected in rural manufacturing rather than in the growth of cities. Although historians of proto-industry have often been enthusiastic about its development potential—hence the term—it was as often associated with economic stagnation as with advance.[21]

[20] Mendels, 'Proto-industrialization'.
[21] Coleman, 'Proto-industrialization'.

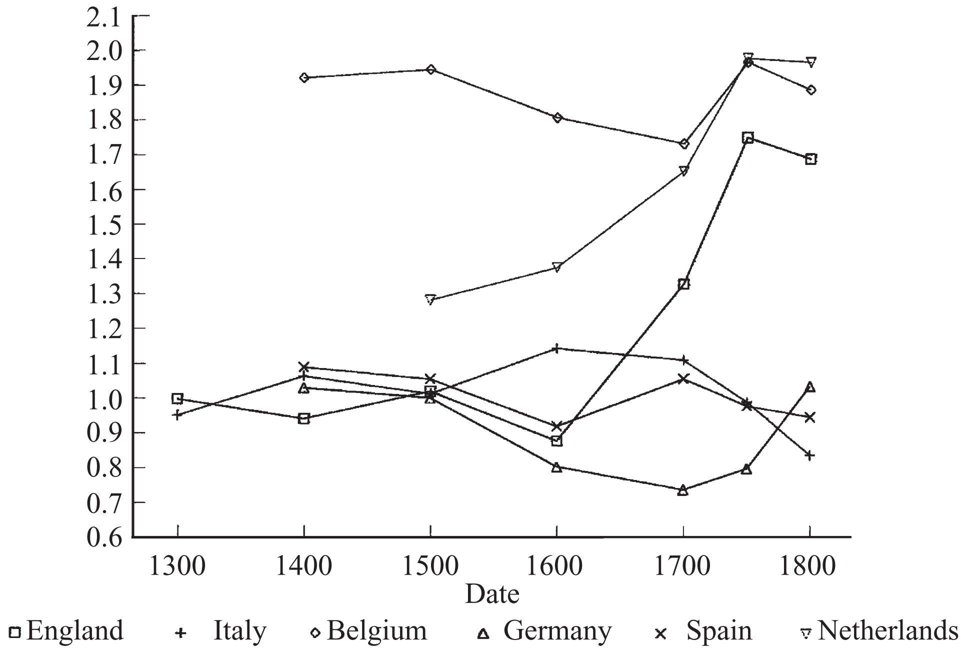

Figure 2. *Total factor productivity in agriculture, 1300-1800*
Source: see app. II.

Agricultural productivity is a third indicator of economic success in the early modern period. An immediate reason why England and the Netherlands could reduce the proportion of their population engaged in agriculture was that the productivity of farmers and cultivators increased substantially between the middle ages and the nineteenth century. In present-day Belgium, output per agriculturalist was high during the middle ages and remained so until 1800. England and the Netherlands were the two countries which experienced agricultural revolutions in the early modern labour productivity in both of these countries was low in the medieval but both closed the gap with Belgium during the seventeenth and eighteenth centuries.[22] Roughly the same was true of total factor productivity, as shown in figure 2.[23] Rising agricultural efficiency contributed to economic development by supplying fo28, wool, and flax to support the non-agricultural economy, by releasing labour for employment in manufacturing, and by providing a surplus that could finance investment or sustain the conspicuous consumption of the aristocracy and the state.

II

In explaining economic development, a distinction must be made between the explanatory variables and those that are explained. The model

[22] Allen, 'Economic structure'.
[23] The calculation of TFP in agriculture is explained in app. II.

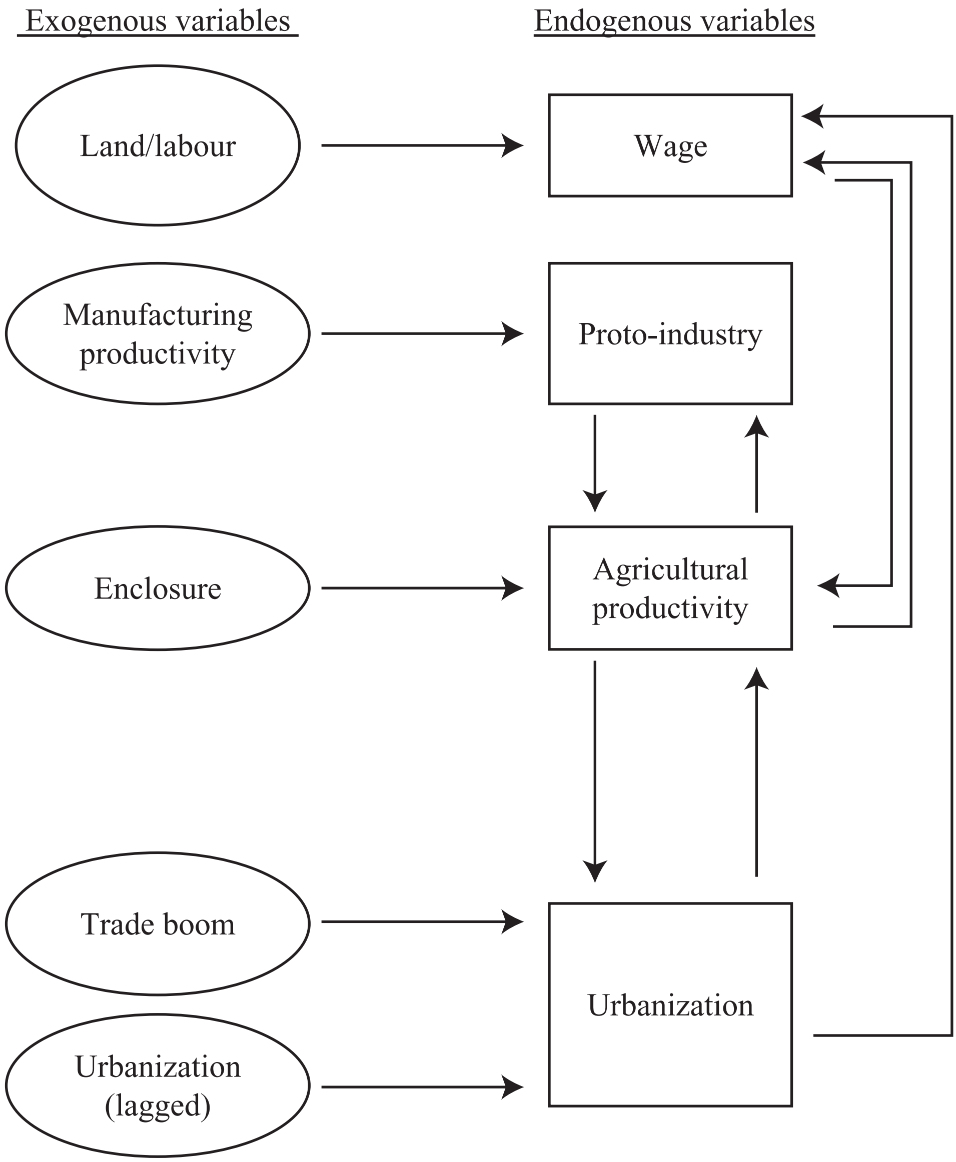

Figure 3. *Flow chart (one period) of the model*
Note: The role of population is explained on p. 411.

developed here explains five variables: population, the real wage, the urban and proto-industrial shares of the population, and agricultural productivity. They are endogenous variables; each influences the others. A productive agriculture, for instance, promoted the development of cities, while urbanization induced growth in agricultural productivity. Hence, the view of development is one in which living standards, urbanization, proto-industrialization, and agricultural revolutions were mutually reinforcing. None was a prime mover pushing all of the others forward.

All of these five variables are ultimately explained by other variables in the model—the enclosure of the open fields, for instance, and the establishment of world empires. Other prime movers include the literacy rate, a productivity variable indexing the growth of competitive advantage in the new draperies, previous levels of urbanization, and the land-labour ratio. The model contains five equations to explain the five endogenous variables in terms of the other variables.

The model works as a recursive system. In each period (century), four equations are solved to determine four endogenous variables—the real wage, the urban and proto-industrial proportions of the population, and agricultural productivity—in terms of the exogenous variables and the population. Figure 3 is a flow diagram that shows the logic of this solution. It demonstrates the links between variables that emerge as important in the statistical analyses to be discussed: many more links were examined but failed to be statistically or historically significant. The four endogenous variables are shown in rectangles and the exogenous variables in ellipses. The endogenous variables influenced each other in many ways. Higher urbanization, for instance, led to higher agricultural productivity. Causation worked in the opposite way as well, with higher agricultural productivity increasing the proportion of the population living in cities. In the model developed here, agricultural and urban revolutions are both a cause and a consequence of economic development.

Population change links successive solutions of the model summarized in figure 3: once the model is solved for one period, the implied wage and urbanization rates are used to project population forward to the next. The process is then repeated as the model is resolved to determine the wage, urbanization, agricultural productivity, and proto-industry for the new period. Urbanization was also a self-perpetuating process that linked one simulation period to the next.

Figure 3 shows the variables that were ultimately causal, and their influence is what would be expected on general grounds. They are now reviewed in turn.

The standard explanation for falling real wages in the sixteenth and seventeenth centuries is population growth in the context of a fixed supply of natural resources.[24] This diminishing returns effect is confirmed in the present model. Here the natural resource base is measured by agricultural land, T, in the 1950s. Although there were improvements in the quality of land over the period, the total did not change in most cases.[25] The labour force, L, is indexed by the population, and the model

[24] Abel, *Agricultural fluctuations*; Le Roy Ladurie, *Peasants*; Postan, 'Agrarian evidence'; *idem*, *Medieval economy*; Wrigley and Schofield, *Population history*; Wrigley, *Continuity*.

[25] Land is the area of agricultural land as given in the UN Food and Agricultural Organization, *Production year-book*, 1958, vol. 12, p. 3. (Figures for England and Wales are taken from Stamp, *Land use statistics*, p. 30. The corresponding figures for the UK agree with those of the FAO.) Agricultural land includes cropped land, meadow, pasture, and rough grazing, but not forest. This total is treated as a constant for each country from 1300 to 1800. The quality of land was certainly improved by drainage, irrigation, and so on, and the intensity of land use grew as a consequence. Nevertheless, the extent of land in the 1950s defines the potential resource base. For instance, in England and Wales between 1688 and 1960 there was a reduction in rough pasture (called 'waste

uses Bairoch's estimates, which are generally taken from McEvedy and Jones.[26] The land and population estimates supposedly relate to boundaries that applied in 1945. Dividing agricultural land by the population gives the land-labour ratio T/L.

The productivity record of early modern manufacturing was mixed, but some signifi

import13.00668.7(products)-674.2(of)-660.3(the)-654.8(age.)-672.6(These)-656.8(impro

Allen, 'Agriculture during the industrial revolution', p. 104; Stamp, *Land use statistics*,

[26] Bairoch, *La Population*, p. 297; McEvedy and Jones, *Atlas*. However, Bairoch reports figures for *Population*; Wrigley and Sch

[27] Rapp, 'Mediterranean trade hegemony'; Harte, ed., *New draperies*.

[28] Munro, 'English “” 'R '; 'New draperies in Norwich'.

[29] Deane, 'Output', pp. 209-10; Davis, 'English foreign trade', p. 165.

[30] Rapp, 'Unmaking of hegemony', p. 502.

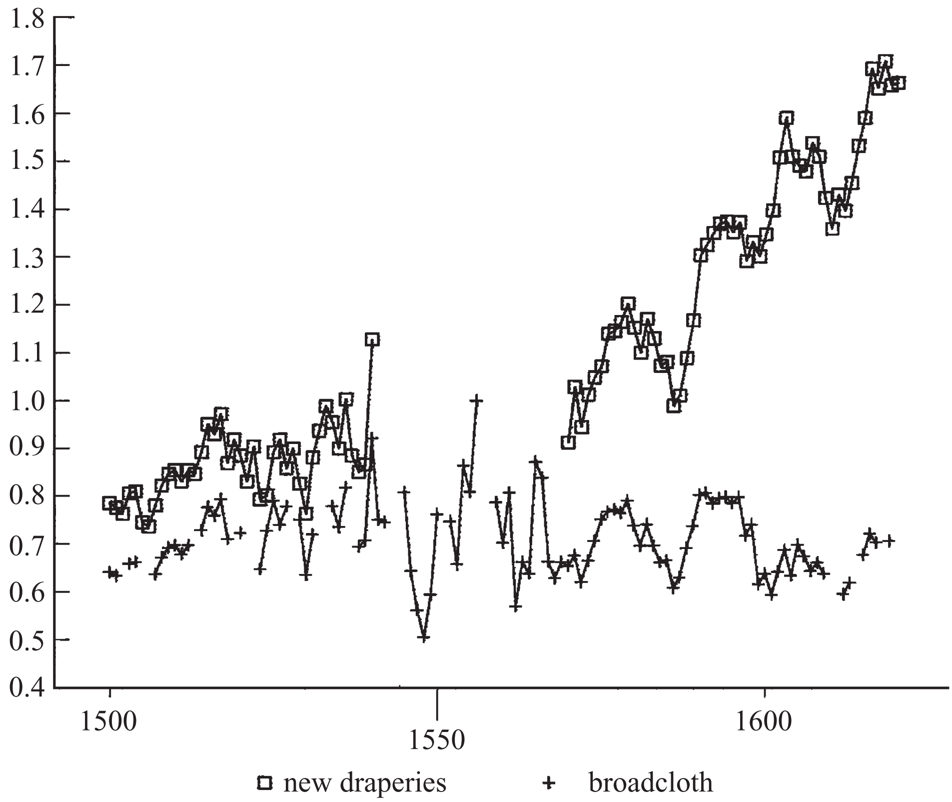

Figure 4. *Total productivity in English cloth, 1500-1620*

Sources: The indices were computed by, first, calculating a geometric average of a series of the price of raw wool and a wage rate and, then, dividing that average by a cloth price series. The raw wool series is described in Allen, *Enclosure*, pp. 327–8, and the wage rate for craftsmen in *idem*, 'Great divergence', p. 435. For the new draperies, the cloth price for Norwich is from Rogers, *History*, IV, p. 569 and V, p. 576. For broadcloth, the cloth price is series A in Beveridge, *Prices*, pp. 85–90.

their efficiency was similar before the invention of the new draperies.[31] The rising efficiency of English worsted production compared with traditional woollens is, thus, also indicative of the increasing advantage enjoyed by northern European worsted producers over the Italians.

The enclosure of the open fields and commons is the best-known aspect of the agricultural revolution in England, and it is measured by ENCL, the proportion of land enclosed. England is famous as the only country that had an enclosure movement in this period, but it was not the only country with enclosed farms. Indeed, there was considerable variation in the proportion of land enclosed as shown by Pounds.[32] For countries other than England, the proportion of land enclosed is taken from this source; for England, where the proportion grew over time,

[31] The cloth market was highly integrated, for, as Munro reports, the cost of shipping woollens between the North Sea and Mediterranean ports was 15% of their value and often less during the fourteenth century: Munro, 'English "new draperies"'.

[32] Pounds, *Historical geography*, p. 335.

Wordie's estimates have been used with slight adjustment to match the dates in the dataset.[33] Including ENCL in cross-national regressions explaining agricultural productivity provides a focused test of England's most distinctive rural institution.

Some countries were successful in the race for empire, while others were not. Spain seized a vast empire in Latin America and the Philippines; England acquired much of North America, some rich sugar islands in the Caribbean, and Bengal; the Netherlands conquered Indonesia, the original Spice Islands and Surinam; and France had important possessions in North America, the Caribbean, and India. Portugal had a substantial empire in Brazil, Africa, and South Asia but is not in the database analysed here. The other European countries were not in the running.

The effect of empire is measured by TRADEPOP, the volume of non-specie trade per caput.[34] All of the countries were mercantilist and tried to reserve trade with their colonies for their nationals. The experience of the Dutch is the exception that proves the rule. They were highly efficient in shipping and came closest to being free traders in the Atlantic economy (but not in the Asian). However, the Dutch were squeezed out of most Atlantic colonial trade by the regulations of the English, French, and Spanish. Only in times of war could the Dutch make much headway.[35] Many factors affect trade volumes, but the experience of the Dutch shows the primacy of politics in this period, and this is why trade is treated as an exogenous measure of imperial advantage.

It should be noted that trade volumes are measured exclusive of shipments of gold and silver. This affects the measurement of Spanish trade where bullion was the main cargo. While the Dutch and, especially, the English empires offered trade and markets, the Spanish may have been too successful in generating loot: the gold and silver from the Americas inflated prices and wages in Spain, rendering much manufacturing unprofitable.[36] The effects of the Spanish empire are tested in some specifications by including a dummy variable SPANEMP.

The early modern period saw the invention and spread of printing with movable type, an increase in book publishing, and a concomitant rise in the ability to read and write. The proportion of the population that could sign its name has been established for most parts of Europe in the seventeenth and eighteenth centuries, and provides a rough indi-

[33] Wordie, 'Chronology of enclosure'.

[34] Trade volumes were derived from Deane and Cole, *British economic growth*, p. 87; Levasseur, *Histoire*, I, p. 18, II, pp. 20-2, 94-6; Haudrere, *La Compagnie française*, IV, p. 1201; Villiers, 'Slave and colonial trade', p. 211; de Vries and van der Woude, *First modern economy*, pp. 393, 445, 460, 474, 478; Garcia Fuentes, *El comercio español*; Morineau, *Incroyables gazettes*, pp. 267, 494; Hamilton *American treasure*, pp. 33-4; Fisher, *Commercial relations*, pp. 67-8; *idem*, *Economic aspects*, pp. 164-70, 201-6. The English imports and exports for the eighteenth century were valued with prices of *c.* 1700, so they are quantity indices. Prices of linen and sugar were used to convert the values of exports and imports, respectively, for other countries to sterling values of 1700 comparable with the English values. For the sources of the prices, see Allen, 'Great divergence'.

[35] De Vries and van der Woude, *First modern economy*, pp. 476-9.

[36] Hamilton, *American treasure*; *idem*, *Money, prices, and wages*; *idem*, *War and prices*.

Table 2. *Adult literacy, 1500-1800*

	1500 %	*1800* %
England	6	53
Netherlands	10	68
Belgium	10	49
Germany	6	35
France	7	37
Austria/Hungary	6	21
Poland	6	21
Italy	9	22
Spain	9	20

Notes and sources: Literacy is taken as the ability to sign one's name. Figures for 1500 are estimated from the rural-urban breakdown. Rural population is assumed to be 5% literate. This is suggested by later data from Nalle, 'Literacy and culture', p. 71, and Houston, *Literacy*, pp. 140-1, 152-3, for Spain; Wyczanski, 'Alphabetisation', p. 713, for Poland; Le Roy Ladurie, *Peasants*, pp. 161-4, for Languedoc; Graff, *Legacies of literacy*, p. 106, for England.

Urban population is assumed to be 23% literate, generalizing from the estimate for Venice in 1587 given in Grendler, *Schooling*, p. 46, that 33% of the men and between 12.2% and 13.2% of the women were literate. The proportion was of the same order in Valencia (Nalle, 'Literacy and culture', p. 71), and among the nobles and bourgeoisie of Poland (Wyczanski, 'Alphabetisation', p. 713), and perhaps a little lower in fifteenth-century London (Graff, *Legacies of literacy*, p. 106). Because of the limited urbanization of countries other than Spain and Italy at this time, the urban literacy rate has no discernible impact on the national average.

Data are fuller for the seventeenth and eighteenth centuries and are taken from: Nalle, 'Literacy and culture'; Houston, *Literacy*; Graff, *Legacies of literacy*; Cressy, *Literacy and social order*; *idem*, 'Levels of literacy'; Viñao Fraga, 'Literacy in Spain'; Grendler, *Schooling*; Ruwet and Wellemans, *L'analphébetisme*; Wyczanski, 'Alphabetisation'; Furet and Ozouf, *Lire et écrire*; Gelabert, 'Niveaux d'alphabetisation'; de Vries and van der Woude, *First modern economy*; Park 'Education revolution?'; Chartier, *Lectures et lecturers*; Cipolla, *Literacy and development*; Kuijpers, 'Lezen en schrijven'; Larguie, 'L'Alphabetisation des Madrileños'.

cator of literacy (table 2). Data for 1500 are less satisfactory, but literacy was clearly far lower at that date, no matter how the material is processed. Literacy increased in all parts of Europe during the subsequent three centuries, but especially in the north where economic growth was most pronounced. Casual speculation suggests that the ability to read and write contributed to technological progress, and this opinion draws some strength from the studies of twentieth-century economic growth that identify schooling and human capital as important causes.[37] Could the same have been true of the pre-industrial economy? The answer appears to be negative, and this is why literacy does not appear in figure 3.

European political systems varied enormously between 1300 and 1800. The model here follows the classification of De Long and Schleifer who have distinguished 'princes' (absolutist monarchs) from more representative and other systems.[38] Medieval Italy, the Dutch Republic, and eighteenth-century England were the classic 'representative' states. Most of the rest were ruled by absolutist 'princes'.[39]

[37] The discussion is voluminous and runs from Denison, *Sources of economic growth*, to Barro, *Determinants*.

[38] De Long and Schleifer, 'Princes and merchants'.

[39] Ibid. Implicitly, these authors have classified Napoleon as a prince. This article does likewise. In 1800, therefore, France and the Netherlands (at that time a dependency of France) are placed in the 'prince' category.

DeLong and Schliefer did not categorize Poland, but it is necessary to do so for the present analysis. Poland is an interesting case, for its government was representative with an exceptionally weak monarch until its dismemberment, which was completed in the 1790s. For the periods before 1800, therefore, Poland is placed in the 'non-prince' category; in 1800 it is assigned to the 'prince' category, for Russia, Prussia, and Austria were all absolutist states.

III

Five equations explain the five endogenous variables—the real wage, agricultural productivity, urbanization, proto-industrialization, and the population. Since the first four of these comprise a simultaneous system, they are estimated by two-stage least squares (instrumental variables). The instruments are all the exogenous variables in the model—LNTL, TRADEPOP, SPANEMP, ENCL, ENG18, LIT, MANPROD, PRINCE, LNURBLG, and the constant. All of these variables are defined in this section. All equations are exactly identified or over identified by the order condition. The four equations solved simultaneously in each period are considered next, and then the equation explaining population growth.

The wage equation is key, for the divergence between north and south is ultimately a question of labour income. Figure 5 defines the problem. D is the demand curve for labour in pre-industrial society. Since the land area is fixed, diminishing returns to labour implies that a larger population can be employed only if the wage falls. For that reason, the demand curve slopes downwards. S represents the supply of labour, which is shown as inelastic (equivalent to the population) for simplicity. With S at a low level, the wage is high at w. In most of Europe, the population expanded between 1500 and 1800, and the wage fell from w to w_1 as shown in figure 5. In the successful economies, however, the story was different. There the demand curve for labour shifted to the right (to D_1) in step with the population growth. As a result, the wage remained at w. The key question in early modern economic history is why the demand curve for labour grew in a few countries and remained constant in the rest. Answering that question will explain the great divergence in incomes that occurred in the early modern period.

The demand curve in figure 5 shifts to the right if capital per worker increases or if efficiency rises. The model can be implemented empirically by choosing proxies for these variables. Regression 1 in table 3 provides a basic specification in which the wage[40] depends on two variables

[40] The wage is the daily wage of a craftsman converted to constant purchasing power with an international inter-temporary consumer price index. The sources of most wages and prices, and the consumer price index, are described in Allen, 'Great divergence'. The English wage is an average of London, southern towns, and northern towns. The series for southern English towns is that of Phelps Brown and Hopkins, 'Building wages', and for northern English towns, Woodward, *Men at work*, is used. For the fifteenth, sixteenth, and seventeenth centuries the York series was used, but it did not differ materially from any of the other northern series; for the eighteenth century the source was the Lancashire wages in Gilboy, *Wages*. All of the English wage series were deflated with the same consumer price index.

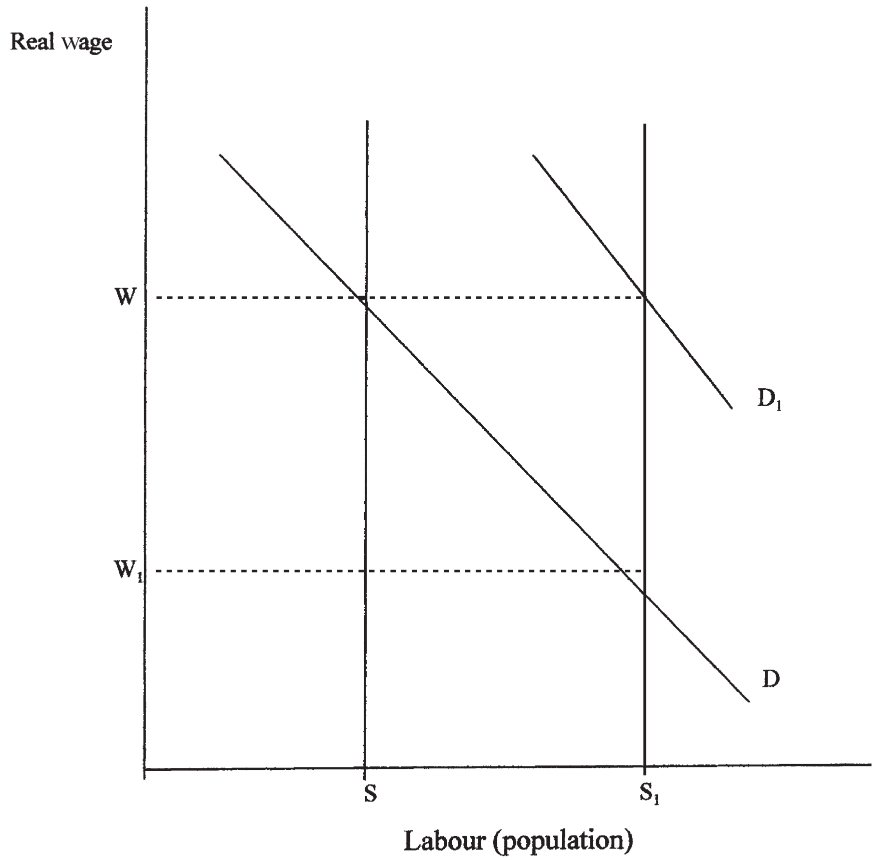

Figure 5. *The supply of and demand for labour*

indexing efficiency and capital per worker—the logarithm of total factor productivity in agriculture (LNAGTFP) and the log of the urbanization rate (LNURB)—as well as on the log of the land-labour ratio (LNTL). The last of these captures the fall-off in productivity as population presses more heavily on the resource base. This effect explains the downward slope of the demand curve in figure 5. The coefficients of all variables are positive and statistically significant, as expected, and the equation fits the data reasonably well.

More variables are added to the basic regression in other specifications. Regression 2 contains PRINCE, a dummy variable equalling 1 for absolutist monarchies. Its coefficient is negative but very small and statistically insignificant, indicating that absolutism had a negligible impact on the demand for labour. Regression 3 includes LIT (the proportion of the adult population that could sign its name), TRADEPOP (intercontinental commodity trade per caput), and LNPROTO (the proportion of the population engaged in rural, non-agricultural activities). None of these variables was statistically significant. It is particularly important that

Table 3. *Wage equation*
(*t*-ratios in parentheses)

regression	1	2	3
dep. var.	LNWAGE	LNWAGE	LNWAGE
estimator	IV	IV	IV
LNTL	.42	.40	.20
	(5.84)	(4.58)	(1.69)
LNURB	.23	.23	−.11
	(3.24)	(3.18)	(−.60)
LNAGTFP	.60	.54	1.03
	(2.68)	(1.98)	(3.25)
PRINCE		−.03	−.09
		(−.43)	(−1.08)
LNPROTO			−.66
			(−1.81)
LIT			−.01
			(−.02)
TRADEPOP			−.03
			(−.03)
constant	−.86	−.66	−.84
	(−1.51)	(−.88)	(−.83)
R^2	.60	.59	.65

Notes: The dependent variable is the real wage.

neither representative government nor literacy shifted the demand for labour to the right.

There are two approaches to explaining the growth in agricultural productivity. The traditional view, discussed above, attributes agricultural revolutions to the 'modernization' of rural institutions. This approach, however, has been called into question by the micro studies which have shown that rural institutions did not influence efficiency. If agrarian institutions, which limit the responsiveness of agriculture to new opportunities, do not explain why some countries were more productive than others, differences in the challenges faced by agriculture may explain the variation in performance. The second approach attributes high agricultural productivity to the growth of the non-agricultural economy. Large cities and rural industries increased the demand for food, flax, wool, leather, and labour, thereby providing an incentive to farmers to modernize their methods. Von Thünen noticed that agriculture was more intensive near cities, and the second approach generalizes that observation into a theory of agricultural development.[41] Hence, the growth of the non-agricultural economy may explain agricultural productivity.

This article measures the relative importance of agrarian institutions and the non-agricultural economy in raising farm efficiency by including

[41] Grantham, 'Diffusion of new husbandry'; *idem*, 'Agricultural supply'; Campbell, *English seigniorial agriculture*, pp. 411-40.

Table 4. *Agricultural productivity equation*
(*t*-ratios in parentheses)

regression	1	2	3	4
dep. var.	LNAGTFP	LNAGTFP	LNAGTFP	LNAGTFP
estimator	IV	IV	IV	IV
LNURB	.27	.24	.23	.50
	(5.67)	(4.61)	(4.27)	(1.84)
LNPROTO	.55	.43	.50	1.19
	(4.39)	(3.07)	(3.05)	(1.73)
LNWAGE	.47	.33	.44	.50
	(3.02)	(1.90)	(2.00)	(1.35)
ENG18				−.31
				(−1.04)
ENCL		.19	.18	.35
		(1.55)	(1.53)	(1.36)
PRINCE			.06	.05
			(.85)	(.37)
LIT				−1.28
				(−1.01)
constant	.63	.58	.40	2.16
	(2.03)	(1.98)	(1.10)	(1.22)
R^2	.53	.57	.58	.29

Notes: The dependent variable is total factor productivity in agriculture; see app. II.

indicators of both in the statistical model. In table 4, regression 1, TFP in agriculture is regressed on LNURB, LNPROTO, and LNWAGE. They are indices of the growth of the non-agricultural economy. All have positive and statistically significant coefficients. Larger values for the first two variables indicate greater demands on agriculture for food and fibre, while higher wages provide an incentive to shed low productivity jobs or to increase efficiency in other ways in order to generate enough net income to keep the farm labour force from migrating to the city. Regression 1 substantiates the view that a larger non-agricultural economy induced an increase in farm efficiency.

The role of agrarian institutions in limiting the response to these demands is ascertained by including two additional variables in equations 2-4. The first is ENCL, the proportion of land enclosed. Its coefficient was usually about .18. ENCL was statistically significant at about the 15

ciency.

Table 5. *Urbanization equation*
(*t*-ratios in parentheses)

regression	1	2	3	4	5
dep. var.	LNURB	LNURB	LNURB	LNURB	LNURBCON
estimator	IV	IV	IV	IV	IV
LNAGTFP	.45		.31	.58	
	(2.32)		(1.47)	(.60)	
TRADEPOP		.16	.10	.10	
		(2.53)	(1.40)	(1.06)	
SPANEMP				.20	
				(.89)	
PRINCE				.02	.01
				(.22)	(.33)
LIT				−.10	
				(−.25)	
MANPROD				−.08	
				(−.13)	
LNURBLG	.82	.90	.84	.77	
	(13.77)	(23.06)	(14.49)	(5.00)	
constant	−.39	−.19	−.35	−.46	
	(−2.67)	(−2.20)	(−2.47)	(−1.35)	
R^2	.90	.92	.91	.89	.01

Note: The dependent variable in regressions 1–4 is the rate of urbanization. The dependent variable in regression 5 is LNURBCON = LNURB −.14*TRADEPOP −.79*LNURBLG −.41*LNAGTFP +.46. The values of the independent variables in this equation are thus constrained to the values in the definition of LNURBCON.

spoke of. Despite the low *t*-ratios, ENCL is included in the model both as a tribute to Young and to make sure that enclosure gets its due.

The second variable representing agrarian institutions was ENG18, a dummy variable equalling one for England in the eighteenth century, at the time when its distinctive agrarian institutions—great estates, large-scale farms, and landless labourers—reached their fully developed form. If they mattered, presumably, they would have pushed the efficiency of England above the level implied by the other variables. However, the coefficient of ENG18 is always negative, close to zero, and statistically insignificant. This finding contradicts the importance of England's eighteenth-century institutions as a source of agricultural improvement.

Finally, PRINCE and LIT were included to see whether they had any observable effect on growth in agricultural productivity. They did not, in any specification.

The proportion of the population living in cities changed very little in many countries during the early modern period, while rising in the Netherlands and, especially, in England. It is difficult to find one equation that captures both stasis and dynamism.[43] The problem is made more difficult by the collinearity among important variables in north-western Europe. This is a bigger problem for this equation than for the others.

Table 5 reports regressions that explain Europe's urbanization rate. The

[43] Magisterial overviews of European urbanization are provided by De Vries, *European urbanization*, and Bairoch, *La Population*. For recent surveys of English urbanization in this period, see Sweet, *English town*; Chalklin, *English town*; Ellis, *Georgian town*.

lagged urbanization rate LNURBLG is included in all equations to account for the persistence of cities, as will be explained below. LNAGTFP is introduced as an explanatory variable since a highly productive agriculture might have nurtured cities by providing them with food, raw materials, capital, and labour. TRADEPOP is included to measure the contributions of American and Asian empires, and SPANEMP to detect any further effects of the Spanish empire. PRINCE and LIT measure the impact of absolutism and of literacy on urbanization. MANPROD measures the productivity of the new draperies relative to traditional woollen cloth and hence the productivity advantage of northern textiles.

The log of the urbanization rate lagged by a century (LNURBLG) is a significant variable in all regressions with a coefficient of about .8. Lagged urbanization captures the persistence of city size since its coefficient means that the urban proportion would have been 80 per cent of its value a century earlier if nothing else had caused it to change.

Persistence represents several social processes. The most common case was countries such as Austria or Germany where the proportion of city dwellers was low and remained so—in other words, where growth was modest. A more interesting case is Italy where the accumulation of social capital allowed cities to renew themselves even when their economic base collapsed. In the middle ages, a major Italian industry was woollen cloth. When its manufacture was destroyed by the exports of the new draperies from northern Europe the Italian cities did not disappear. Instead, their economies were recreated on the basis of silk. This involved raising silkworms in the countryside as well as weaving silk cloth in the city. Although different technical skills were involved, business skills and networks were carried over from wool production. Italians showed tremendous enterprise in the seventeenth century, but they encountered difficulties also, and the economy as a whole did not advance.

The proportion of city dwellers also remained high in Spain throughout the early modern period, but for a different reason. The manufacturing industries that sustained the medieval cities were destroyed by the inflation caused by imports of American bullion. Their population losses were counterbalanced by the growth of Madrid as American treasure was used to build the capital.[44] These very different histories are summarized by the inclusion of the lagged urbanization rate.

Lagged urbanization does not, of course, explain the urban revolutions in England and the Netherlands. Equation 1 indicates that higher agricultural productivity significantly increases urbanization, and equation 2 indicates the same thing for intercontinental commodity trade. However, as equation 3 shows, these variables are highly correlated so they are not jointly significant. Adding PRINCE, LIT, SPANEMP, and MANPROD makes no significant contribution to the explanation (equation 4).

The collinearity problem was addressed on the basis of subsidiary simulations. They indicated that the various national histories could be successfully tracked if the coefficients of LNAGTFP, LNURBLG,

[44] Ringrose, *Madrid*.

TRADEPOP, and the intercept were set to the values noted in table 5. These are all within a standard error of their values in the rest of the table. Equation 5 shows the value implied for the coefficient of PRINCE if these restrictions are imposed, and that is also very close to its unconstrained value. Consequently, in subsequent simulations, equation 5 is used for urbanization. With this specification, urbanization depends on its lagged value, agricultural productivity, the volume of intercontinental trade, and PRINCE, the dummy variable coding absolutism. The last is not statistically significant but is included, as in the other equations, to give the representative government argument the best possible run for its money.

Proto-industry was not a direct determinant of labour demand, but it influenced wages and other variables through its impact on agricultural productivity. Proto-industry had contradictory causes that reflect its ambiguous role in early modern development. On the one hand, there were large rural manufacturing industries in the leading economies, and these industries played an important role in economic growth. The English woollen cloth industry is a case in point. On the other hand, many rural industries developed in backward regions and left no legacy for industrialization.

The dual nature of proto-industry is reflected in the statistical analysis of its causes (table 6). The negative coefficient of LNAGTFP means that proto-industrialization was a consequence of low agricultural productivity rather than of high productivity: it was often the occupation of poor peasants practising a backward agriculture as in central Europe (table 1). The negative coefficient on LNWAGE conveys the same lesson.

Why, then, was there a proto-industrial revolution in north-western

Table 6. *Proto-industry equation*

(*t*-ratios in parentheses)

regression	1	2	3
dep. var.	LNPROTO	LNPROTO	LNPROTO
estimator	IV	IV	IV
LNAGTFP	−1.14	−.93	−.94
	(−1.98)	(−1.58)	(−.83)
LNWAGE	−.84	−1.00	−1.01
	(−3.67)	(−4.02)	(−1.63)
MANPROD	1.48	1.27	1.36
	(3.29)	(2.76)	(2.59)
PRINCE		−.18	−.17
		(−1.50)	(−.99)
LIT			−.14
			(−.10)
TRADEPOP			.01
			(.08)
SPANEMP			(−.08)
			(−.20)
constant	−1.41	−.80	−.83
	(−2.01)	(−.99)	(−.57)
R^2	.37	.40	.40

Notes: The dependent variable is the rate of proto-industrialization.

Europe? Table 6 shows that MANPROD, which indexes the growth in productivity in the new draperies, offset the depressing effect of high-productivity agriculture. The proximate cause of north-western Europe's proto-industrial revolution was, thus, quite different from the cause of its urban revolution. The former was due to rising productivity in textile manufacturing in the sixteenth and seventeenth centuries, and the latter was due, in the first instance, to empire. Manufacturing productivity did not directly promote urban growth, nor did empire promote rural manufacturing. It should be emphasized, however, that these are 'first-round' effects. Allowing for feedback between the sectors means that all exogenous variables affected urbanization and proto-industrialization, sometimes in dramatic ways.

Equations 2 and 3 also include PRINCE. Its coefficient in these tables is larger in absolute value than in the other tables and almost statistically significant by the usual criteria. This is the strongest evidence that absolutism depressed economic development, and equation 2 will be used in simulations to assess its impact. LIT is included in equation 3, and it remains insignificant.

With the data at hand, it is impossible to explore the determinants of fertility and mortality separately; only the overall impact of wages on population change can be examined. As a first step, the population growth rate over a century was graphed against the real wage at the beginning of that century. Century data are of much lower frequency than the annual data usually used in such investigations, but the wage and population cycles extend over periods of several centuries, so century data can reveal the elements of the system.[45]

Graphical analysis revealed two very different demographic regimes. In England and the Netherlands, population growth clearly rose with the wage—these countries, in other words, exhibited the Malthusian preventive check. The rest of the continent did not: no relationship was discernible between population growth and wages. It may be that other data would reveal Malthusian behaviour, but it is not apparent here.

The graphical analysis was extended with regression models of population growth. Table 7 shows regressions for England and the Netherlands as well as for the rest of Europe. Mendels's view that proto-industrialization caused population growth[46] was tested with these data by including the proto-industrial share of the population as an explanatory variable, but it was never significant. Other variables included in the regressions are the wage rate, the urbanization rate, and dummy variables for the Black Death (DBD), the Thirty Years War (D30), and the Netherlands (DN). Urbanization is included in recognition of the very high mortality rate in cities.[47] The results are plausible: according to equation 2, population growth increased with the wage and decreased with urban density.

[45] For the same reason, Lee, 'Population in pre-industrial England', analysed English data at 50-year intervals.

[46] Mendels, 'Proto-industrialization'.

[47] Wrigley, 'London's importance'; van anden, 'Holland's economy'.

Table 7. *Population growth equations*
(t-ratios in parentheses)

regression	1	2	3	4	5
region	Eng/Neth	Eng/Neth	Eng/Neth	cont	cont
dep. var.	POPGROW	POPGROW	POPGROW	POPGROW	POPGROW
CONSTANT	−.47	.15	.43	1.27	1.28
	(−.89)	(.29)	(1.11)	(15.88)	(15.72)
WAGE	.21	.16	.14	−.0042	−.0016
	(3.13)	(2.65)	(2.65)	(−.44)	(−.14)
URBRATE	.68	−.62	−1.58		−.16
	(.44)	(−.43)	(−2.20)		(−.57)
DBD		−.58	−.68	−.52	−.51
		(−2.00)	(−2.70)	(−2.79)	(−3.52)
DN	−.64	−.30			
	(−1.53)	(−.80)			
D30				−.21	−.21
				(−1.53)	(−1.53)
R^2	.64	.80	.77	.36	.34

Notes: The dependent variable is the ratio of the population at one time to its value a century earlier. Equations 1-3 were estimated for England and the Netherlands, equations 4 and 5 for the remaining continental countries.
WAGE = real wage
URBRATE = proportion of the population living in cities
DBD = dummy variable for Black Death
DN = dummy variable for the Netherlands
D30 = dummy variable for the Thirty Years War

Urban density was higher in the Netherlands than in England, and so there is some collinearity between a dummy variable for the Netherlands and urbanization. The t-statistic on DN in equation 2 shows it to be insignificant, so equation 3 has been used in later analysis. This gives a large, negative weight to urbanization in accounting for population change.

The rest of the continent had a different demographic regime according to this regression analysis. As equations 4 and 5 indicate, neither the wage nor urban density had an appreciable impact. The equation predicts population growth of about 24 per cent per century (0.2 per cent per annum) over much of Europe irrespective of economic conditions. The fourteenth century aside, population growth in north-western Europe varied between zero and 50 per cent per century on account of changes in the wage and in urbanization. The mean was similar, but the sensitivity to economic conditions was more Malthusian.

IV

An important test of the simulation model is to see whether it can account for the different paths of development followed by different parts of Europe. If the model is simulated from 1400 onwards, do Italy and France show falling wages and limited structural transformation? Do the Netherlands and England maintain their wages and exhibit urban and agricultural revolutions? The questions have been addressed using simulations with the five-equation version of the model in which population is endogenous and with a four-equation version in which population is

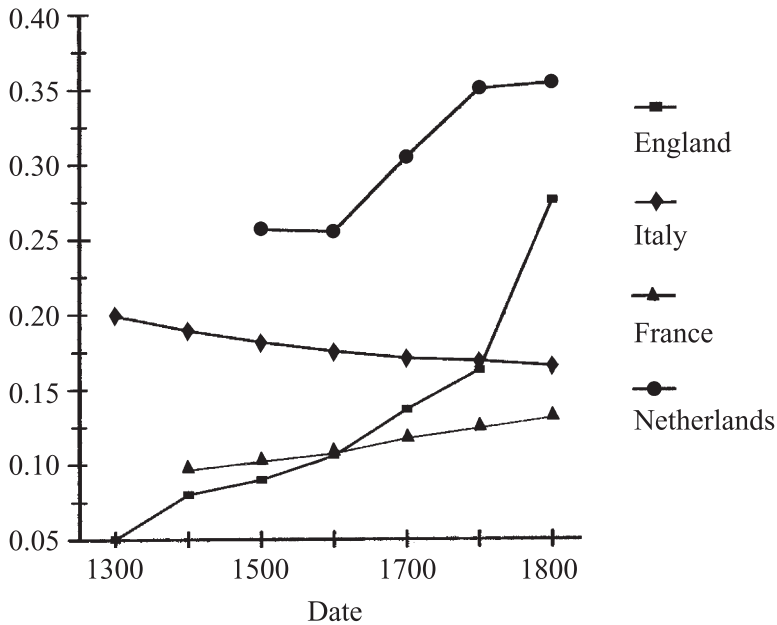

Figure 6. *Simulated urbanization rate, 1300-1800*

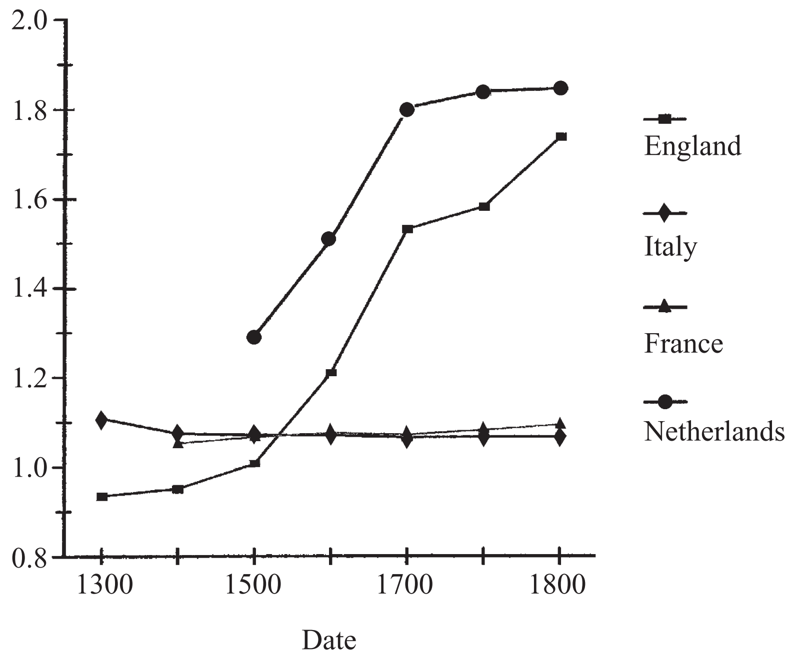

Figure 7. *Simulated total factor productivity [TFP] in agriculture, 1300-1800*

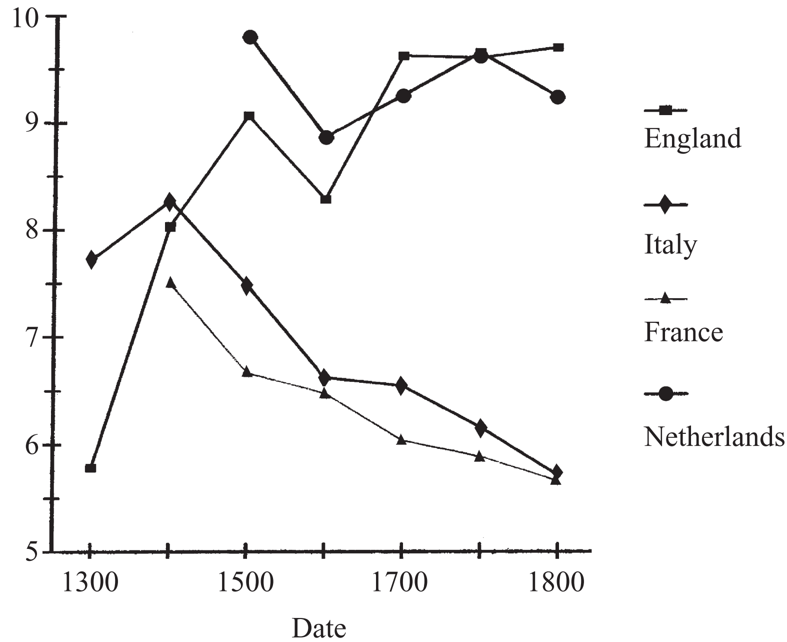

Figure 8. *Simulated real wage, 1300-1800*

treated as exogenous. The answers are similar in both cases, but the model with endogenous population introduces some erratic movements in simulated wages when there are discrepancies in simulating population. The simulations of the other variables are scarcely affected. This section concentrates on the model with exogenous population and considers the effects of endogenous population at the end of the discussion.

Figures 6-8 compare simulated trajectories for urbanization, agricultural productivity, and wages for England, Italy, France, and the Netherlands. The simulations use regression 2 in table 3, regression 3 in table 4, regression 5 in table 5, regression 2 in table 6, and regressions 3 and 4 in table 7. The simulations for France are very similar to those for Germany, Austria, and Poland. They show little cumulative urbanization, static agricultural productivity, and falling real wages. For France and the major countries of central Europe, the model predicts little economic development. The simulations for Italy and Spain are almost as bleak, although their initially higher urban shares are largely maintained.

The simulations for the Netherlands and England, on the other hand, show successful patterns of economic development. In the first place, urbanization was much more extensive. The Dutch were already more highly urbanized in 1500 than much of the continent, and the development of commerce and empire built on that base to produce the highest rate of urbanization in 1800. The English started from a much lower level of urbanization in 1500, overtook France and Italy, and almost caught up with the Dutch by 1800.

Unlike the major continental countries, both England and the Netherlands had agricultural revolutions, and the simulation model reproduces these. Revisionist historians have undermined the view that the modernization of agrarian institutions caused productivity growth in agriculture, which, in turn, spurred economic development generally. This article has taken that reassessment to its logical conclusion by modelling the growth in farm efficiency as a response to the development of the non-agricultural economy. This hypothesis works rather well. It replicates the agricultural revolutions of north-western Europe and the stagnation of productivity in much of the continent.

Urbanization, greater farm efficiency, and proto-industrialization had a pronounced impact on wages. In north-western Europe, the simulated wage remains high during the early modern period. The simulation for England shows a drop in the sixteenth century and then a rebound in the seventeenth and eighteenth centuries as economic development tightened up the labour market. This was escape from the Malthusian trap through rapid development. The contrast with most of the continent is impressive. There, simulated real wages fell as population grew and the economy stagnated.

V

The simulation model can be used to factor out the differences between successful and unsuccessful economies. This section concentrates on the comparison between England, the most successful economy, and its large continental rivals such as France and Austria. How did England maintain a high wage despite rapid population growth, while continental wages fell even though the population grew little? The possibilities—as incorporated in the model—include the replacement of absolutist by representative government in the seventeenth century, the enclosure of the open fields, the productivity advantage associated with the new draperies, and the growth in intercontinental trade consequent upon the formation of the British empire.[48] In addition, the preventive check demographic regime may have accelerated economic development. By successively removing these sources of growth and re-simulating the model, the fundamental differences between England and the continent are identified. These simulations include the ramifications of the changes throughout the economy and not simply in the sector concerned.

Figures 9-11 show alternative simulations for England of TFP in agriculture, the urbanization rate, and the real wage from 1300 to 1800. In all figures, the top line is the 'simulated actual' history of the variable, that is, the value implied by the model when it is simulated with the historical time paths of the variables describing the proportion of the land enclosed, relative textile productivity, and so forth. If the model

[48] In principle, development could also be simulated holding literacy at medieval levels. Since the sign of the coefficient of literacy was usually negative, these simulations perversely generate greater growth than actually occurred. However, they have little relevance because the negative coefficients on literacy were never statistically significant.

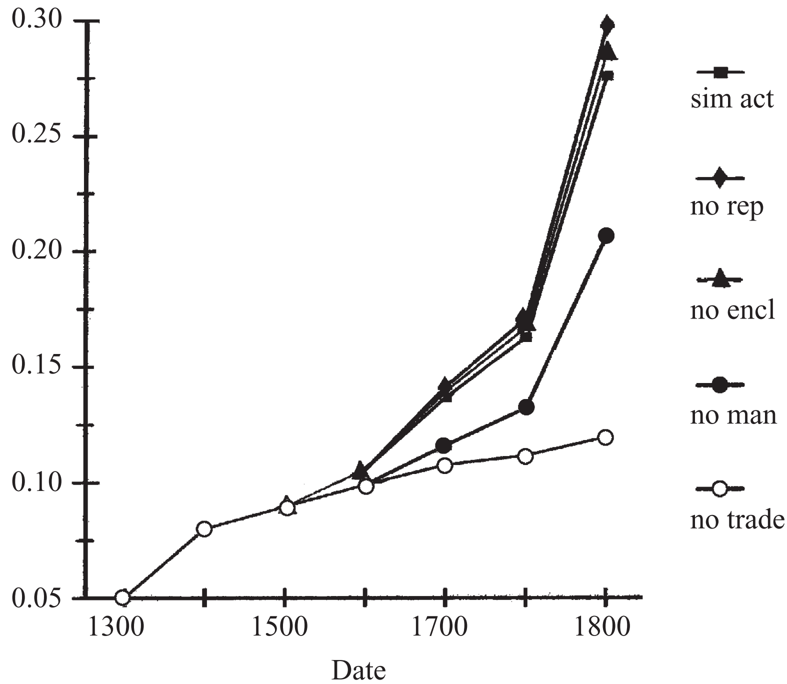

Figure 9. *Simulated urbanization rate for England, 1300-1800*
Note: The abbreviations are explained in the text

were perfect, the simulated values would equal their historical time paths. In the event, the main features are replicated.

The lower lines show the simulated value of the variables as growth-promoting factors are removed from the calculations. The line marked 'not representative' shows the course of the variable if England had remained an absolutist monarchy in the eighteenth century. The removal of exogenous factors cumulates as one moves down the graphs. Thus, the line marked 'no enclosure' keeps the proportion of enclosed land at its 1500 level, while also eliminating representative government. The difference between the 'not representative' line and the 'no enclosure' line, therefore, shows the impact of enclosure, and the difference between the 'no enclosure' line and the 'no manufacturing' line shows the effect of the new draperies. By the same reasoning, the bottom line labelled '

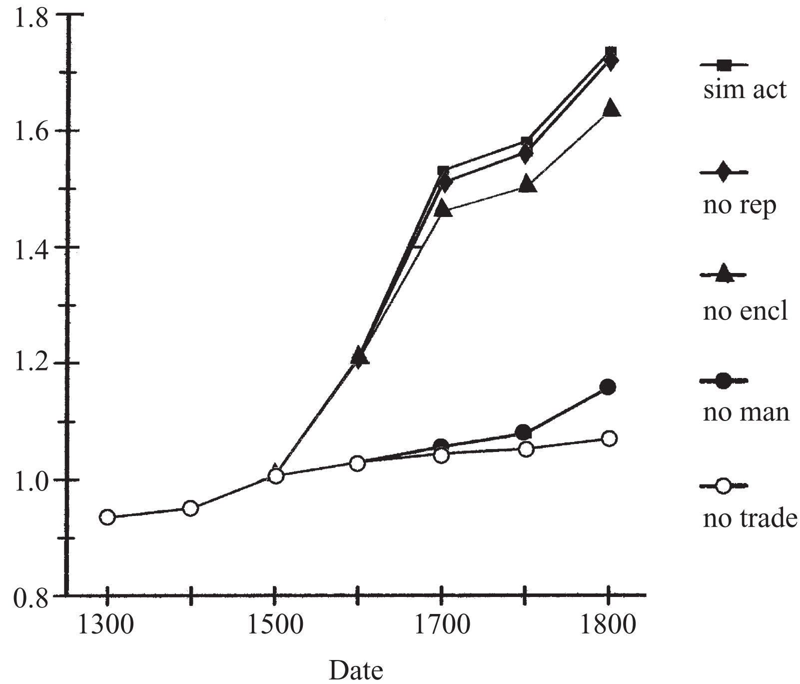

Figure 10. *Simulated total factor productivity [TFP] in English agriculture, 1300-1800*
Note: The abbreviations are explained in the text

growth-promoting result of the Glorious Revolution of 1688,[49] and the present study supports that view.

It is not surprising that representative government did not accelerate growth. Property was secure in all the leading European countries, whatever their constitution. Indeed, as Rosenthal has shown, one of France's problems was that property was too secure: the state, for instance, could not push forward profitable irrigation projects in Provence because landowners could block these initiatives in the courts.[50] Parliamentary ascendancy in England led to higher taxes than in France, contrary to the views of liberals then or now.[51] And while representative government could provide good government—England's local improvement acts are a case in point—it could also provide spectacularly bad government. The concentration of power in the diet emasculated the Polish state and ultimately destroyed it. It would be a great surprise if there were a straightforward statistical relationship between absolutism and underdevelopment, and there was not in these tests.

[49] Clark, 'Political foundations'; Epstein, *Freedom and growth*, pp. 12-37; Quinn, 'Glorious Revolution's effect'.

[50] Rosenthal, 'Irrigation in Provence'.

[51] Mathias and O'Brien, 'Taxation in England and France'; Mathias and O'Brien, 'Incidence of taxes'; Hoffman and Norberg, *Fiscal crises*; Bonney, *Fiscal state*.

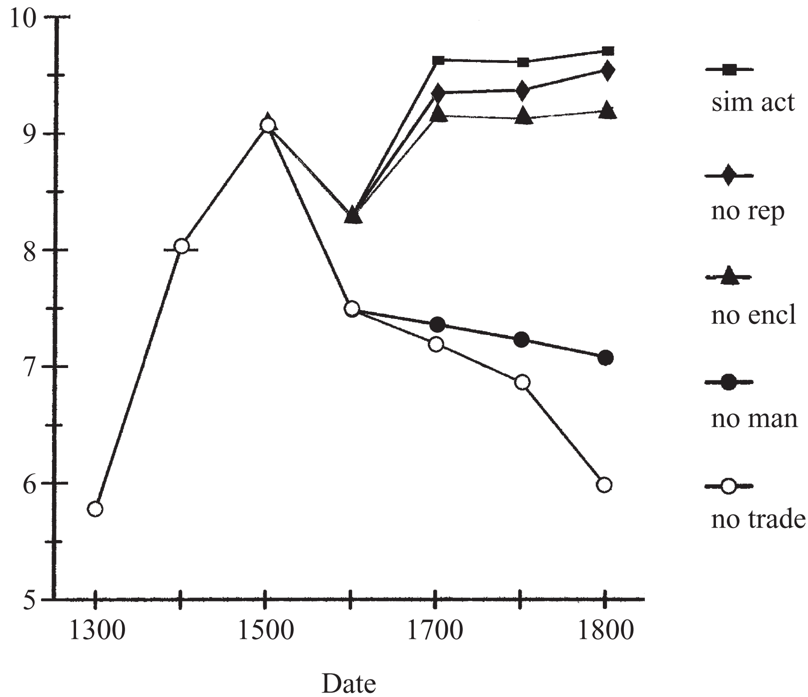

Figure 11. *Simulated real wage for England, 1300-1800*
Note: The abbreviations are explained in the text

Third, the enclosure movement made little contribution to England's progress. In all cases, the 'no enclosure' trajectory grows almost as rapidly as the 'simulated actual'. Figures 9-11 extend the findings of agricultural historians who downplay the importance of enclosure by showing that it had only a small impact on urbanization, on the real wage—and even on TFP in agriculture. This simulation includes not only the direct effect of enclosure on farm efficiency but also the feedback effect when the impact of rising farm efficiency on city growth, for instance, is taken into

that

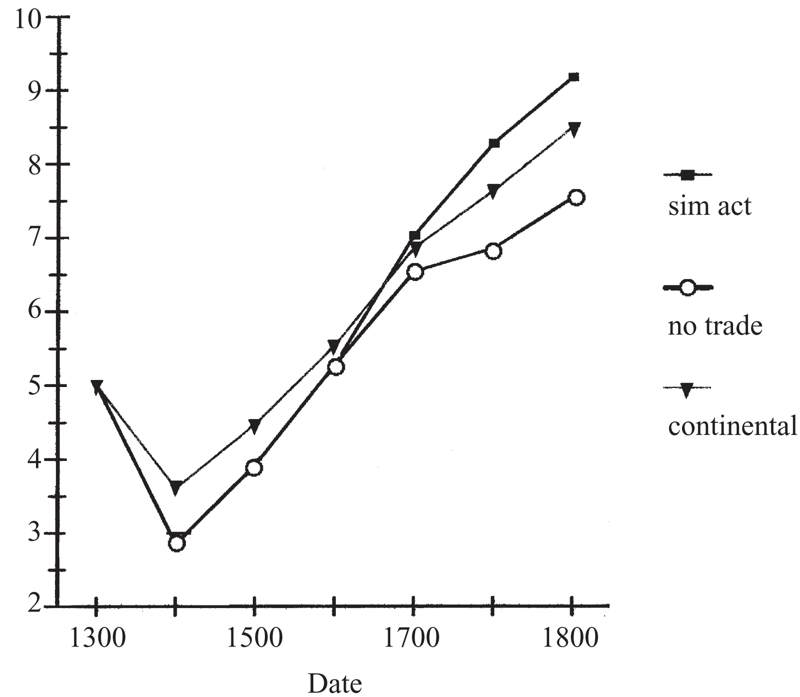

Figure 12. *Simulated population for England, 1300-1800*
Note: The abbreviations are explained in the text

reasons.) In other words, the traditional historiography should be stood on its head.[52]

Fourth, the rise in productivity underlying the success of the new draperies in the seventeenth century was of great importance for England's success. It provided a strong boost to urbanization, and the growth of rural industry. Through these effects, the success of the new draperies was responsible for a large proportion of the growth in TFP in agriculture as farmers successfully responded to the greater demand for food, wool, and labour. Without seventeenth-century success, wages, agricultural productivity, and city size would all have been lower in 1800.

Fifth, the empire established in the seventeenth and eighteenth centuries also contributed to growth. The greatest impact was on city size. Over half of England's urban expansion is attributed to empire in these simulations.

How are these conclusions affected by demographic considerations? There are two questions to consider. The first is how English population history would have been affected by changes in the development of the economy, and the second is how English history would have differed had England had a continental population regime. Figure 12 summarizes

[52] This view is not shared by Crafts and Harley, who argue that capitalist agriculture played an important role in explaining the growth of industrial employment in the British industrial revolution: N.F.R. Crafts and C.K. Harley, 'Precocious British industrialization: a general equilibrium perspective' (London School of Economics, Working Papers in Economic History, no. 67/02).

some simulations that highlight the important features. First, the rapid growth of the English economy due to the new draperies and the intercontinental trade boom had an important effect on population growth. This is indicated in figure 12 by the difference between the 'simulated actual' population history and the 'no trade' simulation, which eliminates representative government, enclosure, the new draperies, and the trade boom. Without these growth-stimulating effects, England's population would have been cut from a simulated 9.2 million in 1800 to 7.5 million. This is the expected result in a preventive check population model where population surges in response to economic expansion.

Second, the substitution of a continental demographic regime would not have had much impact on English development. With continental demography, the population would have been insensitive to the real wage and to urbanization, and so would have reached 8.5 million whatever happened to the economy. If all the growth-promoting developments occurred, the population would have remained at 8.5 million rather than rising to 9.2 million, and the real wage in England would have been somewhat higher than it actually was. There would have been very little difference in urbanization, proto-industry, or agricultural productivity. A population regime that was less responsive to economic variables would probably have benefited labour at the expense of landlords and capitalists, but would probably have had little impact on growth. Malthus and Ricardo would not have been surprised.

VI

The simulations show that a simple model captures the factors responsible for success and failure in the early modern economy. The intercontinental trade boom was a key development that propelled north-western Europe forwards. This conclusion has also been advanced by Acemoglu and his co-authors.[53] However, this article emphasizes that the ascent of north-western Europe began in the century before the American and Asian trades became important. This emphasis extends the work of historians such as Davis and particularly Rapp, who have noted that the commercial revolution began in the seventeenth century before the Atlantic trades became significant and was an intra-European reorganization in which north-west Europeans outstripped Mediterranean producers in woollen textiles.[54] On this reading of the evidence, the ascendancy of north-western Europe and the eclipse of Italy predated the rise of the Atlantic economy. The success of north-western Europe was based on a two-step advance—the first within Europe, the second in America and Asia.

This success, it might be noted, marked the first steps out of the Malthusian trap. High wages were sustainable even with pre-industrial fertility so long as the economy grew fast enough. The reason is that the population growth rate was limited to about 2 per cent per year, the

[53] Acemoglu et al., 'Rise of Europe'.

[54] Davis, 'English foreign trade'; Rapp, 'Mediterranean trade hegemony'.

difference between the maximum observed fertility rate (50 per 1,000 or 5 per cent per year) and the mortality rate, which was about 3 per cent per year in the early modern period. If the demand for labour grew faster than 2 per cent annually, wages could rise even without the fertility restraint of twentieth-century Europeans. This favourable conjuncture first occurred in England and the Low Countries in the early modern period when high wages were maintained even as the population expanded at a brisk rate. In the rest of Europe, where population grew less rapidly, wages sagged as the economy stagnated. Rapid economic development, rather than fertility reduction, was the basis of continued high wages.

The simulations reported here have some important lessons for thinking about economic growth. The dominant paradigm in economics sees sustained growth as the result of human capital accumulation and invention. These are promoted by limited government. This view receives little support from the analysis of this article.

The establishment of representative government had a negligible effect on development in early modern Europe. The stress placed on its importance links together the form of the constitution, the security of property, low taxes, and good government. These could come in many combinations, however. In England, for instance, most agricultural producers acquired the secure property that was a precondition for the agricultural revolution when royal courts created copyhold and beneficial leasehold tenures in the late fifteenth and sixteenth centuries.[55] This was judicial activism by royal officials rather than the action of parliament. Much of England's rise to pre-eminence occurred before the Glorious Revolution of 1688. The English had displaced the Italians in woollen cloth production by then, and the population of London had exploded from 55,000 in 1520 to 475,000 in 1670.[56] In eighteenth-century France, property was secure enough for the Atlantic ports to boom as a result of their involvement in intercontinental trade. Would representative government have made them grow faster? Perhaps by voting higher taxes, France could have contested mastery of the seas more successfully and expanded its empire rather than losing it. The possible gains are doubtful, however, since the population of France was three or four times that of England (and 10 times greater than that of the Netherlands), so that intercontinental trade would have needed to have been larger by the same proportion to have had the same per caput effect. French development was not held back by high taxes, the inability to enforce commercial contracts, or royal interference with private credit.[57] Good government was not cheap nor did it require a parliament.

Likewise, literacy was generally unimportant for growth. What the regression coefficients of literacy measure is its marginal value. The national adult literacy rate reached 50 per cent when labourers learned to read. Their ability probably had no economic pay-off, and Reis has argued that they

[55] Allen, *Enclosure*, pp. 55-77.
[56] Wrigley, 'Urban growth'.
[57] Hoffman et al., *Priceless markets*.

learned to read in order to study religious tracts and enjoy pulp fiction rather than as an investment.[58] The finding of a negligible economic return on the margin is consistent with literacy's having a high value to some merchants and scientists but to few others. This view is consistent with Mitch's argument that schooling had little pay-off during the industrial revolution, and Sandberg's observation that literacy was widespread in backward parts of northern Europe such as Sweden.[59]

These findings, so jarring to modern expectations, gain plausibility in the light of recent research on science and technology.[60] Mokyr, for instance, has argued that the 'knowledge economy' is a recent phenomenon. Its origins lie in the scientific revolution of the seventeenth century, but it became significant on a broad scale only in the nineteenth. Approaching the matter from a different direction, Goldin and Katz have traced the origins of 'capital-skills complementarity' to the early twentieth century.[61] Mass literacy was irrelevant to economic growth before these developments.

The results of this article are much more akin to the findings of recent work on the British industrial revolution. Crafts and Harley have argued that productivity growth was limited to agriculture and a few leading industrial sectors.[62] Most growth came from structural transformation including the remarkable release of labour from English farming. The openness of the economy to international trade was important in explaining this outcome. It might be noted that other historians—including Pomeranz, Frank, and Inikori—have also emphasized the importance of the international economy, although their theoretical frameworks are very different.[63] These conclusions all have echoes in the themes of this article.

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APPENDIX I: Data

See spreadsheet datafile.xls in table A1.
The variables are:

agland: agricultural land (thousands of hectares)
pop: population (millions)
urbpop: urban population
agpop: agricultural population

[58] J. Reis, 'Human capital, immaterial goods, and the standard of living in pre-industrial Europe' (paper delivered at a conference on new evidence on the standard of living in pre-industrial Europe and Asia, Arild, Sweden, 2000).
[59] Mitch, 'Role of human capital'; Sandberg, 'Impoverished sophisticate'.
[60] Mokyr, *Gifts of Athena*.
[61] Goldin and Katz, 'Technology-skill complementarity'.
[62] Crafts and Harley, 'Output growth'; Crafts and Harley, 'Simulating the two views'; Crafts and Harley, 'Precocious industrialization' (see above, n. 53).
[63] Pomeranz, *Great divergence*; Frank, *ReOrient*; Inikori, *Africans and the industrial revolution*.

protopop: rural, non-agricultural population
wage: real wage
agout: index of agricultural output (England in 1500 = 1)
agtfp: TFP in agriculture (see appendix II)
spanemp: dummy variable for Spanish empire
encl: proportion of agricultural land enclosed
manprod: index of productivity in textile manufacturing
urbratlg: lagged value of urbanization rate
literate: proportion of adults who were literate
eng18: dummy variable for England in eighteenth century
popgrow: ratio of population to its level a century earlier
dbd: dummy variable for Black Death in that century
d30: dummy variable for Thiry Years War in Germany
popgrowlg: lagged value of population growth
prince: dummy variable for nonrepresentative government
imports: real value of imports from Asia and Americas
exports: real value of exports to Asia and Americas
trade: imports plus exports

APPENDIX II: Total factor productivity in agriculture

TFP in agriculture was estimated as follows. First, the logarithm of output per agricultural worker was regressed on the logarithm of the land-labour ratio for those 41 observations in which productivity was manifestly low. Excluded were all observations for Belgium, the Netherlands, and for England in 1700, 1750, and 1800. The estimated regression was:

$$\begin{array}{rl} \text{lnlp} = -3.19\ + & .29^{*}\text{lntagl} \\ (-7.82) & (5.75) \end{array}$$

In this equation lnlp is the logarithm of output divided by the agricultural population and lntagl is agricultural land divided by the agricultural population. The *t*-ratios are shown in parentheses. R^2 was .45. This equation was used to predict output per worker for all observations in the sample including those excluded from the estimation. The index of TFP in agriculture is the ratio of actual output per worker to output per worker predicted by the regression equation.

Ideally, capital per worker should also be included as an independent variable in this regression, but data to measure it are not available for all of the countries and time periods. However, when the productivity indices derived here can be compared with indices of TFP based on fuller information, there are no major discrepancies.[64] That is the warrant for referring to these productivity indices as TFP.

Table A1 begins overleaf.

[64] e.g. for England as in Allen, 'Tracking'.

Table A1. *Datafile, continued*

Country	*year*	*agland*	*pop*	*urbpop*	*agpop*	*protopop*	*wage*	*agout*	*agtfp*	*spanemp*	*encl*	*manprod*
Poland	1400	20403	2.75	0.12	2.104	0.526	9	1.148022	0.959225	0	0	1
	1500	20403	4	0.24	3.008	0.752	8.2	1.496169	0.965448	0	0	1
	1600	20403	5	0.38	3.3726	1.2474	6.5	1.432637	0.851068	0	0	1
	1700	20403	6	0.26	3.7884	1.9516	5.2	1.924188	1.050931	0	0	1
	1750	20403	7	0.31	4.1478	2.5422	6.7	2.0884	1.068279	0	0	1
	1800	20403	9	0.43	5.0563	3.5137	3.8	2.930787	1.299189	0	0	1
England	1300	13798	5	0.22	3.824	0.956	5.9	1.651504	0.998477	0	0.45	1
	1400	13798	2.5	0.2	1.84	0.46	7.8	0.917306	0.941125	0	0.45	1
	1500	13798	2.5	0.18331	1.853352	0.463338	9.3	1	1.020617	0	0.45	1
	1600	13798	4.408602	0.425	3.027538	0.956065	5.5	1.22625	0.877734	0	0.47	1.35
	1700	13798	5.208333	0.8841	2.853994	1.470239	6.9	1.779346	1.329161	0	0.71	1.7
	1750	13798	6.041667	1.39412	2.695577	1.95197	8.8	2.248834	1.75067	0	0.75	1.7
	1800	13798	9.0625	2.60838	3.22706	3.22706	7.5	2.47054	1.688644	0	0.84	1.7
Netherlands	1500	2306	0.95	0.28	0.536	0.134	11.4	0.312059	1.281979	0	1	1
	1600	2306	1.5	0.52	0.7252	0.2548	9.5	0.416902	1.376459	0	1	1.35
	1700	2306	1.9	0.74	0.7888	0.3712	9	0.532103	1.653221	0	1	1.7
	1750	2306	1.9	0.69	0.7986	0.4114	9.9	0.642213	1.977598	0	1	1.7
	1800	2306	2.14	0.73	0.8742	0.5358	8	0.682051	1.967334	0	1	1.7
Belgium	1400	1718	1	0.39	0.5795	0.0305	12.1	0.456203	1.921865	0	0.5	1
	1500	1718	1.25	0.35	0.72	0.18	11.7	0.540278	1.945474	0	0.5	1
	1600	1718	1.5	0.44	0.7844	0.2756	11.6	0.53405	1.807561	0	0.5	1.35
	1700	1718	1.7	0.52	0.8024	0.3776	9.2	0.520204	1.732055	0	0.5	1.7
	1750	1718	2.3	0.51	1.1814	0.6086	10.4	0.78136	1.966903	0	0.5	1.7
	1800	1718	3	0.65	1.457	0.893	8	0.872719	1.887879	0	0.5	1.7

Table A1. *Datafile, continued*

Country	*year*	*urbratlg*	*literate*	*eng18*	*popgrow*	*dbd*	*d30*	*popgrowlg*	*prince*	*imports*	*exports*	*trade*
Germany	1400	0.1	0.06	0		0	0	1.5	1	0	0	0
	1500	0.111429	0.06	0	1.5	0	0	1.190476	1	0	0	0
	1600	0.081905	0.12	0	1.190476	1	0	1.04	1	0	0	0
	1700	0.0848	0.19	0	1.04	0	0	1.538462	1	0	0	0
	1750	0.080766	0.27	0	1.538462	0	0	1.34375	1	0	0	0
	1800	0.0875	0.35	0	1.34375	0	0		1	0	0	0
Spain	1400	0.25	0.09	0		0	0	1.25	0	0	0	0
	1500	0.263333	0.09	0	1.25	0	0	1.16	1	0	0	0
	1600	0.184	0.4	0	1.16	0	0	0.988506	1	191.3043	0	191.3043
	1700	0.212644	0.2	0	0.988506	0	0	1.060465	1	89.79592	12.6	102.3959
	1750	0.208016	0.2	0	1.060465	0	0	1.354167	1	141.9355	41.85417	183.7897
	1800	0.213542	0.2	0	1.354167	0	0		1	161.9632	137.9737	299.9369
France	1400	0.09	0.07	0		0	0	1.416667	0	0	0	0
	1500	0.1075	0.07	0	1.416667	0	0	1.117647	0	0	0	0
	1600	0.087647	0.14	0	1.117647	0	0	1.157895	0	0	0	0
	1700	0.107895	0.21	0	1.157895	0	0	1.057955	1	983	517.44	1500.44
	1750	0.115072	0.29	0	1.057955	0	0	1.155102	1	3370.506	1897.933	5268.439
	1800	0.126939	0.37	0	1.155102	0	0		1	0	0	0
Italy	1300	0.22	0.1	0		1	0	0.727273	0	0	0	0
	1400	0.208182	0.1	0	0.727273	0	0	1.25	1	0	0	0
	1500	0.24125	0.09	0	1.25	0	0	1.33	1	0	0	0
	1600	0.221	0.14	0	1.33	0	0	1.007519	1	0	0	0
	1700	0.225564	0.18	0	1.007519	0	0	1.361445	1	0	0	0
	1750	0.225841	0.2	0	1.361445	0	0	1.193548	1	0	0	0
	1800	0.225161	0.22	0	1.193548	0	0		1	0	0	0
Austria[a]	1400	0.05	0.06	0		0	0	1.222222	0	0	0	0
	1500	0.051852	0.06	0	1.222222	0	0	1.212121	0	0	0	0
	1600	0.048485	0.11	0	1.212121	0	0	1.15	1	0	0	0
	1700	0.04875	0.16	0	1.15	0	0	1.304878	1	0	0	0
	1750	0.048286	0.19	0	1.304878	0	0	1.308411	1	0	0	0
	1800	0.072897	0.21	0	1.308411	0	0		1	0	0	0

Note: a Austria includes Hungary and Czechoslovakia

Table A1. *Datafile, continued*

Country	*year*	*urbratlg*	*literate*	*eng18*	*popgrow*	*dbd*	*d30*	*popgrowlg*	*prince*	*imports*	*exports*	*trade*
Poland	1400	0.04	0.06	0		0	0	1.454545	0	0	0	0
	1500	0.043636	0.06	0	1.454545	0	0	1.25	0	0	0	0
	1600	0.06	0.11	0	1.25	0	0	1.2	0	0	0	0
	1700	0.076	0.16	0	1.2	0	0	1.088889	0	0	0	0
	1750	0.057388	0.19	0	1.088889	0	0	1.285714	0	0	0	0
	1800	0.044286	0.21	0	1.285714	0	0		1	0	0	0
England	1300	0.04	0.06	0		1	0	0.5	1	0	0	0
	1400	0.044	0.06	0	0.5	0	0	1	1	0	0	0
	1500	0.08	0.06	0	1	0	0	1.763441	1	0	0	0
	1600	0.073324	0.19	0	1.763441	0	0	1.181402	1	0		0
	1700	0.096402	0.35	1	1.181402	0	0	1.118571	0	1956	656	2612
	1750	0.127922	0.48	1	1.118571	0	0	1.5	0	3512	2094	5606
	1800	0.230751	0.53	1	1.5	0	0		0	12520	12188	24708
Netherlands	1500	0.28	0.1	0		0	0	1.578947	0	0	0	0
	1600	0.294737	0.4	0	1.578947	0	0	1.266667	0	0	0	0
	1700	0.346667	0.53	0	1.266667	0	0	1	0	1928.542	204.82	2133.362
	1750	0.367447	0.6	0	1	0	0	1.126316	0	2144.195	256.1754	2400.371
	1800	0.363158	0.68	0	1.126316	0	0		0	0	0	0
Belgium	1400	0.39	0.12	0		0	0	1.25	1	0	0	0
	1500	0.39	0.1	0	1.25	0	0	1.2	1	0	0	0
	1600	0.28	0.23	0	1.2	0	0	1.133333	1	0	0	0
	1700	0.293333	0.36	0	1.133333	0	0	1.352941	1	0	0	0
	1750	0.299542	0.43	0	1.352941	0	0	1.304348	1	0	0	0
	1800	0.221739	0.49	0	1.304348	0	0		1	0	0	0

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as an entity that continuously expands and adds to itself.[17] As such his influence helped inspire the Industrial Enlightenment.[18] The understanding of nature was a collective project in which the division of knowledge was similar to Adam Smith's idea of the division of labor, another enlightenment notion. Smith realized that such a division of knowledge in a civilized society "presented unique and unprecedented opportunities for further technical progress."[19] The more pragmatically inclined thinkers of the Industrial Enlightenment concurred.[20] Bacon's idea of bringing this about was through what he called a "House of Salomon"—a research academy in which teams of specialists collect data and experiment, and a higher level of scientists try to distill these into general regularities and laws. Such an institution was the Royal Society, whose initial objectives were inspired by Bacon.[21] A finer and more extensive division of knowledge could not have been attained without improved access that made it possible to share the knowledge, and then apply and adapt it to solve technical problems. Access to useful knowledge created the opportunities to recombine its components to create new forms that would expand the volume of knowledge at an ever faster rate. Bacon, indeed, placed a high value on compiling inventories and catalogues of *existing* knowledge and techniques; some of these ideas are reflected in the interest the Royal Society displayed in the

[17] As always, there were earlier expressions of such ideas, not always wholly acknowledged by Bacon. One example is the sixteenth-century French theologian Pierre de la Ramée (Peter Ramus), with whom Bacon would have agreed that "the union of mathematics and the practice of scholarly arts by artisans would bring about great civic prosperity" (Smith, *Business*, p. 36).

[18] Farrington, *Francis Bacon*. Vickers, "Francis Bacon." Bacon's influence on the Industrial Enlightenment can be readily ascertained by the deep admiration the *encyclopédistes* felt toward him, exemplified by a long article on *Baconisme* written by the Abbé Pestre and the credit given him by Diderot himself in his entries on *Art* and *Encyclopédie*. The *Journal Encyclopédique* wrote in 1756 "If this society owes everything to Chancellor Bacon, the philosopher does not owe less to the authors of the *Encyclopédie*" (cited by Kronick, *History*, p. 42). The Scottish Enlightenment philosophers Dugald Stewart and Francis Jeffrey agreed on Baconian method and goals, even if they differed on some of the interpretation (Chitnis, *Scottish Enlightenment*, pp. 214–15). A practical enlightenment scientist such as Humphry Davy had no doubt that Bacon was ". . . was the first philosopher who laid down plans for extending knowledge of universal application; who ventured to assert, that all the science could be nothing more than expressions or arrangements of facts . . . the pursuit of the new method of investigation, in a very short time, wholly altered the face of every department of natural knowledge. Davy, "Sketch," pp. 121–22. Across the channel, the French minister of the Interior, Nicolas-Louis François de Neufchâteau invoked the spirit of Francis Bacon when opening the 1798 French industrial exhibition. See Jacob, "Putting Science."

[19] Rosenberg, "Adam Smith," p. 137.

[20] A typical passage in this spirit was written by the British chemist and philosopher Joseph Priestley: "If, by this means, one art or science should grow too large for an easy comprehension in a moderate space of time, a commodious subdivision will be made. Thus all knowledge will be subdivided and extended, and *knowledge* as Lord Bacon observes, being *power*, the human powers will be increased . . . men will make their situation in this world abundantly more easy and comfortable." Priestley, *Essay*, p. 7.

[21] McClellan, *Science Reorganized*, p. 52.

omy and the organization of knowledge.[74] Access to knowledge required search engines. The new search engine of the eighteenth century was the encyclopedia, exploiting that miracle of organizational technology, alphabetization. To be sure, Diderot and d'Alembert's *Encyclopédie* did not augur the Industrial Revolution, it did not predict factories, and had little or nothing to say about mechanical cotton spinning equipment or steam engines. It catered primarily to the landowning elite and the bourgeoisie of the *ancien régime* (notaries, lawyers, local officials) rather than specifically to an innovative industrial bourgeoisie, such as it was. It was, in many ways, a conservative document.[75] Moreover, the idea of such a search engine was not altogether new, and attempts to sum up all that is known in some fashion can be found in China and in medieval Europe. However, the drive to organize knowledge in a way that made it accessible at a high level of detail yet easy to use was very much a product of the eighteenth century.[76] The *Encyclopédie* and similar works of the eighteenth century symbolized the very different way of looking at technological knowledge: instead of intuition came systematic analysis, instead of tacit dexterity came an attempt to attain an understanding of the principles at work, instead of secrets learned from a master came an open and accessible system of training and learning. It also insisted on organizing knowledge in user-friendly compilations, arranged in an accessible way, and although subscribers may not have been mostly artisans and small manufacturers, the knowledge contained in it dripped out and trickled down through a variety of leaks to those who could make use of it.[77] Encyclopedias allowed not only for faster searches, but also underlined the agnosticism of the project to biased taxonomies of knowledge. While it may be an overstatement that they were a starting point toward a new concept of knowledge, as pragmatic and heuristic documents they reflected an intellectual innovation that deliberately sought to reduce access costs.[78]

Furthermore, then as now, works that have an "encyclopedic" nature are instinctively trusted. It is believed—perhaps too optimistically—that such synthetic works reflect authority and best-practice knowledge, and that any statements reflecting baseless speculation and personal bias have been ex-

[74] Burke, *Social History*, chap. 5.

[75] Darnton, *Business*, p. 286.

[76] Heilbron, "Introductory Essay," p. 20, notes that Diderot and d'Alembert were but indolent in comparison with the massive (64 volumes) work published by J. H. Zedler, *Grosses vollständiges Universal-Lexikon aller Wissenschafte und Künste*, published 1732–1754.

[77] Pannabecker points out that the plates in the *Encyclopédie* were designed by the highly skilled Louis-Jacques Goussier who eventually became a machine designer at the Conservatoire des arts et métiers in Paris. They were meant to popularize the rational systematization of the mechanical arts to facilitate technological progress. Pannabecker, "Diderot," pp. 6–22, and "Representing Mechanical Arts."

[78] Broberg, "Broken Circle," pp. 45–71.

In France, great institutions were created under royal patronage, above all the *Académie Royale des Sciences*, created by Colbert and Louis XIV in 1666 to disseminate information and resources.[102] Yet the phenomenon was nationwide: McClellan estimates that 33 official learned societies were functioning in the French provinces during the eighteenth century, counting over 6,400 members, and that overall during the eighteenth century perhaps between 10,000 and 12,000 men belonged to learned societies that dealt at least in part with science.[103] The *Académie Royale* exercised a fair amount of control over the direction of French scientific development and acted as technical advisor to the monarchy. By determining what was published and exercising control over patents, the *Académie* became a powerful administrative body, providing scientific and technical advice to government bureaus.[104] French academies had a somewhat different objective than did British: it is often argued that the *Académie* linked the aspirations of the scientific community to the utilitarian concerns of the government, creating not a Baconian society open to all comers and all disciplines but a closed academy limited primarily to Parisian scholars. French science was in some ways different from British science, both in its agenda and its methodology. Yet the difference between France and Britain was one of emphasis and nuance, not of essence: they shared a utilitarian optimism of man's ability to create wealth through knowledge. French science, as the old truism has it, was more formal, deductive, and abstract than British science, which had a pragmatic and more experimental bend.[105] But instead of a source of weakness, this diversity ultimately provided the Enlightenment project with strength through, as it were, a division of labor between various societies specializing in the areas of their comparative advantage. Rather than a set of competing players or a horse race, we should regard the European Enlightenment as a joint project in which collective knowledge was produced, increasingly accessible to the participants.

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veins and streaks that disfigured glass at the time. See Schofield, *Lunar Society*, p. 172. Henry Cort,
[illegible]

and as such their direct impact was limited. However, as Jürgen Habermas has maintained, at least the theory—if not the practice—of formal and informal meeting places in the eighteenth century was for members to disregard status and wealth and treat one another as equals, recognizing only the authority of a "better argument."[113] To be sure, the bulk of their work—as in all creative processes—was wasteful, wrong-headed, and ineffective.[114] But the membership shared a desire to make useful knowledge more accessible, an important trend in the intellectual development of Europe that helped to create the foundation of sustained technological progress in the nineteenth century through reduced access costs.

ACCESS COSTS: ECONOMIC FACTORS

The economic issue of the endogeneity of access costs must be confronted head-on. The decline in access costs was not, of course, a purely supply-driven process. The demand for such technical knowledge by the inventors of the time is exemplified by the rise in technical publications and technical essays in general-purpose periodicals that popularized and summarized best-practice research, and did not publish original findings but popularized and summarized (and often plagiarized) best-practice research published elsewhere. The influence of the Industrial Enlightenment came from both sides, the desire of the *savants* to give and the desire of the *fabricants* to receive. The only attempt to date to try to estimate the impact of exogenous variables such as population and relative prices on the diffusion of knowledge in agriculture is an important and neglected paper by L. Simon and Richard Sullivan.[115] Thinking of it in a supply and demand framework may, however, not be the only way to think of the mechanisms

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idea of agricultural progress on the eighteenth-century Continent was personified in the work of Duhamel du Monceau, a French *agronome* and "specialist in things English" and in that of the German Albrecht Thaer. The Florence *Accademia dei Georgofili* (1753) and the *Société d'Agriculture, de Commerce et des Arts de Bretagne* (1757) in Rennes were followed by the *Académie d'Agriculture de la France* (1761), the Royal Danish agricultural society (1769) and many others. Terms such as "useful knowledge" start cropping up increasingly after 1750, in the names and charters of institutions such as the *Akademie Gemeinnütziger Wissenschaften zu Erfurt* and the British *Society for the Encouragement of Arts, Manufactures and Commerce* (both founded in 1754).

[113] Habermas, *Structural Transformation*, p. 36.

[114] This was well expressed by Eric Jones 20 years ago: "Much of the activity of the science subculture, the club meetings, the flooding exchange of information by mail, fell by the wayside as far as material gain was concerned at the hands of tired or dilettantish or unlucky individuals . . . Nevertheless there was so very much activity . . . that some seeds from hobby science and technological curiosity were almost certain not to fall on stony ground." Jones, "Subculture," p. 877.

[115] Simon and Sullivan, "Population Size," pp. 21–44. They find the growth of publications and patenting to depend on population size and the relative price of food products. The problem of course is that if the relative price of agricultural goods explains publication of tracts on farming technology, how can we explain the increase of works in chemistry, mechanics, and mathematics?

as a mediator between the world of propositional knowledge and that of technology was Joseph Banks, one of the most distinguished and respected botanists of his time whose life was more or less coincident with the Industrial Revolution. Wealthy and politically well connected, Banks was a cofounder (with Rumford) of the Royal Institution in 1799, a friend and scientific consultant to George III, and president of the Royal Society for 42 years. Banks labored tirelessly to help bring about the social and economic improvement the Baconian program advocated, corresponded with many people, supported every innovative branch of manufacturing and agriculture, and was the dominant political figure in Britain's world of science for much of his life. Among his close friends were the agricultural improvers John Sinclair and Arthur Young, as well as two pillars of the Industrial Revolution, Matthew Boulton and Josiah Wedgwood. He was associated with, among others, the Society for the Arts, before taking over the Royal Society, which he ruled with an iron if benign hand.[124] He was every inch an enlightenment figure, devoting his time and wealth to advancing learning and to using that learning to create wealth, "an awfully English *philosophe*" in Roy Porter's memorable phrase.[125]

Britain had no monopoly on such facilitators, The same traditions can be observed on the Continent, although after 1789 some talented persons were distracted by and diverted into political or military careers. Among the more notable of them was Henri-Louis Duhamel de Monceau, a noted *agronome* and the chief editor of the massive *Descriptions des Arts et Métiers*.[126] François Rozier (1734–1793), another *agronome* and scientific entrepreneur, "a clergyman whose vocation was the enlightenment" in Gillispie's succinct characterization, publisher of the *Observations sur la Physique, sur l'Histoire Naturelle, et sure les Arts,* widely regarded as the first independent periodical to be concerned wholly with advances in cutting-edge science.[127] Jean-Antoine Chaptal, a noted chemist, successful entrepreneur, and Minister of the Interior early in the rule of Bonaparte, played a major part in the founding of the *Societé d'Encouragement pour l'Industrie Nationale* and "sought to instill a new scientific ideology to educate entrepreneurs in applied science and engineers in business

Kirwan admitted his conversion to the antiphlogistonist position. Lever and Turner, *Discussing Chemistry,* passim. See also Reilly and O'Flynn, "Richard Kirwan," pp. 298–319.

[124] Drayton, *Nature's Government*, chap. 4. Gascoigne, *Joseph Banks*, passim.

[125] Porter, *Creation*, p. 149.

[126] For details see Bourde, *Agronomie*, pp. 253–76, 313–68. Gillispie, who also studied Duhamel in some detail summarized his intellectual persona: "his hallmark was neither style nor wit but usefulness." Condorcet, in his eulogy, wrote of him that in his writings he expected little prior knowledge of his readers and composed his works, not for scientists but for persons who would put what they had learned to use. See Gillispie, *Science . . . End of Old Regime*, p. 338.

[127] McClellan, "Scientific Journals," pp. 45–46. Gillispie, *Science . . . End of Old Regime*, p. 188.

rect contact with the Scottish scientists Joseph Black and John Robison, and as H. W. Dickinson and Rhys Jenkins note in their memorial volume, "one can only say that Black gave, Robison gave, and Watt received."[135] Whether or not Watt's crucial insight of the separate condenser was due to Black's theory of latent heat, there can be little doubt that the give-and-take between the scientific community in Glasgow and the creativity of men such as Watt was essential in smoothing the path of technological progress.[136] Much the same can be observed in Cornwall a bit later.[137] Decades later, the work of Mancunians Joule and Rankine on thermodynamics led to the development of the two cylinder compound marine steam engine.[138] The growth of a machine culture in the eighteenth century involved a close collaboration and interaction between natural philosophy and highly skilled craftsmen, grappling with difficult mechanical issues such as heat, power, inertia, and friction, recently described by Larry Stewart.[139] The same is true in many other key industries, especially chemical and engineering, and although it is not nearly as obvious in textiles, access to developments in one industry inspired and stimulated inventors elsewhere.[140]

Nothing of the sort, I submit, can be detected at this time in the Ottoman Empire, Japan, India, Africa, or China. Floris Cohen, indeed, has argued flat-out that Francis Bacon was a typically European figure, who could not possibly have come from anywhere else.[141] The Enlightenment touched lightly (and with a substantial delay) upon Iberia, Russia, and South Amer-

[135] Dickinson and Jenkins, *James Watt*, p. 16.

[136] Hills explains that Black's theory of latent heat helped Watt compute the optimal amount of water to be injected without cooling the cylinder too much. More interesting, however, was his reliance on William Cullen's finding that in a vacuum, water would boil at much lower, even tepid temperatures, releasing steam that would ruin the vacuum in a cylinder. In some sense that piece of propositional knowledge was essential to his realization that he needed a separate condenser. Hills, *Power*, p. 53.

[137] Richard Trevithick, the Cornish inventor of the high pressure engine, posed sharp questions to his scientist acquaintance Davies Gilbert (later President of the Royal Society), and received answers that supported and encouraged his work. See Burton, *Richard Trevithick*, pp. 59–60.

[138] Thermodynamics not only made essential contributions to the design of steam engines, such as pointing to the advantages of compounding and steam-jacketing, but also created an entirely new way of thinking about what thermal efficiency was and how to measure it. Most important, the widening of the understanding of power technology in this direction pointed to what could *not* be done, for example the realization that John Ericsson's caloric engine (1853) based on the idea that energy could be "regenerated" (that is, used over and over again) was impossible. See Bryant, "Role."

[139] Stewart, "Meaning."

[140] In Leeds, for instance, both the flax-spinner John Marshall and the woolen manufacturer Benjamin Gott had wide-ranging interests in hydraulics, bleaching, mechanics, and related topics. In Manchester, M'Connell and Kennedy, one of the most successful early cotton manufacturers were highly technologically "literate" and closely involved with the Manchester Philosophical and Literary society.

[141] Cohen, "Causes." In a similar vein, Mark Elvin, "Some Reflections," p. 58, notes whereas Giambattista Dellaporta, who dominated the *Accademia dei Lincei* in its early days, can be compared to a Chinese intellectual of that time, he was replaced by Galileo, who cannot.

Dalton's atomic weights, created a pragmatic and useable set of tricks and techniques that soon enough found industrial and other applications, yet did not hypothesize about the deep structure of matter and why the observed regularities were in fact true.[149]

Once such knowledge had been established and found to be helpful, it needed to be made available to the men in the workshops. From the widely felt need to rationalize and standardize weights and measures, to the insistence on writing in vernacular languages, to the launching of scientific societies and academies, to the construction of botanical gardens by enthusiasts such as Georges-Louis Buffon and Joseph Banks to teach the knowledge of plants, to that most paradigmatic Enlightenment triumph, the *Grande Encyclopédie*, the notion of the diffusion and accessibility of shared knowledge found itself at the center of attention among intellectuals.[150] Taxonomies and classifications were invented to organize and systematize the new facts gathered, and new forms of mathematical and chemical notation were proposed to standardize the languages of science and make propositional knowledge more accessible. To understand these languages, it was realized that increased technical and mathematical education was required, and mathematics teaching and research expanded from the establishment of chairs in mathematics in the Scottish universities in the late seventeenth century to the founding of the *école polytechnique* in 1794.[151]

To summarize, then, the *philosophes* realized that, in order for useful knowledge to be economically meaningful, low access costs were crucial and useful knowledge should not be confined to a select few but should be disseminated to those who could put it to productive use. Some Enlightenment thinkers believed that this was already happening in their time: the philosopher and psychologist David Hartley believed that "the diffusion of knowledge to all ranks and orders of men, to all nations, kindred and tongues and peoples . . . cannot be stopped but proceeds with an ever accelerating velocity."[152] Diffusion needed help, however, and much of the

[149] Lundgren, "Changing Role," pp. 263–64.

[150] See especially Headrick, *When Information,* pp. 142–43. Daniel Roche (*France*, pp. 574–75) notes that "if the *Encyclopédie* was able to reach nearly all of society (although . . . peasants and most of the urban poor had access to the work only indirectly), it was because the project was broadly conceived as a work of popularization, of useful diffusion of knowledge." The cheaper versions of the Diderot-d'Alembert masterpiece, printed in Switzerland, sold extremely well; the Geneva (quarto) editions sold around 8,000 copies and the Lausanne (octavo) editions as many as 6,000.

[151] See Jacob, "Putting Science."

[152] Hartley, a deeply religious man, made this point in the context of the diffusion of Christian beliefs, but then added that "the great increase in knowledge, literary and philosophical, which has been made in this and the two last centuries . . . must contribute to promote every great truth . . . the coincidence of the three remarkable events, of the reformation, the invention of printing, and the restoration of letters . . . deserves particular notice here." See Hartley, *Observations*, p. 528.


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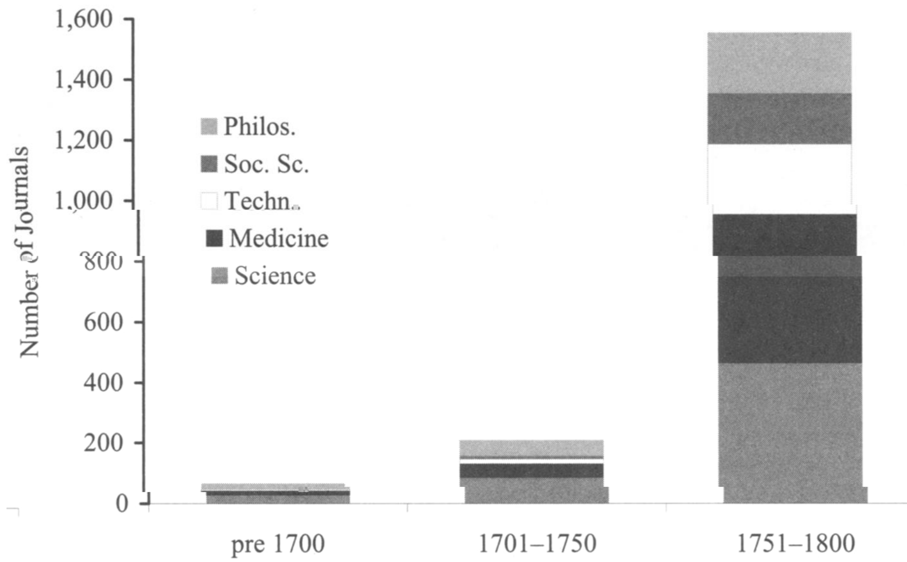
Number of Journals
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1701–1750
1751–1800


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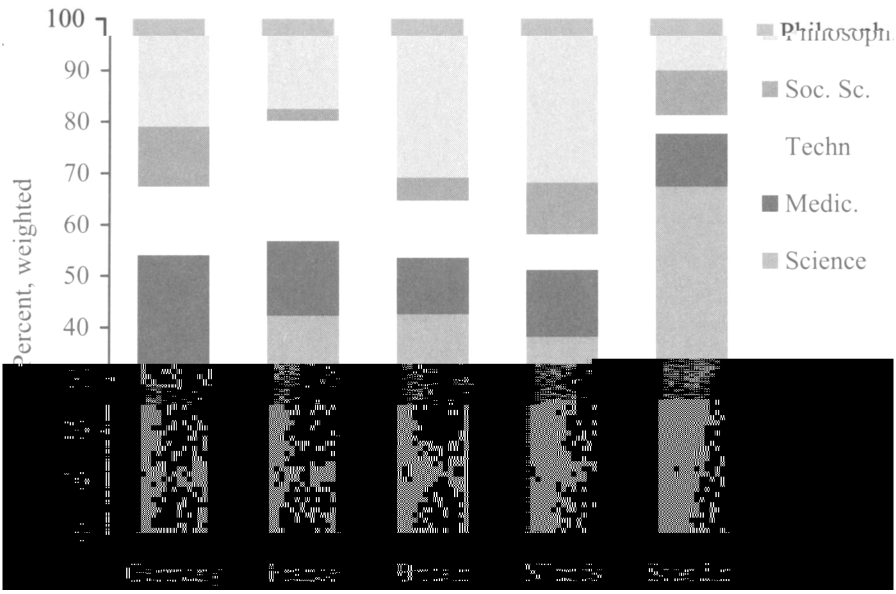


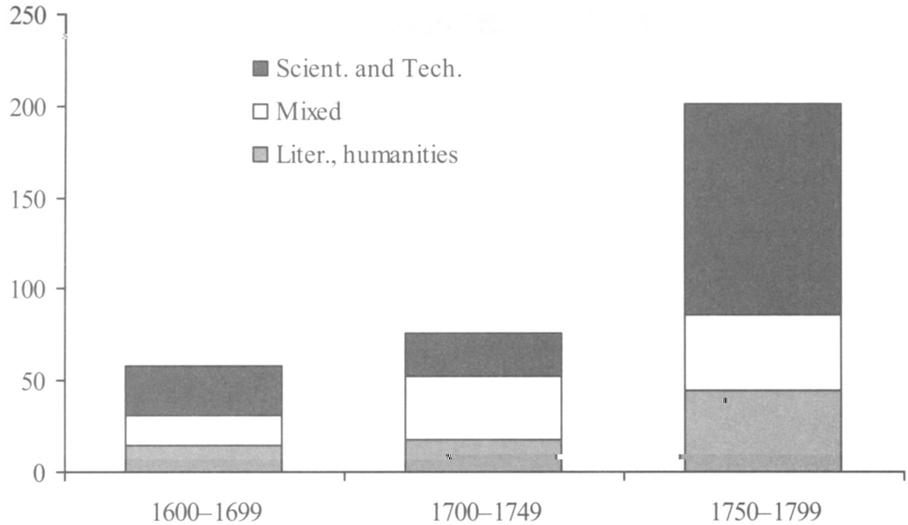
FIGURE 4
SUBJECT AREA OF NEW PERIODICALS, BY COUNTRY

Source: Computed from Kronick, *Scientific and Technical Periodicals*.

Europe's small countries and Germany clearly took the lead in this kind of intellectual activity after 1750, with Italy and to a lesser extent France falling behind. Within the "small countries," the literate nations in Scandinavia and the Netherlands experienced a veritable outburst of such societies after 1750. Third, as Figure 6 shows, there was a considerable growth in the number of societies interested primarily in applied and science-oriented nature after 1750, although all three categories experienced considerable growth in the second half of the eighteenth century. As can be seen from Figure 6, Britain had perhaps a slight advantage in terms of the relative importance of societies classified as "scientific," but this difference is far from overwhelming.

Such numbers, taken at face value, are misleading. In Italy and Germany many of the local societies reflect the political fragmentation of the countries, in which local aristocrats or magistrates had to display their independence, accounting for some provincial societies in small towns such as Cortona, Palermo, and Rovereto. Yet similar provincial institutions are found in France and Spain. It is also true that some societies were of an ephemeral nature and duplicated others.[168] One interesting finding is that

[168] A good example is the *Societas Disputatoria Medica Haunienis* (Medical Debating Society of Copenhagen), founded in 1785 as the result of a disagreement between two Danish physicians. It folded two years later.


250
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Scient. and Tech.
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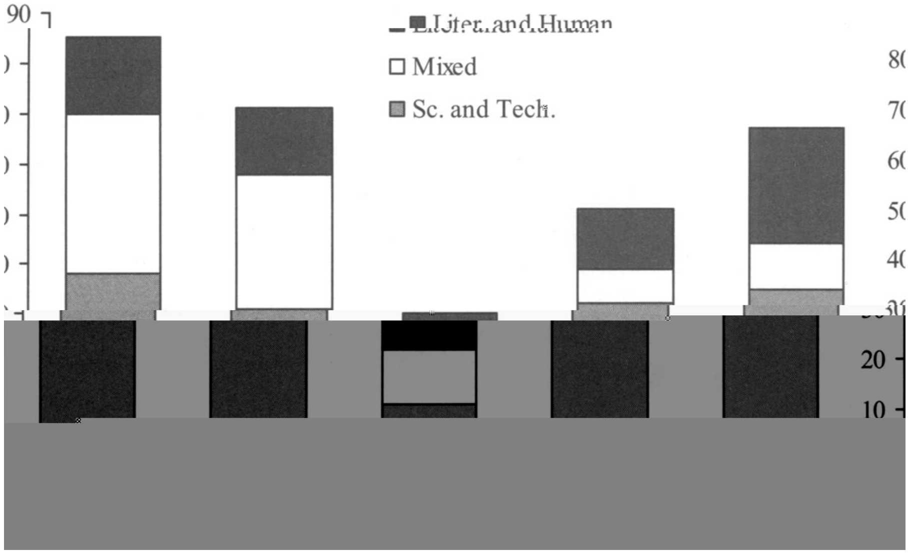
1750–1799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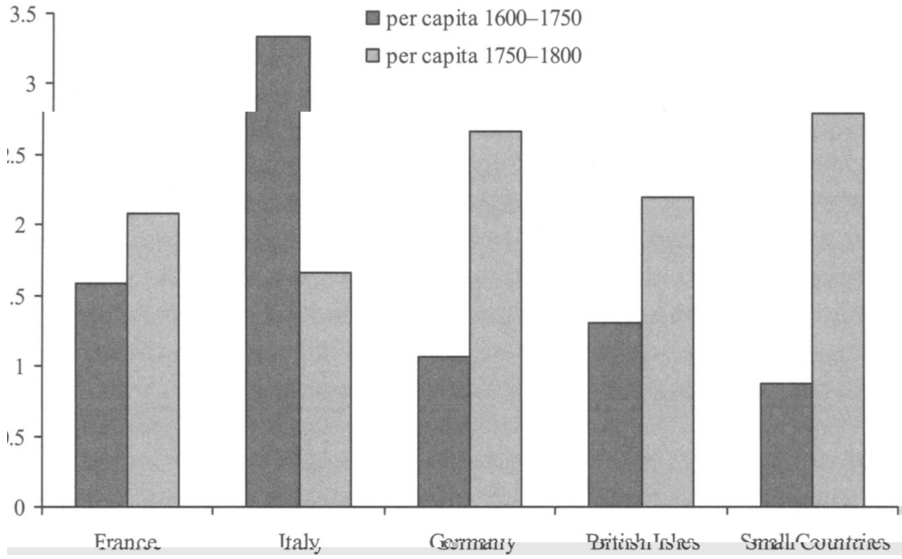
per capita 1600–1750
per capita 1750–1800
3.5
3
2.5
2
1.5
1
0.5
0
France
Italy
Germany
British Isles
Small Countries

Antiquity were no longer available to subsequent generations. The decline in access costs meant that knowledge was spread over many more minds and storage devices, so that any reversals in technological progress after the Industrial Revolution were ruled out. If the continued growth of the West was ever in danger, it came from the imbalance between rapid progress in the accumulation of useful knowledge and the more halting and ambiguous changes in supporting institutions.

Such an approach to modern growth would imply that the differences between the nations of the West should be less important than their basic commonalities. The point is not so much that there were no national differences in the institutions and culture that generated useful knowledge in France, Germany, or Britain, as that when the knowledge was accepted, it was readily diffused within the world in which the Enlightenment had taken root through periodicals, translations, international exhibitions and conferences, and personal communications. Stressing national differences in style and emphasis within the West is to miss the fundamental unity of the world affected by this intellectual movement. In this view of the Industrial Revolution, Britain had a first-mover advantage that was extended by the political upheavals of the Revolutionary and Napoleonic era, but the convergence of technology and income in the later nineteenth century was inherent in the nature of the movement that generated economic growth.

All this leaves in the middle what explains the Enlightenment itself. It surely was no autonomous shock like the Black Death or a Mongol invasion that altered the course of European history without requiring an explanation itself. The Enlightenment had roots in the commercial capitalism of the later middle ages and the sixteenth century. Many of the elements of a progressive society—such as individualism, man-made formal law, corporatism, self governance, and rules that were determined through an institutionalized process (in which those who were subject to them could be heard and have an input)—already existed in late medieval Europe.[173] Pre-1750 economic growth created the economic surpluses that made it possible for a considerable number of people to move to urban areas and nonagricultural occupations, including by becoming full-time intellectuals. Yet despite the stimuli of the Great Discoveries and the technical advances of the fifteenth century, Renaissance Europe did not generate anything like modern growth. Many highly commercial societies of the past, for one reason or another, failed to switch from trade-based growth to technology-based growth. Even the great Dutch prosperity of the seventeenth century dissipated and petered out in the end.

[173] Greif, *Institutions*, chap. xiii–17.

feated in a set of wars that left Europe bleeding and divided, but that also marked a sizeable part of the Continent that was open to fresh ideas introduced in the competitive intellectual marketplace.[176]

If so, there was nothing inevitable or inexorable about modern economic growth. Much like the emergence of *homo sapiens sapiens* in the Pleistocene after some 60 million years of mammal development, and not, say, in the long period (50 million years) between the Eocene and the end of the Miocene, a long period of "prehistory" occurred before the dramatic phase transition that changed the face of the planet forever. There is nothing in evolutionary theory that makes the rise of homo sapiens inevitable or its precise timing an explicable phenomenon. Although metaphors may mislead, the parallel points to the possibility that radical and irreversible historical change may occur as a contingency. That does not absolve us from the possibility of thinking about its causes—contingency does not mean randomness.

To understand the origins of the triumphs of Enlightenment thought, we must understand the victory of skepticism and rebellion against authority in the centuries of early modern Europe. Aside from the obvious cases of Luther and his fellow reformers, we may point to the growing proclivity of Europeans to question traditions that had ruled during centuries in which original scholarship had rarely consisted of more than exegesis and commentary on the classics.[177] Of course, Francis Bacon himself was a leader among those skeptics.[178] Criticism of authority was prevalent in every society, no matter how reactionary and repressive, but the question of essence must be what explains the survival and success of this movement. Here, part of the answer must be sought in the system of political fragmentation and countervailing power in which those who contested the "truth" as perceived by the status quo could normally find protection against the

[176] See Lebow, Parker, and Tetlock, eds., *Unmaking the West*.

[177] Illustrative of this inclination is the career of Lorenzo Valla (1407–1457). Humanist, philologist, and professional rebel, most famous for his demonstration that the "Donation of Constantine" was a forgery, he attacked other sacrosanct icons such as Cicero's style, Livy's history, and St. Thomas's theology. He seemed to "delight in challenging established authorities" and his work was "an attempt by a humanist intellectual to change rhetorical study from a process that involved the 'passive' acquisition of erudition into an 'active' discipline that would be capable of engaging practical problems" (Connell, "Introduction," pp. 1, 6).

[178] In an unpublished work, oddly entitled *The Masculine Birth of Time,* Bacon launched a sharp and severe attack on Aristotelian philosophy. The entire canon of classical thought, from Plato to Hippocrates and from Thomas Aquinas to Peter Ramus was denounced. Their sin was, above all, moral: they were, in Bacon's view, indifferent to the mastery of man over nature, which was the only way to alleviate the plight of mankind "with new discoveries and powers." See Farrington, *Francis Bacon*, pp. 62–68. Ramus (1515–1572) himself, an influential Calvinist philosopher, had been similarly disrespectful of accepted orthodoxy (his 1536 thesis was entitled *Everything that Aristotle Taught is False*), but had the bad fortune to find himself in Paris on St. Bartholomew's Day in 1572, where he was murdered.

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AMERICAN EXCEPTIONALISM AS A PROBLEM IN GLOBAL HISTORY

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American Exceptionalism as a Problem in Global History

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Abstract

The causes of the USA's exceptional economic performance are investigated by comparing American wages and prices with wages and prices in Great Britain, Egypt, and India. Habakkuk's views on the causes of American industrial pre-eminence are reassessed. While the USA had abundant natural resources, they did not promote manufacturing since international trade equalized prices in Britain and the USA or American tariffs made resources dearer in the USA. Wages were higher in the USA than in Britain since labor markets were tightly integrated and labor was drawn to the USA as the continent was settled. Capital services were also more expensive in USA. American industrialization required tariffs since virtually all input prices were higher than in Britain and industrial productivity was comparable. America's comparative advantage shifted from agriculture to manufacturing after 1895 was industrial productivity soured. This was due to a fall in energy prices in the USA, the American policy of mass schooling which increased the supply of skilled adults and induced firms to invent technology to raise their productivity since the supply of child labor was restricted in comparison to Britain, and the great growth of manufacturing investment induced by the tariff which provide a large market for inventions and generated technical knowledge through learning by doing. Egypt and India could not have industrialized by following American policies since their wages were so low and their energy costs so high that the modern technology that was cost effective in Britain and the USA would not have paid in their circumstances. The development of Egypt and India required more draconian state intervention than a protective tariff, mass education, and infrastructure investment–the American model.

American exceptionalism' is a long standing theme in academic and popular culture.[1] It has also been controversial, at least on the academic plain. Sometimes, exceptionalism is taken to mean that Americans are morally superior to other people and are, therefore, entitled–perhaps obliged–to intervene in their affairs. I am not concerned with these claims here. At other times, exceptionalism means that American history is exempt from the usual laws and regularities of social science. On the contrary, my aim here is to assess and account for remarkable features in American economic history with normal social scientific explanations. One of those remarkable features has been rapid economic growth, and another has been the flourishing of democracy. Sometimes, indeed, the two are linked by claiming that the economic success has been the result of the democratic commitment.

How exceptional has American economic history been? The question is fundamentally comparative, and one obvious comparator is Great Britain. Indeed, it is just half a century since Habakkuk published his influential *American and British Technology in the Nineteenth Century: The Search for Labour-Saving Inventions* (1962). It was written when America was the world's economic hegemon, and the question was how to account for that great lead. Habakkuk found the answer in an extended path of development that ran back to the early nineteenth century when the USA had an abundance of land and natural resources. He believed that these advantages led to exceptionally high wages and 'the search for labour-saving inventions.' These ideas provoked tremendous debate for some time.[2] Today America's economic lead is not so pronounced, so it is a good time to reconsider how deep exceptionalism runs in American economic history.

Comparisons should not be confined to Britain. The study of long run economic development has 'gone global,' so that we must consider progress and stagnation in a world wide frame work. In addition, to Britain, I will compare the USA to Egypt and India. These are interesting comparators since both countries were major cotton exporters as was the USA.

American economic history can be divided into two phases each with impressive economic accomplishments. Before 1895, economic growth was extensive. Between 1820 and 1913, the American population grew by a factor of ten, while the populations of India, Egypt, and the United Kingdom approximately doubled. The USA had a similar lead in GDP growth. American growth required mass immigration and was based on the settlement of the continent and the development of its agricultural potential. There was also a large growth in manufacture that catered to the domestic market. The size and growth of this sector was important for the later surge in productivity even if it was not the main driver before 1895. In this period, American GDP per head grew slowly and trailed that of Britain (Figure 1).

The character of American growth changed at the end of the nineteenth century. Figure 2 shows the shares of American exports that were agricultural or processed agricultural products versus manufactured goods. Between 1820 and 1895, farm products made up a steady 80% of American exports with manufactured goods accounting for the other

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[1]The literature is vast. Recent contributions include Lipset (1997), Bacevich (2010), Hodgson (2009), Pease (2009), Baldwin (2009), Marry (2013), and Zinn (2005). Joe Ferrie and Jason Long have interpreted American exceptionalism in terms of social mobility and studied that phenomenon as a problem in economic history: Ferrie (2005), Long and Ferrie (2007), Ferrie and Long (2013). Temin (1991) tackles the question but not the term.

[2]The literature is very large and includes David (1975), Temin (1966b, 1971a, 1971b), James (1981a), James and Skinner (1985), Field (1983), Rosenberg (1967), Ames and Rosenberg (1968), Rothbart (1946).

20%. The stability ended abruptly in 1895 when the share of manufactures began to rise towards the value of 75% after the Second World War. Improved American performance is also apparent in the GDP figures. According to Maddison's (2006, pp. 436-43, 465-7) estimates, the USA overtook Britain in GDP per head in 1901. Britain regained the lead as all resources were mobilized during the First World War, but demobilization left the USA far ahead.[3] An important aspect of the American lead was very strong productivity performance in manufacturing. There is no doubt that labour productivity in USA manufacturing was double that of British in the first decade of the twentieth century (Broadberry 1997). When this lead emerged is controversial, and I will argue that it was a feature of the late nineteenth century. These accomplishments are more significant than the extensive growth realized earlier when the continent was settled.

Figure 1 conveys another lesson that must be born in mind in assessing US performance. The most striking feature of the graph is the gap between Britain and the USA, on the one hand, and India and Egypt on the other. Anglo-American differences shrink to insignificance compared to this gap, which is the result of the great divergence in the world economy. Seen from a global perspective, it is the West as a whole that is exceptional. The USA is exceptional since it is part of the West–and why it is so is a problem that must be solved–but it is hardly unique.

How can we explain these features of American economic history? My approach is based on comparative wage and price history.[4] This approach has thrown new light on the causes of the British Industrial Revolution (Allen 2009). I argued that eighteenth century Britain was unique in having particularly high wages and low energy prices. The breakthrough technologies of the industrial revolution increased the use of capital and energy per worker. These techniques, in their earliest, crudest forms were profitable to use in Britain but not abroad in view of Britain's unusual factor prices. I even argued that eighteenth century Britain was the prequel to Habakkuk's nineteenth century America where cheap resources and dear labour made labour saving technology profitable. Here I want to examine that claim more carefully by comparing the USA, Britain, Egypt, and India in terms of wages, living costs, the prices of natural resources, energy, and capital services. Was nineteenth century America really the sequel to industrializing Britain, as I had supposed?

My approach differs from many others that emphasize culture or institutions or some combination of the two. Cultural explanations attribute American success to a 'nation of

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[3]The comparative history of national income in the USA and UK is still, after decades of research, highly contested. See, for instance, Prados de la Escosura (2000), Ward and Devereux (2003), Broadberry (2003), and Lindert and Williamson (2011). The argument of this paper does not place much emphasis on specific national income estimates or related indicators like sectoral labour productivity. Factor prices and industry specific estimates are preferred.

[4]Price history has a long history, beginning with Rogers (1866-1902). Recent contributions focussing on wage history include Allen (1994), Williamson (1995), van Zanden (1999), Allen (2001), Özmucur and Pamuk (2002), Allen, Bassino, Ma Moll-Murata, van Zanden (2011), Allen, Murphy, Schneider (2012), Abad, Davies, van Zanden (2012).

tinkerers' or 'the enterprise of a free people.'[5] Political institutions are the main stream explanation in economics today.[6] What these theories have in common is a focus on the responsiveness of economic actors to the incentives they face. Good culture means that businessmen and inventors respond vigorously and effectively to those incentives. Good institutions ensure that economic actors correctly perceive the 'true' incentives generated by endowments, technology, preferences, and markets, while bad institutions are either like a smoke screen that obscures the true economic incentives or, worse, like a signal pointing the wrong way that actively generates misleading incentives that lead to unproductive rent seeking. In either case, entrepreneurs and inventors go off in the wrong direction. The limitation of these approaches is that they leave unanalysed the true incentives arising from markets, endowments, and so forth. The implicit assumption is that these incentives were the same in all times and places. But were they? Were the incentives that Americans faced the same as those faced by Brits, Egyptians, or Indians? Was America's economic success the result of an unusual responsiveness to incentives or was it the result of unusual incentives?

Three features of nineteenth century economic history play roles in this discussion. One, already mentioned, is technology, in particular, the idea that advances in technology were biased and consisted of new machines that raised capital and energy per worker as they increased output per worker. These machines were profitable to use where labour was dear and energy cheap. A second is globalizat1.22997(c)3.74(u)-0.295585(r)2.80561(e)3.74122(s)-1.22997( )-0.1
wat f.22997(er)2.80439(a)s, w

Natural Resources and Globalization

America's success is plausibly attributed to geographical features of which 'abundant natural resources' are an important case in point. Natural resources, of course, are not entirely natural, for they require discovery, development, and transportation before they can be abundant. Those investments depended on public policy as well as private initiative. How were the abundant resources supposed to have promoted American development? There are several arguments. Habakkuk (1962), for instance, thought that the availability of farmsteads on the frontier raised the wage of unskilled labour in eastern cities and induced labour saving technical change. I will consider this argument shortly. Here I take up the long standing argument that abundant natural resources underpinned American industrialization by providing industry with essential raw materials (Rostas 1948, Melman 1956, Frankel 1957, Franko 1976, Nelson and Wright 1992, Broadberry 1997, pp. 98-102). Gavin Wright (1990) has argued for this interpretation by analysing the factor intensity of American exports.

Wright's work focuses on *quantities*. Here I analyse *prices*. Resource abundance could promote industrialization by providing manufacturers with cheap raw material inputs. Did abundance have that effect? Here globalization enters the picture. In the nineteenth century world markets became more integrated. Britain was the centre of the world economy and imported many resource products from peripheral countries like the USA (Lewis 1978). In the absence of a British tariff, transport costs defined the difference between the price of an American export in the USA and in Britain. With non-traded goods or goods that the USA imported, the price in the USA could be higher than the British price, especially if the USA imposed a high tariff on the item. These considerations raise the possibility that American industrialization was not based on cheap natural resources, and that, indeed, was the case generally.

Cotton is an important example, as it was the most important American export, and the raw material input for the core industry of the Industrial Revolution. Precise comparisons of prices require close attention to the terms of sale and systems of product grading. Harley (1992) has attended to those matters in comparing the prices of cotton in New York and Liverpool in the antebellum period (Figure 3). Evidently, in the 1850s, there was virtually no difference in the price of raw cotton in Britain and the American northern states. The reason is that there was little difference in the cost of shipping from New Orleans to either destination. This situation continued throughout the nineteenth century as Figure 22 makes clear.

I have compared US and British prices for many natural resource products. The only case where American prices are substantially below British prices was lumber, and the American advantage disappeared by the twentieth century. Figure 4 shows the price of soft wood lumber for general construction in the two countries. The US price was about half of the British price until about 1905 after which they were similar. It is always a worry that grades and terms of sale may not be exactly matched, so it is reassuring that the same differential appears in comparisons of pine flooring and oak timbers. Indeed, the price differential in the nineteenth century equals the cost of transporting timber across the Atlantic (Potter 1955, pp. 125-6). Some discussions of Habakkuk's views suggested that machine technology may have been favoured in America since such methods were wasteful of wood even as they economized on labour (Ames and Rosenberg 1968, p. 831, Church 1975, p. 619). This view receives some support from a comparison of lumber prices.

With all other products, the opposite result obtains, i.e. American prices exceeded

British prices in the nineteenth century and were very similar in the twentieth. Figures 5-7 make the point for copper, lead, and even tin. Both countries imported much or all of their tin from southeast Asia, but even in that case, nineteenth century American purchasers were at a slight disadvantage vis-a-vis British buyers. The playing field was only leveled in the twentieth century.

American blacksmiths and metal using industries were at an even greater disadvantage in so far as iron and steel products were concerned. Britain had abundant coal and iron ore conveniently located near major metropolitan areas. With the advent of coke smelting, came th

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The final industrial input to cons5(s)-1.2312(d)-0.295585en in the energy. There was generally, most

these countries reflected domestic demand and suppl

there were several sources of energy. Wood was use

century and was widely used in some places in the U

odd quotations for cord wood in the seventeenth cent

[9]For an alternative view, see Irwin (2003a).

Temin 1966, Hunter 1979-91) In both countries, however, coal was the 'backstop' fuel once the good water power sites were occupied. We can compare the prices of energy from coal in Britain and on the east coast of the USA (Figure 10). Up until about 1880, British manufacturing districts had cheaper energy than Philadelphia or New York. This was true of both bituminous and anthracite sold in the region.

After 1880, America's energy situation improved. Bituminous coal dropped in price on the east coast and sold for a similar price to British coal. Equality extended to one of the great new fuels of the period–petroleum. While the USA had 'abundant' supplies of crude oil, and the British had (at the time) none, oil was traded internationally, and trade equalized prices in the two countries. The US export prices of gasoline and kerosene, at any rate, were only slightly below the British import prices. The development of electricity, the other great fuel of the twentieth century, did, however, confer positive advantages on the USA. Electricity was not traded across the Atlantic, so prices in North America and Europe could diverge. In the 1920s and 1930s, American manufacturers paid half as much for electricity as their British competitors (Melman 1956, p. 206).

So what was the impact of America's abundant natural resources on the country's economic development? The integration of world commodity markets meant that American industry did not benefit from cheap resources. When the effects of tariffs (eg. iron) and non-traded goods (eg energy) are taken into consideration, American firms probably paid more for natural resources than did British firms. Indeed, the point is more far reaching. America's abundant natural resources meant that the country's comparative advantage lay unequivocally in agriculture and forestry. Manufacturing should not have been profitable, and, indeed, it was not. Or, to make the point in monetary terms, the very large volumes of exports of farm and forest products were inflationary–they produced a 'Dutch disease' situation in which the prices of non-tradeables, protected imports, and labour were raised to levels that made manufacturing uncompetitive. The effect of abundant natural resources in a global economy was to retard the industrialization of the USA–not to promote it.

Labour Markets and Living Standards

Abundant natural resources is one way in which geography might have influenced American economic history. There are others. A second was proximity to Europe. Even in the colonial period, the future USA was close enough to Britain to make the export of agricultural products a basis for economic growth. This is a marked difference from Mexico, Peru, Brazil, or Argentine, which were too remote from Europe for such development to have been possible (Allen 2011) Another geographical consideration was that the continent was very large but had only a small native population. There were perhaps 250,000 aboriginals in the thirteen colonies on the eve of European settlement, and their number dropped dramatically due to disease, war, and mistreatment (Thornton 1987, p. 29). The small size and high mortality of the native population has been an underappreciated feature of American history since Acemoglu, Johnson, and Robinson (2001) placed so much emphasis on settler mortality. There were not enough natives to exploit as a labour force, so extraction was limited to seizing their land. Forced labor was a cheap way for European settlers to develop an (almost) empty continent (Domar 1970), so an ersatz native labor force was created by importing slaves from Africa to grow cotton and sugar in the South (Fogel and Engerman 1974, Engerman and Sokoloff 2011).

White settlers were attracted from Europe, and wages in America had to be high enough to make settling in an empty wilderness an attractive option. The implications of this proposition are clear in the data.

I begin with nominal wages, which are plotted for London, Lancashire, Massachusetts, and Philadelphia in Figure 11. The wages in the figure are those of labourers, generally in the construction industry. Similar results are obtained with craftsmen like carpenters. Before 1776, London had the highest wages although Philadelphia occasionally took the lead. Nominal wages converged at the end of the eighteenth century, and in the nineteenth American wages were generally higher than British wages. The high nominal wage in the United States was the result of the Dutch disease just discussed.

The significance of the high wage depends on the cost of living (among other things). The cost of living can be computed in many ways. In a paper on colonial living standards, a 'bare bones basket' based on the cheapest available grain (maize in the Americas, oats in England) was used as the deflator (Allen, Murphy, Schneider 2012). However, since the early nineteenth century, workers in Britain and America have been well enough off to be eating products made from wheat flour rather than the cheaper grains. Consequently, wheat flour has been substituted for the other grains in the deflator (Table 1). Figure 12 shows the deflator for England, Philadelphia, and Massachusetts in the eighteenth and nineteenth centuries. There was little difference in the cost of living. This is surprising since the USA was exporting wheat to England at the time. However, the cost of living index depends on the retail price of wheat flour and not on the wholesale price of wheat. The higher nominal wage in the United States meant that processing, transportation, and trade margins were higher, and they offset the advantage of cheaper wheat.

The real wage is measured as the ratio of a labourer's annual earnings divided by the cost of maintaining a family of four people at the subsistence level defined by the basket in Table 1. When the real wage, computed in this manner, equalled one, a fully employed labourer could just keep his family at that standard, which also corresponds to the World Bank's famous 'dollar a day' poverty line (Allen 2013). In the colonial period, London and Philadelphia had the highest real wages, and Lancashire hand the lowest. Real wages converged by the end of the eighteenth century. Thereafter, they were often highest in the American cities. In both countries real wage growth accelerated over the nineteenth century.

The real wage series in Figure 13 look correlated with each other, and, indeed, they were. Error correction models (Table 2) have been estimated for these series, and Granger causality tests used to explore their interconnection. These result indicate that the series were co-integrated and causation between them shifted back and forth. My interpretation of these results is that the British and American labour markets were closely integrated. Of course, people came to the USA from many countries often fleeing desperate situations. Nonetheless, British and Irish immigrants were a always a significant share of the total (US *Historical Statistics*, series C90-C92). Since they had the option of going to Lancashire or London, wages in those cities became the foregone income of the marginal migrant. This situation lasted until the mass migration from southern and eastern Europe at the end of the nineteenth century. Until then, we can regard the United States as an outlying, if rapidly developing, region of Britain. The unskilled wage rate was not determined by farm income on the frontier, as Habakkuk supposed, but rather in the British Isles. The labor market in the USA was not exceptional after all.

The finding of a unified, trans-Atlantic market for unskilled men immediately raises the question of how general that result might have been. Does it hold for other types of workers? The situation for skilled craftsman appears similar, but the question requires further investigation. One category of worker, however, for which the conclusion does not hold is the ‘average factory worker.’ Nominal and real average annual earnings in manufacturing were both very much higher in the USA than in Britain. The finding raises obvious questions regarding the invention of labour saving machinery in the two countries.

Why were average earnings in manufacturing in the US so high? While the data are imperfect, the structure of the workforce in the two countries appears to have been very different at least from the middle of the nineteenth century onwards. Tables 3 and 4 show breakdowns of the manufacturing workforce in the USA and Britain in the 1860s. On the face of it, a far higher proportion of the British workforce was women and especially children. Tables 3 and 4 may overstate the differences between the two countries as children may be more broadly defined in Britain (although the division between males and females should be accurate), but the results are still striking. Goldin and Sokoloff (1982, 1984) have argued that many women and children were employed in US manufacturing in the antebellum period, but their employment looks to have been relatively more widespread in Britain after 1850.

In any event, the difference in average manufacturing earnings between the two countries in the 1860s is due to the different shares of male, female, and child labour as shown in the tables. The average earnings of men in the two tables are similar to the average earnings of male labourers at the time (roughly \$1.50 per day in the USA versus \$1.00 in Britain) and the earnings of women and children were roughly in proportion. The differences in composition explain the differences in average earnings in manufacturing.

The result raises questions of cause and consequence. As to cause, the most likely explanation is the greater provision of education in the USA. Throughout the nineteenth century, enrollment rates were much lower in England and Wales than they were in the USA especially outside the South. The difference was pronounced in the years when the USA was building its technological lead. In 1880, for instance, 90% of school aged children in the USA were enrolled in schools in contrast to only 55% in England and Wales (Lindert 2004, p. 92, Engerman and Sokoloff 2011, pp. 121-67). The child proletariat was much bigger in England than in the USA.

Why did the USA lead in this regard? The answer comes down to differences in public educational policy. Policies differed in the two countries for three reasons. First, the USA was more democratic (Engerman and Sokoloff 2011, p. 166). Indeed, England only got universal, free primary education in 1891–six years after the Third Reform Act expanded the franchise from 31% to 63% of adult males (Lindert 2004, p.114). Second, the American Revolution eliminated established churches, and the Church of England was an important opponent of universal education. Universal education is a concrete example of one way political exceptionalism contributed to economic exceptionalism. Third, manufacturing interests were probably more favourable to public universal education in the USA than they were in England. The difficulty of assimilating a large, immigrant population disposed Massachusetts business interests to support the common school movement that began in 1837 and that aimed to require all children to attend school. (A large Irish population in northern British cities did not have the same result.) There was also a technological difference between the countries that may have played a role. In England, spinning was done with mules, and many boys were employed as piecers assisting in their operation. American mills, in contrast, spun with throstles, and they did not require piecers. English employers may have been more opposed to universal schooling, as it would have prevented them from employing a large part of their work force. We will consider the consequences of the educational differences shortly.

Relative factor prices and technological progress

What did the history of factor prices in Britain and America imply for the invention and adoption of technology? The answer depends on relative factor prices. I concentrate on the wage relative to both the price of energy and to the price of capital services. The more expensive was labour relative to energy and capital, the greater was the incentive to use–and

America, their counterparts were in school, so American firms from an early date invented automatic shut-offs and other control devices to take the place of children. This commitment to automatic technology lead to higher productivity of the adult workers.

Can these considerations explain the history of American and British technology in the nineteenth century? We have firm comparisons of relative efficiency only at the end of the period. Comparisons of the 1907 British census of production with US censuses of manufactures show that in the early twentieth century labour productivity in American manufacturing was about twice the British level (Broadberry 1997). The situation in earlier years is not so clear. Broadberry (1994) and Broadberry and Irwin (2006) have argued that the USA had much higher productivity as early as the 1830s. An important part of the argument is that historical national accounts for the USA and Britain indicate that manufacturing valued added per worker grew at similar rates from 1870 to 1907, so America must have been twice as productive throughout. However, the employment figures are not standardized for changes in the age, sex, or educational attainment of the workforce, and in all of these regards we have seen that there were major differences between the countries and changes over time. The matter warrants more research with industry level data. My own calculations indicate that there was little difference in labour productivity between Britain and the USA in iron technology in the middle of the nineteenth century (Allen 1979, p. 922). Furthermore, there seems to have been little difference in the spinning and weaving of cotton in factories. Figure 18 uses data from the US censuses and a little known investigation of Wood (1903, p. 302) to compare output per worker in spinning and weaving analysed as an integrated activity in the two countries. In 1830, labour productivity in Britain look(o)-0.295585(o)-0.295585

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handicraft methods.

Nominal wages were low in both Egypt and India as Figure 19 shows. Food prices were also much lower than they were in Britain or America. Nonetheless, real wages were also low in the third world (Figure 20). Male labourers in Egypt earned just enough to support families at bare bones subsistence. Labourers in India were even more poorly paid with the result that all family members had to work in order for the family to survive (Allen 2007, Broadberry and Gupta 2006).

Globalization disrupted the economies of many poor countries by integrating markets and increasing trading opportunities. Figure 21 shows the evolution of wheat prices in Britain, the USA, Egypt, and India from 1820 to the First World War. The differences were substantial in the antebellum period, and prices were highest in Britain and lowest in Egypt and India. By the twentieth century, the differences had collapsed. Prices fell in Britain and America to the benefit of their consumers. The history of raw cotton prices was similar (Figure 22) with large differentials early in the nineteenth century that disappeared after 1875. Prices were highest in Liverpool and fell the most there. The gains from globalization accrued mainly to buyers in Britain and (to a lesser extent) the USA, Farmers were never gainers.

There were parallel developments in manufactured goods prices that benefited consumers in most places. Figure 23 shows the history of cotton cloth prices in the four countries. Prices were highest in the USA at the end of the eighteenth century followed by England. India, whi0439( )-0.146571(A)]TJ 251.788 (n)-0.25585(d)-0.295585(l)-2.16558(o)-0.294363(p)-0.

the rich countries, labour relative to capital services was much lower in Egypt (Figure 28). The incentive to use machinery in Egypt (let alone to invent it) was very much lower than in the USA or Britain.

The situation was similar with energy. Neither country possessed a coal industry at the time, and most energy came from wood. The price of charcoal in Cairo was very high as it was made by Bedouins in the Sinai and carried by camel to the capital (Rabinowitz 1985). Wood was also expensive in India (Figure 29). As a result, the ratio of the wage rate to the price of energy in Britain or America was vastly higher than in the Third World (Figure 30). The incentives to use steam power to boost the productivity of human labour in Egypt or India were nonexistent.

India and Egypt would not have spontaneously industrialized since it did not pay their firms to use most modern technology. Labour was cheap relative to energy and capital. It did not pay to adopt the technology that would have alleviated their poverty. In the USA a tariff was necessary to make industry pay, but once in place American industry chose the modern methods. Development of the third world required policies that ignored comparative advantage.

From this perspective, Egypt is one of history's great missed opportunities. In 1805 Mohammed Ali seized power and tried to turn Egypt into a modern military-industrial power. A Soviet style procurement policy financed stated led industrialization. It all came undone in 1838 when the British forced a treaty on the Ottoman overlords that ended the fiscal system. The Egyptian economy reverted to the pattern implied by comparative advantage, and Egypt remained an underdeveloped country (Rivlin 1961, Panza.and Williamson 2013).

Conclusion

Was American economic development 'exceptional'? Before 1895, it consisted of settling a vast continent with only a small indigenous population. This was an impressive achievement but not unusual. Population movements into remote areas have been a recurrent feature of world history. After 1895, America became a leading industrial power by developing high productivity manufacturing. This was a more unusual achievement that rested on three factors–(1) cheap energy, (2) universal public schooling that induced firms to develop technology to raise the productivity of adult labor while at the same time training children to meet that demand, and (3) the rapid growth of manufacturing before 1895. While the nineteenth century industrial sector was not internationally competitive, the high rate of capital accumulation led to a rapidly growing demand for capital goods as well as learning by doing and collective invention. The accumulation of engineering experience provided knowledge inputs for the inventions that augmented adult labour.

Likewise, the American development model was exceptional in the sense that it would not have delivered similar results if applied in poor countries. The model consisted of transportation investment, universal schooling, and tariff protection. Consider the tariff. In nineteenth century America, it was necessary for the development of a modern manufacturing sector sinc74(o)-0.295585(u)-055(a)3.74(n)-0.295585(u)-0.295585(f)2.80439(a)3.-0.295585(e)3.74(r)2.8043

-2.16436(h5(m)-2.45995(p)-0.295585(a)3.7-0.146571(i)-2.16436(n)-0.295585( )-0.146571(t)-2.16436(h)-0.2955p)-0.29558

wages, at least, were much lower than those in Britain. Some of this difference was due to the lower efficiency of poorly trained workers in these countries. Beyond that, low wages not accounted for in this way reduced the incentive to adopt modern technology since it was not worth investing large sums to save cheap labour. In many cases, the traditional hand technology remained the least cost choice of technique. In that circumstance, the American model was a non-starter, and more draconian policies were necessary for successful industrialization.

While the differences between the USA and Britain have exercised generations of historians, the differences between the two economies were small when seen from a global perspective. For much of its history, the USA was an outlying province of Britain–albeit an increasingly dynamic one. Both Britain and the USA were rich, while much of the rest of the world was poor. Indeed, globalization and the character of technological change widened the gap between rich and poor. The USA and Britain were winners in a global process of economic divergence. America has been a leader in that development, and that is the essence of American exceptionalism.

Table 1

Subsistence Basket

flour	kg	195
beans/peas	kg	20
meat	kg	5
butter	kg	3
soap	kg	1.3
cloth	metres	3
candles	kg	1.3
lamp oil	litres	1.3
fuel	Mill BTU	2
calories/day		2103

Table 2

Co-integration between wages in US and UK cities (Error Correction Models)

		London-Massachusetts			London-Philadelphia	
		1781-1802	1836-1913		1727-1802	1836-1913
$\Delta wage_{UK}$		0.31	0.72***		0.34**	0.38**
		(0.25)	(0.17)		(0.13)	(0.16)
ECT (z_{t-1})		-0.64***	-0.32***		-0.51***	-0.52
		(0.22)	(0.10)		(0.13)	(0.12)
N		21	62		51	51
r^2		0.32	0.30		0.38	0.34
F		4.31	12.76		14.92	12.60

		Lancashire-Massachusetts			Lancashire-Philadelphia	
		1781-1802	1836-1913		1727-1802	1836-1913
$\Delta wage_{UK}$		0.42*	0.66***		0.25*	0.32**
		(0.23)	(0.15)		(0.13)	(0.14)
ECT (z_{t-1})		-0.63***	-0.28***		-0.48***	-0.58***
		(0.22)	(0.10)		(0.13)	(0.12)
N		21	62		51	51
r^2		0.35	0.31		0.32	0.32
F		4.89	13.10		11.37	11.37

Note: the dependent variable is changes in wages in the US city. The ECT (error correction term) equals the difference between the actual and the equilibrium wage in the previous period where the equilibrium wage is determined by the co-integrating regression.

Table 3

Employment in British Manufacturing in the 1860s

	% workers	Earnings (£/year)	Earnings ($/year)
[illegible]	[illegible]5%	5[illegible].5	250.68
women	29%	22.[illegible]	[illegible]07.72
boys	13%	16.[illegible]	[illegible]9.90
girls	3%	12.5	60.93
average	[illegible]	[illegible]	[illegible]

Source: Baxter (1868, pp. 88-95) and Peter Lindert's (1997) spreadsheet 'Baxter EW & UK 1867".

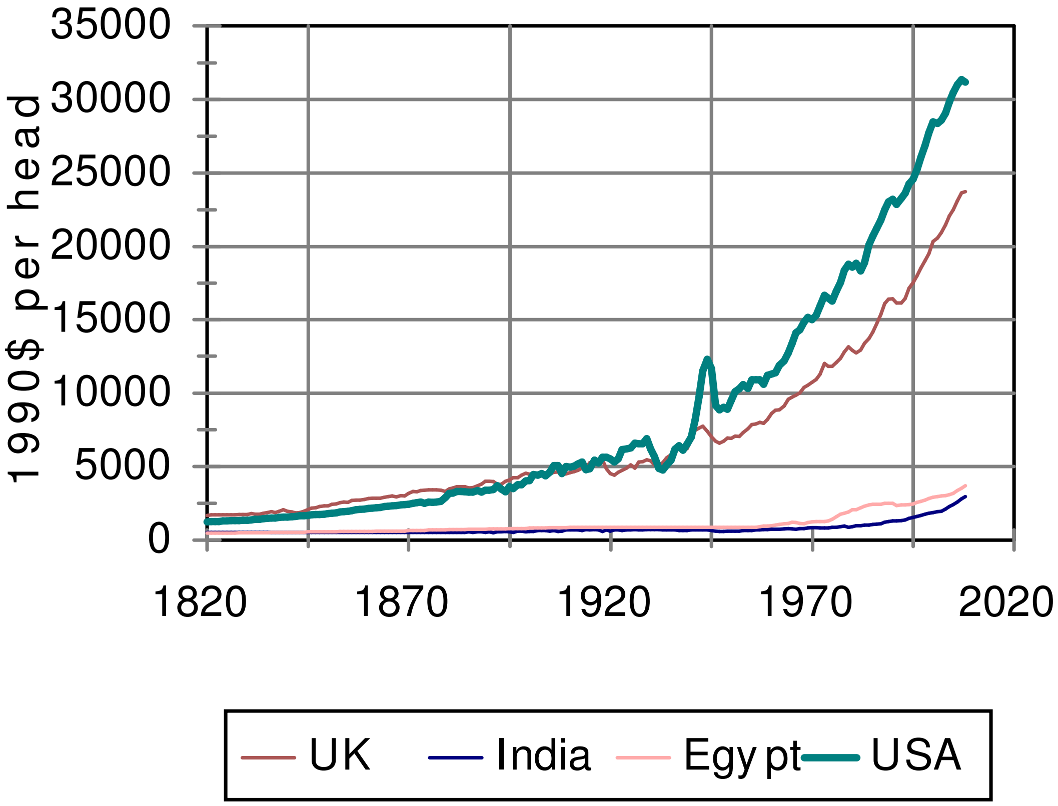
Table 4

	%	Earnings	USA/UK	
			workers	($/year)
.37	Men>16	79%	343.64	1
.60	Women>15	16%	171.82	1
.22	youths	5%	85.91	1
.87	average		302.18	1

Employment in USA Manufacturing in 1869
U.S. Census, *Compendium of the Ninth Census*, 1872, pp. 796-7.

Figure 1

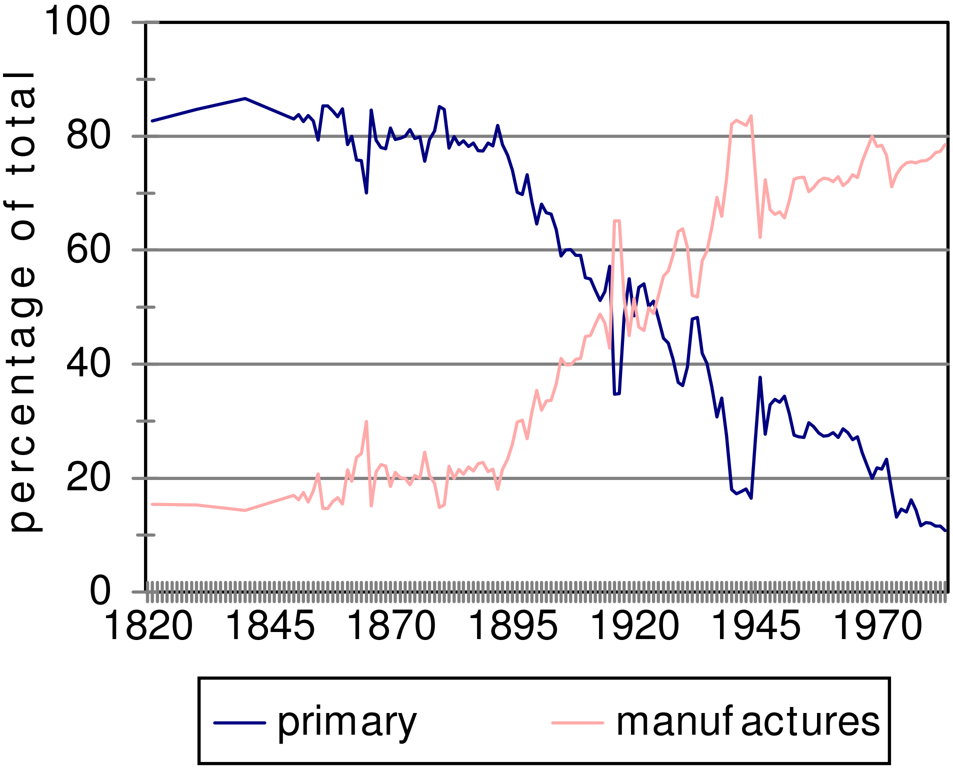
GDP per Capita



Source: Maddison (2006)

Figure 2

Percentage Composition of American Exports



Hist Stat
primary is sum of series Ee447, Ed448, and Ed449.
Manufactures is sum of series Ed450 and Ee451.

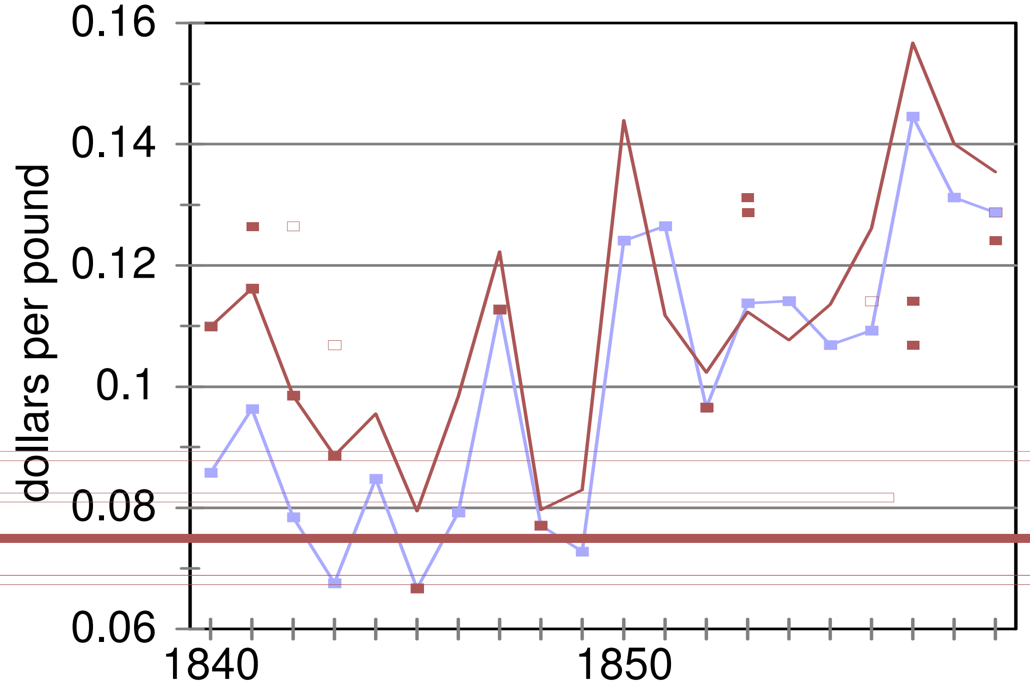
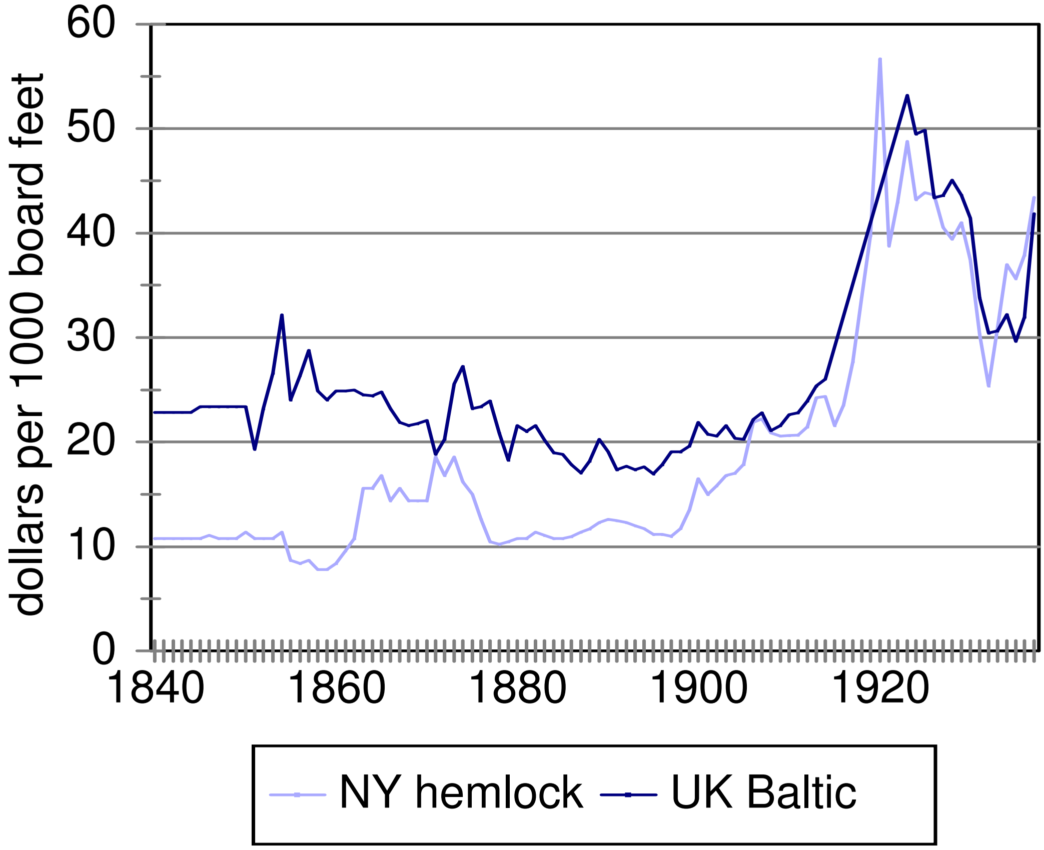

0.16
0.14
0.12
0.1
0.08
0.06
dollars per pound
1840
1850

Figure 4

Price of Softwood Structural Lumber

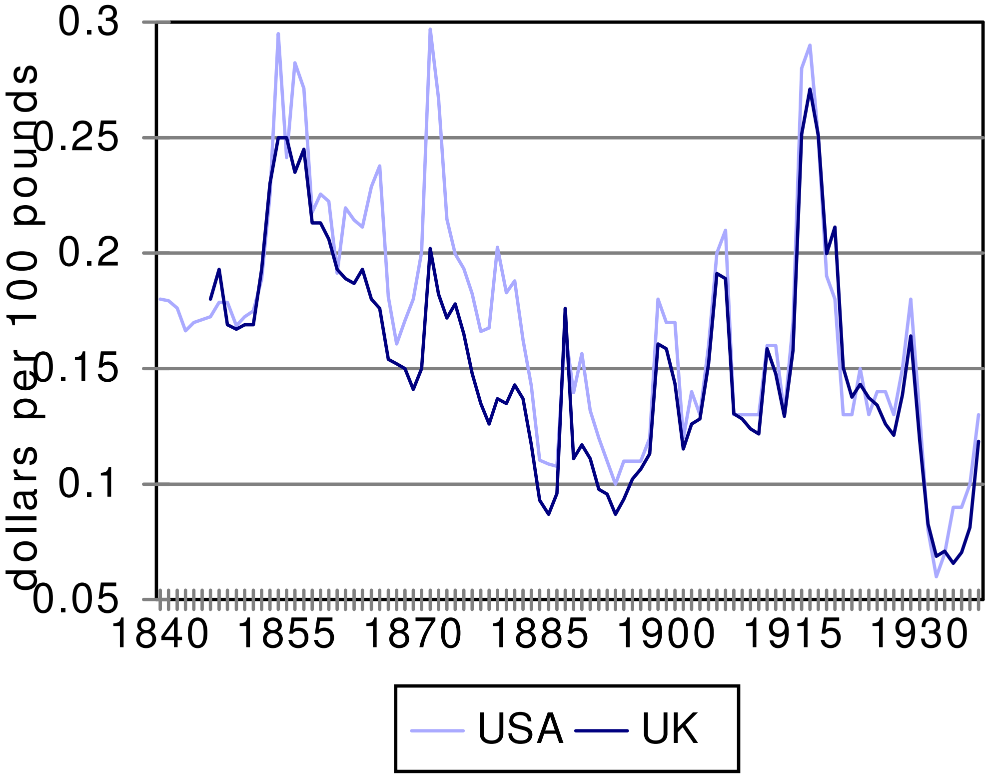


source:
New York Hemlock–
1890-1920: United States, Department of Labor, Bureau of Labor Statistics (1922. p. 184, Table 9), 'New York Market, average price per M feet'.
1840-1890: extrapolated with Aldrich (1893, Vol. I, p. 46), 'one inch first quality hemlock boards not planed'.
1921-39: extrapolated with Potter and Christy (1962, p. 244, series L).

UK Baltic–
1840-60 extrapolated with *Economist* series of price of Canadian yellow pine from Aldrich (1893, Vol. I, pp. 213-4).
1861-1937 UK Stat Abst and Sauerbeck,, unit value of imported timber, sawn or split, shillings per load of 50 cubic feet.

Figure 5

Price of Copper

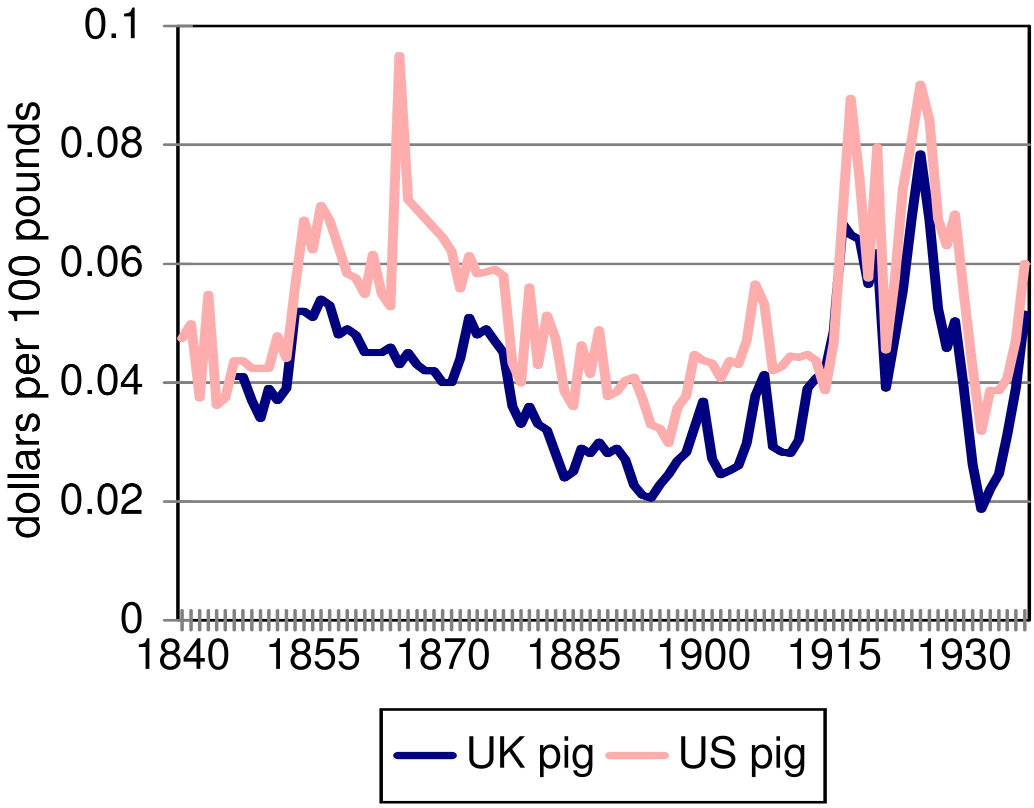


Source:
USA
1840-1891: Aldrich (1893, Vol. I, p. 40) copper ingots
1892-1939: US Hist Stats

Britain
1846-91: Aldrich (1893, Vol.I, p. 234), Saurbeck's prices of copper bars from Chile.
1892-1937: Sauerbeck.

Figure 6

Price of Lead

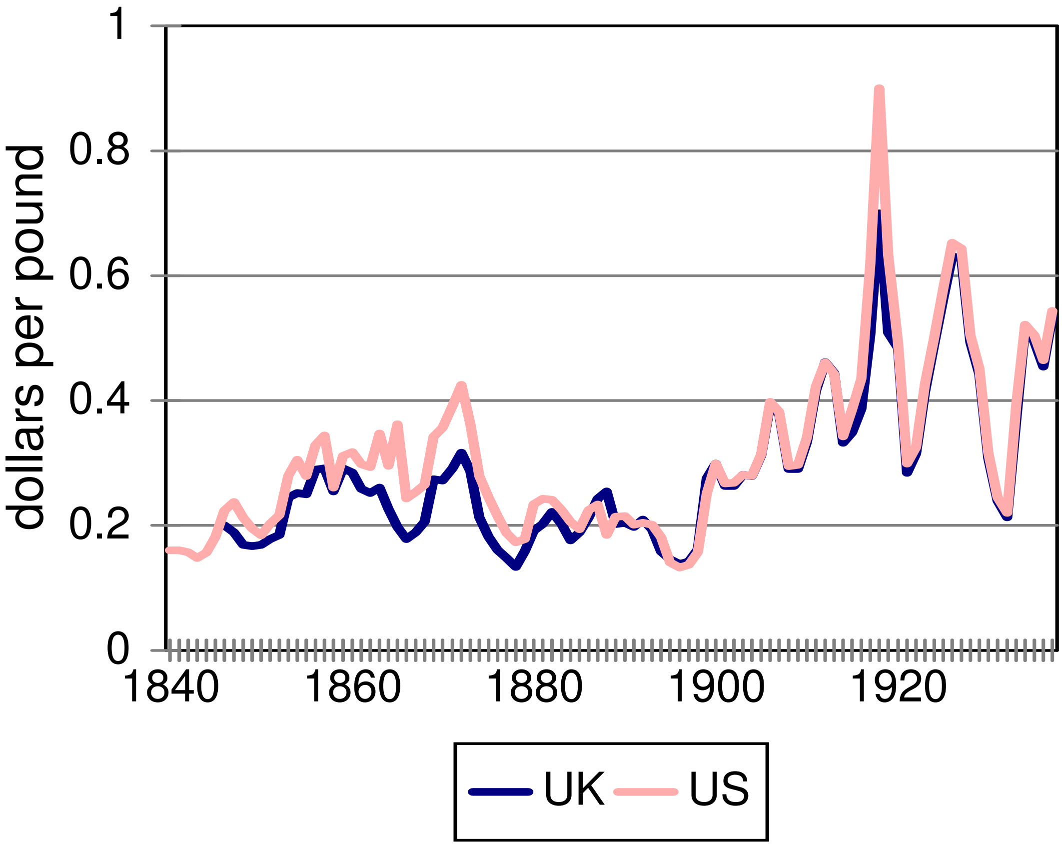


Source:
USA
1840-1891: Aldrich, I, p. 41, lead pig, second series
1892-1937: Schmitz 1979, p. 278, series 27.3

Britain
1846-91: Aldrich, I, p. 234, Saurbeck's prices of copper bars from Chile.
1892-1937: Schmitz 1979, p.278-9 series 27.2

Figure 7

Price of Tin

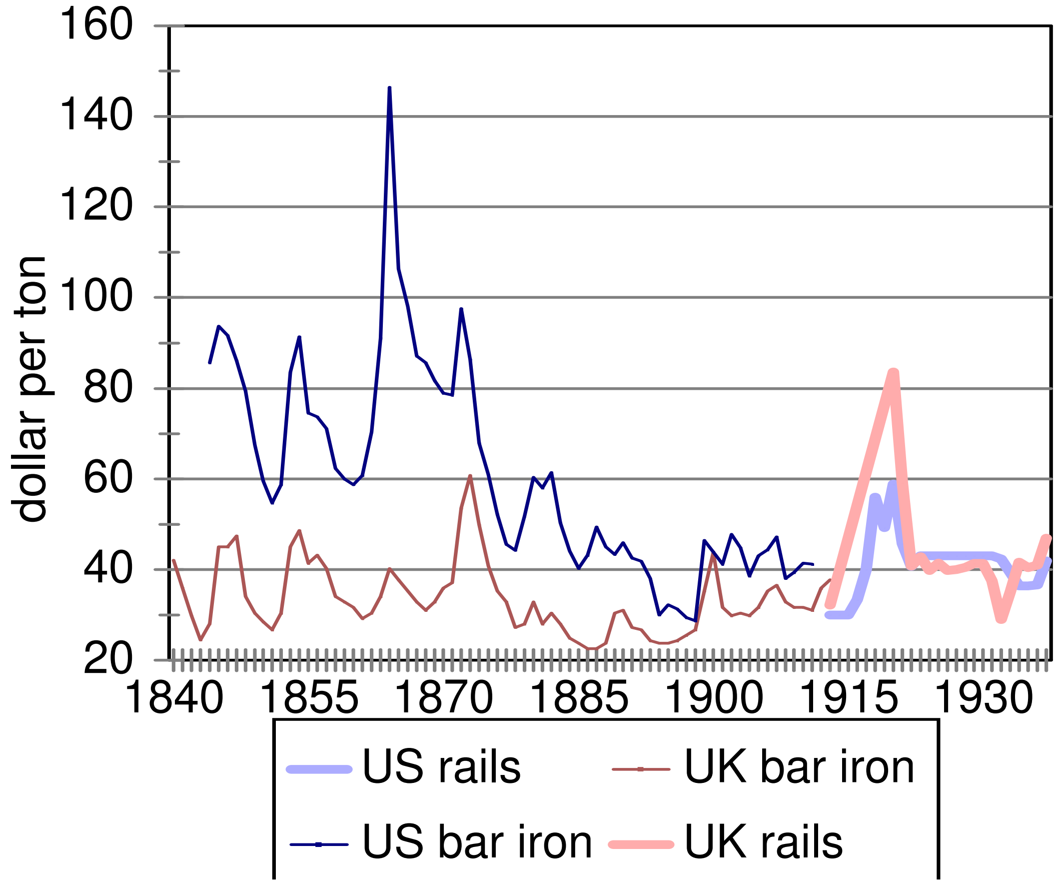


Source:

USA
1840-91 Aldrich, II, pp. 215-6
1892-1937 Schmitz 1979, p.297-8 series 34.4
Britain
1846-91: Aldrich, I, p. 235, Saurbeck's prices of Straits tin
1892-1937: Schmitz 1979, p.297-8 series 34.3

Figure 8

Prices of Iron and Steel

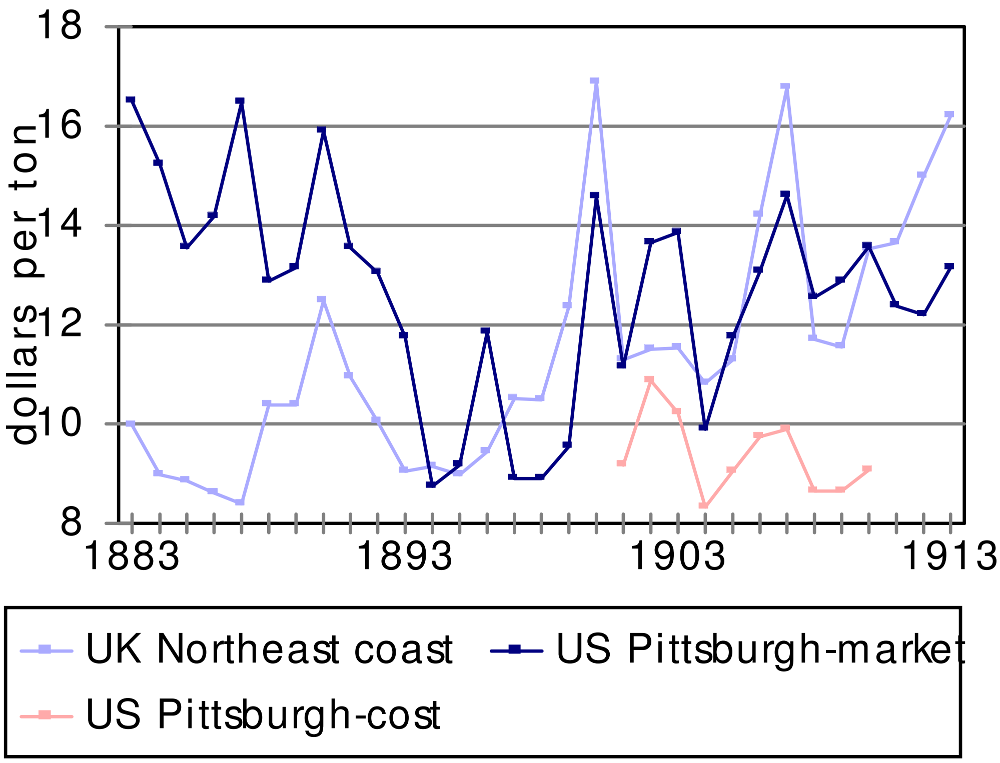


Sources:
US rails–Hist Stat Cc245 open hearth steel rails
US bar iron–Philadelphia, best refined bar iron, US Stat Abst.

UK rails–UK Stat Abst. unit value of exported heavy steel rails
UK bar iron–common bars, Mitchell and Deane (1971, pp.493-4).

Figure 9

Ore and Coke Cost per ton of Acid Bessmer Pig Iron



Source: Allen (1978, p. 66).

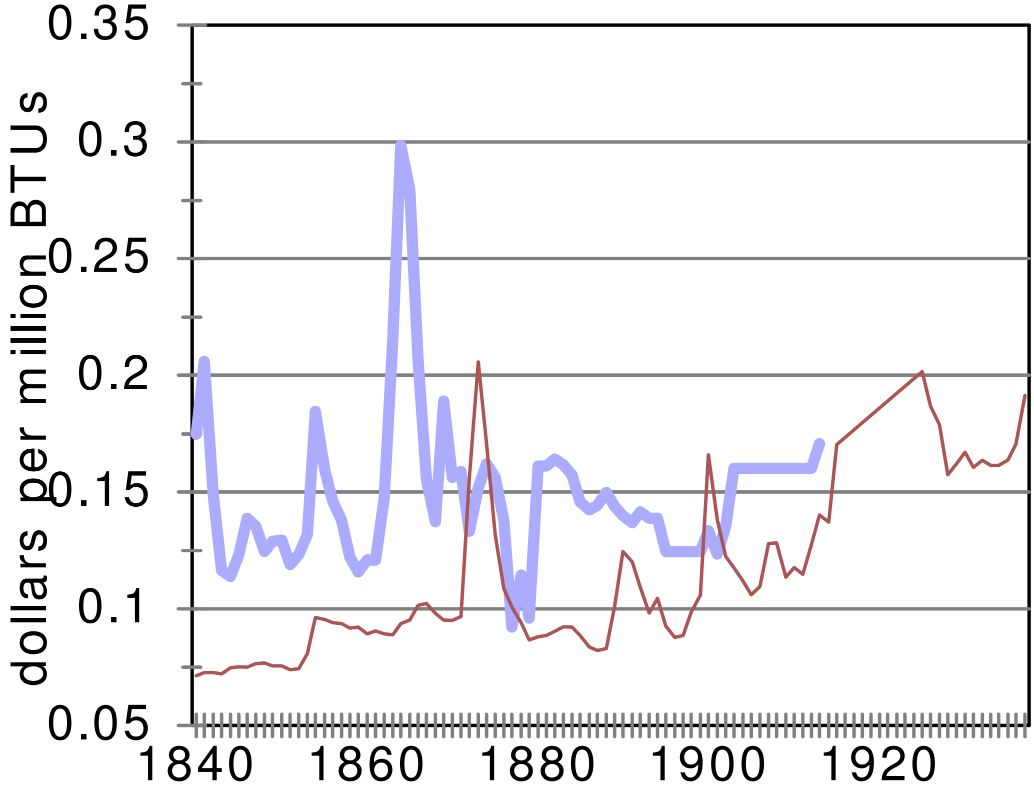
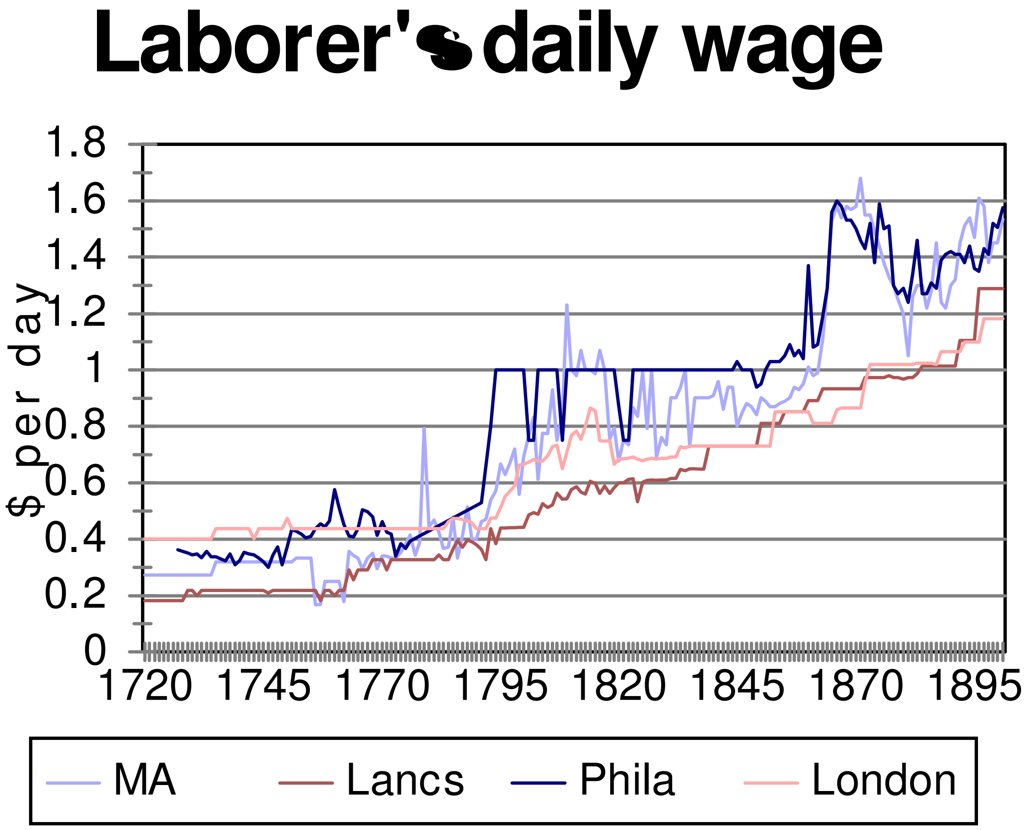

0.35
0.3
0.25
0.2
0.15
0.1
0.05
dollars per million BTUs
1840
1860
1880
1900
1920

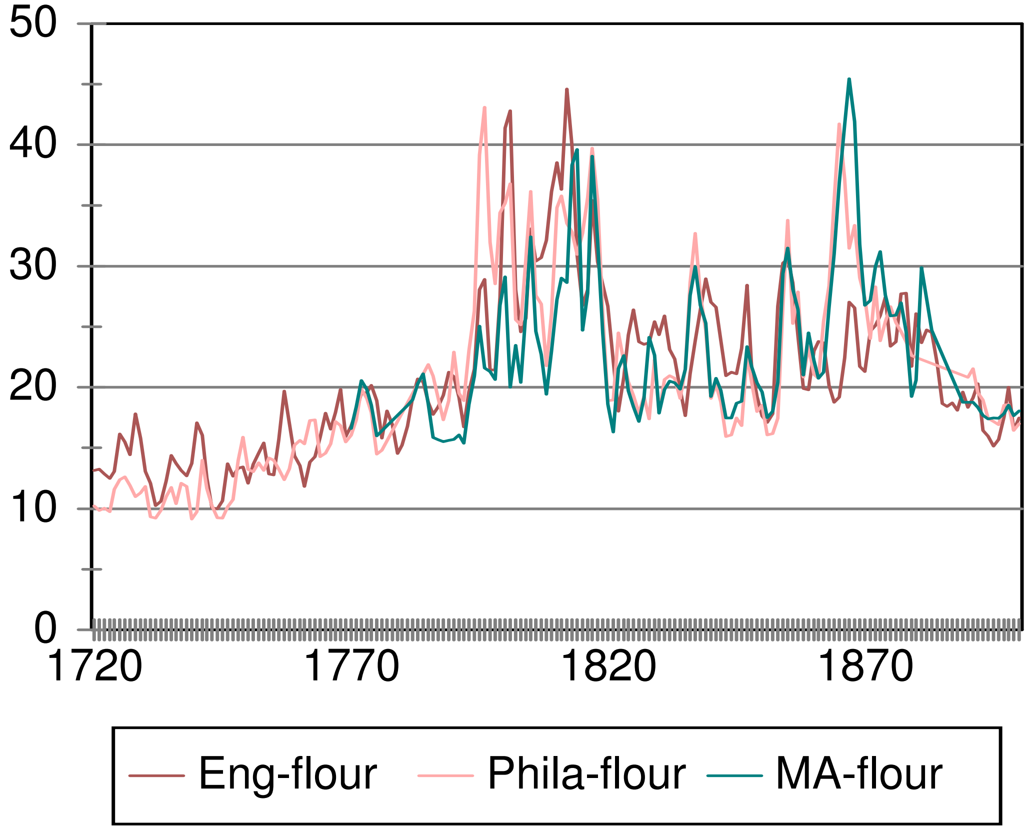
Figure 11



source:
Philadelphia
1727-1776: Nash (1979, pp. 392-4) and Smith (1981, p. 184).
1785-1830: Adams [1968: 420]
1840-99: BLS 604, pp. 253-60
1900-28: BLS 604, p. 186 (wage per hour multiplied by hours per week and divided by six).
Massachusetts
1720-1839 Wright series for 1752-1839 extrapolated backwards using Main (1994, p. 48).
1752-1839 Wright (1885, pp.323-5).
1840-98: BLS 604, pp. 253-60
1900-28: BLS 604, p. 185 (wage per hour multiplied by hours per week and divided by six).
London
1720-1860 Schwartz (1985, pp.36-8).
1860-1900 Bowley (1901, pp. 104).
1900-36 Bowley (1937, pp. 10, 15). missing values interpolated
Lancashire
1810-25: United Kingdom, House of Commons, *Tables of the revenue, population, commerce, &c. of the United Kingdom and its dependencies. Part I. From 1820 to 1831, both inclusive. British Parliamentary Papers*, 1833, Vol. 41, p. 165.
1839-1900 Bowley (1900, pp. 310-11).

Figure 12

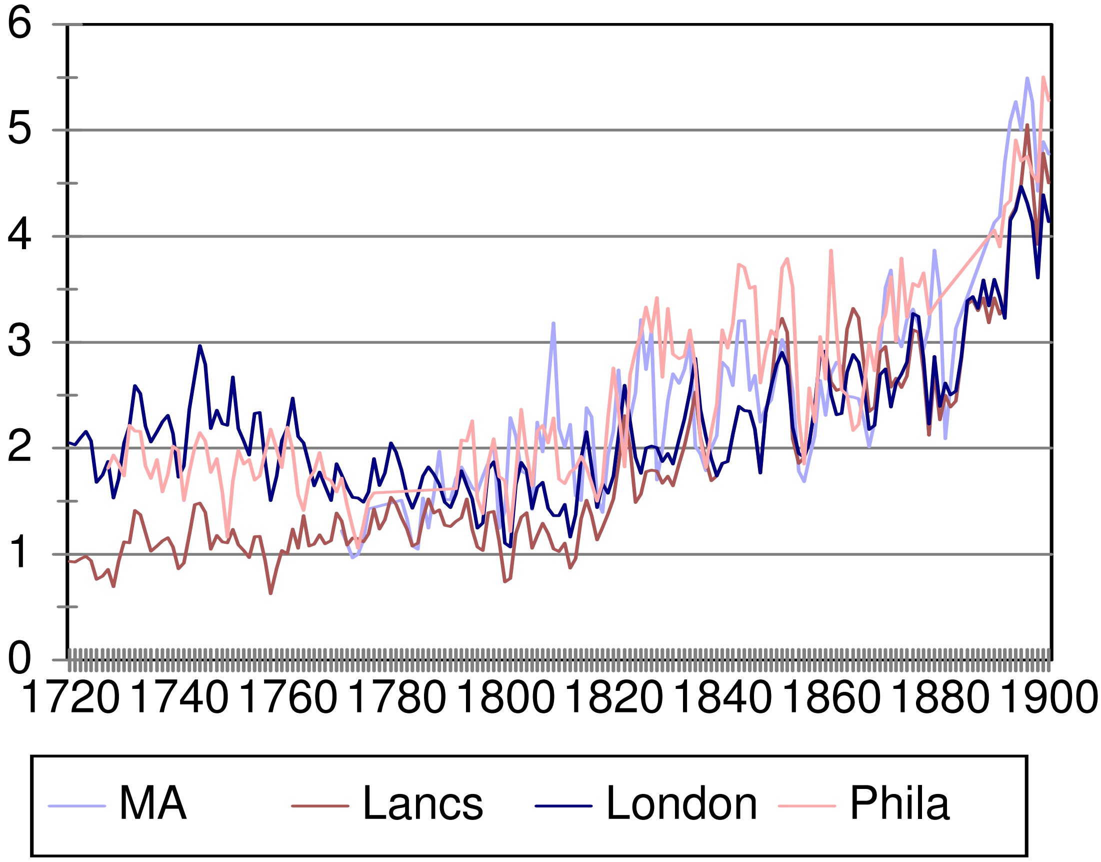
Cost of a Subsistence Basket based on Flour



Source:
cost of the basket shown in Table 1. See Data Appendix.

Figure 13

Real Wages as Multiples of Subsistence
Source: nominal wage multiplied by 250 divided by cost of subsistence basket



multiplied by 4 people per household and by 1.05 as an allowance for rent.

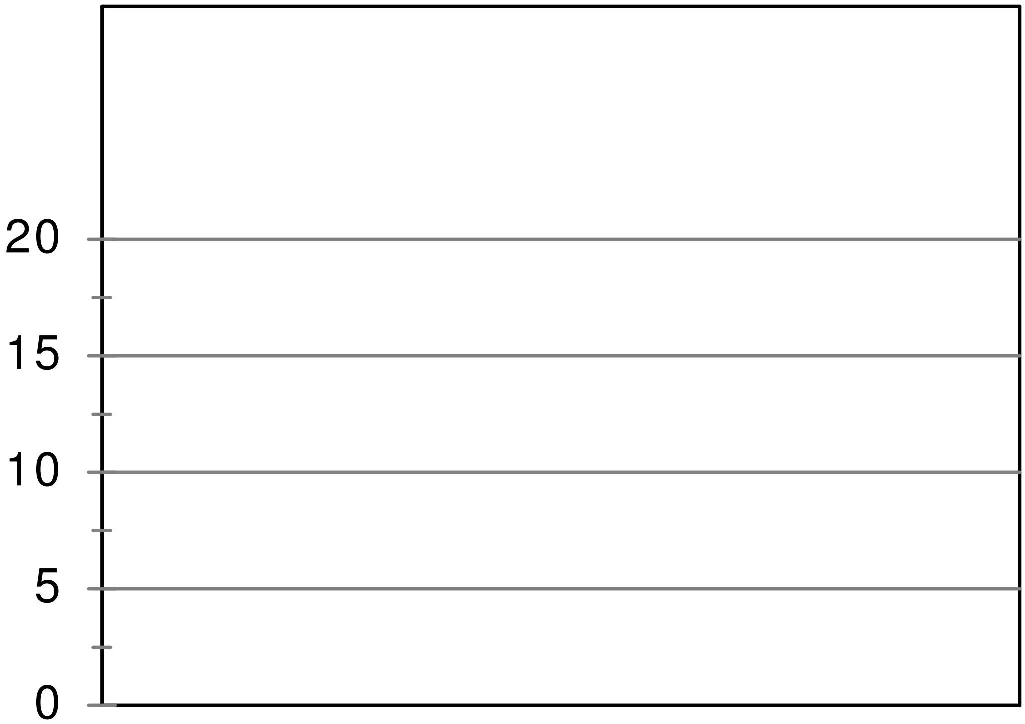
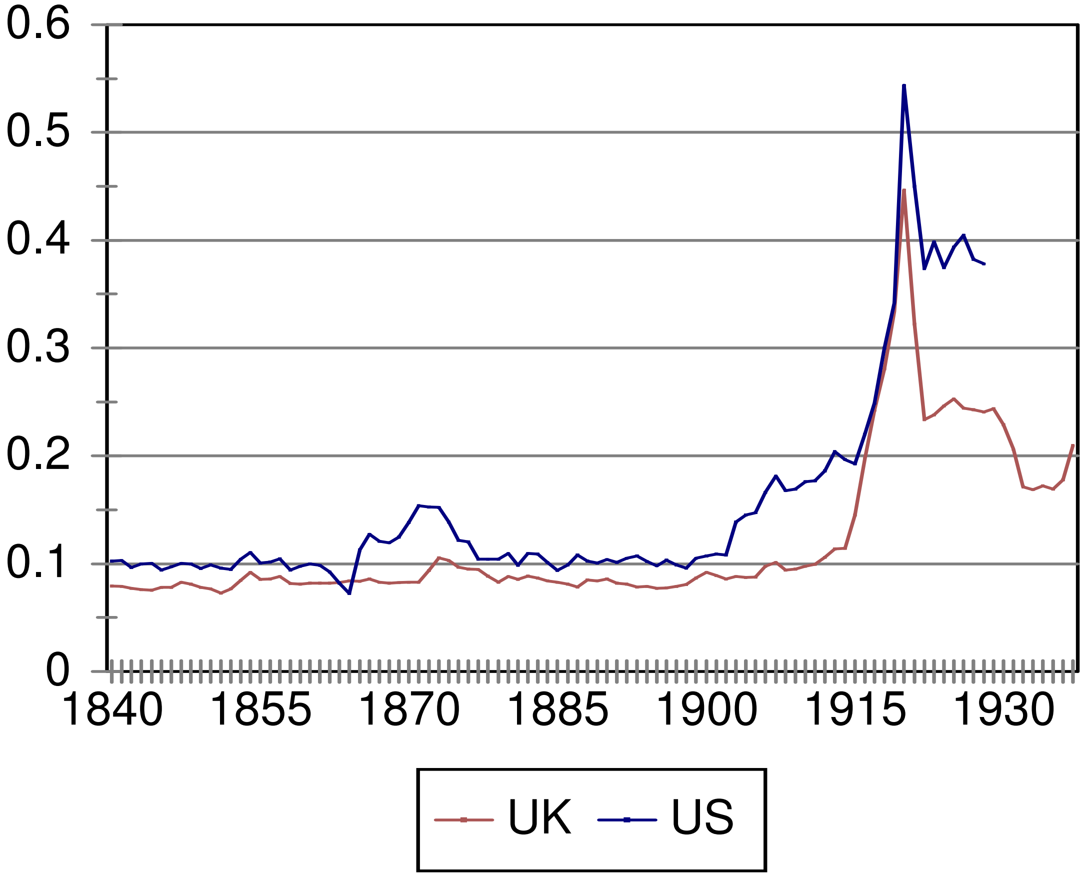

20
15
10
5
0

Figure 15

Price of Capital Services



Source:

index equals (interest rate + depreciation rate)*index of cost of capital goods

interest rate:
USA new England municipal bonds, Homer and Sylla (1996, pp. 287-8, 342, 350).
UK yield on long term government bonds, Homer and Sylla (1996, pp. 196-7, 444-5).

depreciation rate: assumed to be 5%

index of cost of capital goods = geometric average of building labour wage rate and arithmetic average of prices of bar iron, copper, soft wood building lumber, and bricks.
Sources of prices of bar iron, copper, and lumber have already been given (with the addition that the US bar iron price was extrapolated to 1937 using the price of steel rails).
Bricks–

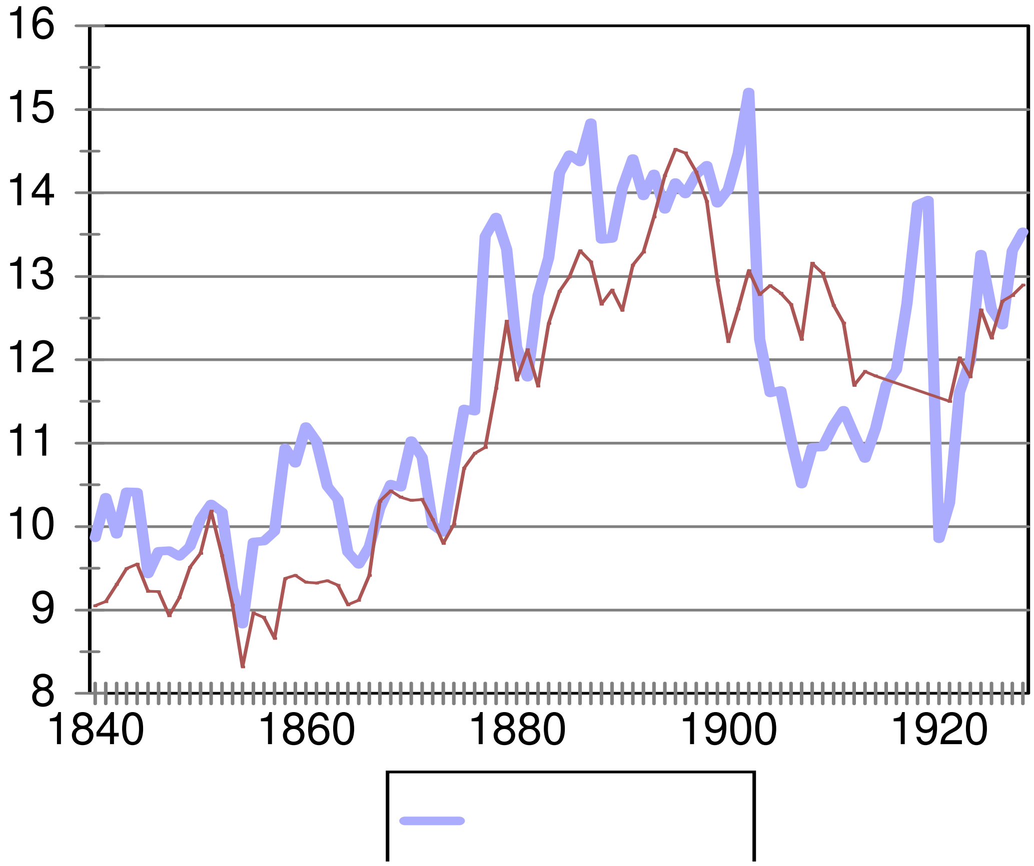
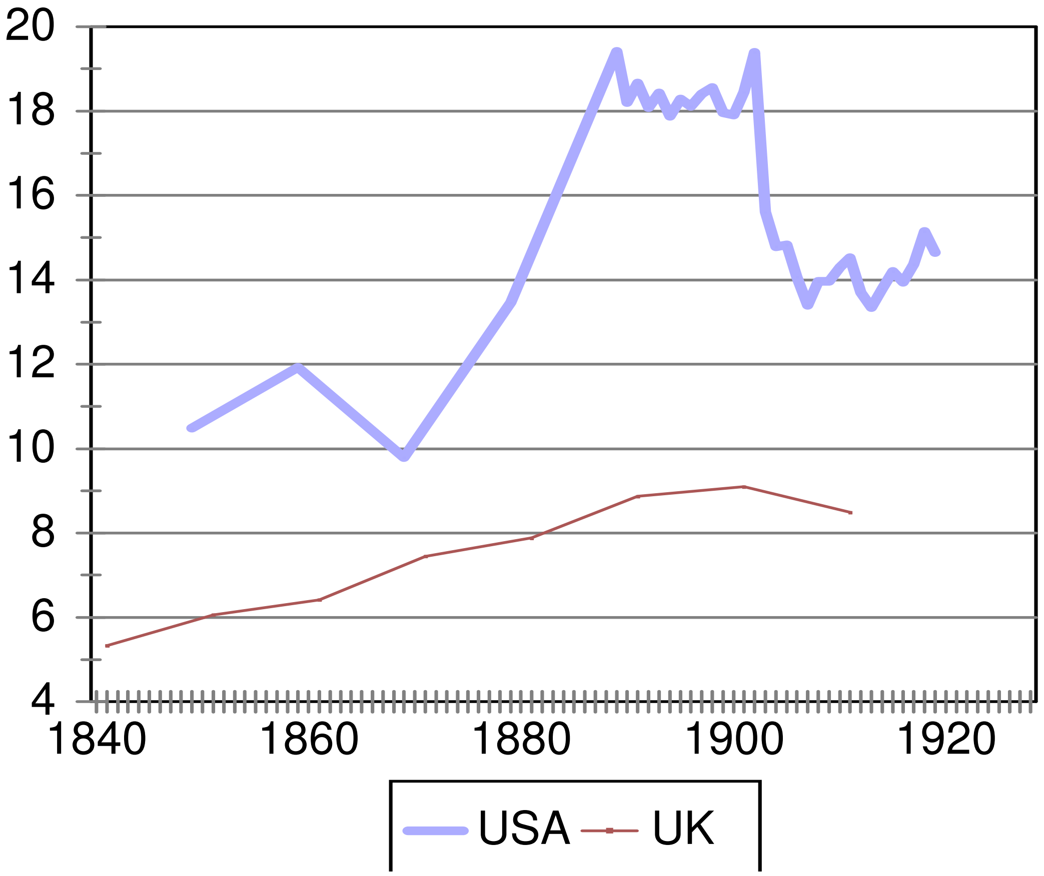

16
15
14
13
12
11
10
9
8
1840
1860
1880
1900
1920

Figure 17

Average Earnings in Manufacturing relative to the Price of Capital Services.



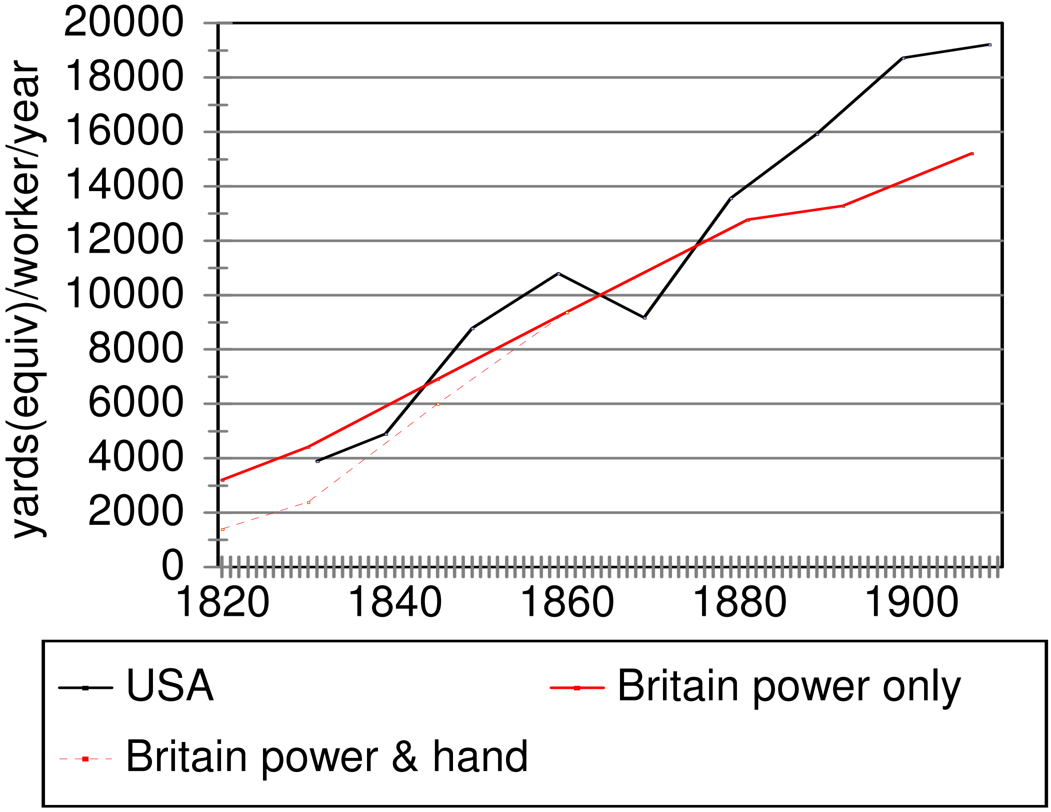
average annual earnings in manufacturing divided by price of capital services plotted in Figure 15.

Average annual earnings in manufacturing:
UK: Deane and Cole (1969, pp. 143, 152), total wages and salaries in manufacturing divided by labour force in manufacturing.

USA: total wages paid in manufacturing divided by manufacturing employment. Data from US censuses of manufactures as summarized in US Hist Stat series Dd5 and Dd9. 1889-1920: Average hourly earnings in manufacturing from Rees (1959, pp. 15-6, col. 3) multiplied by estimate of hours worked per year. This was worked out for census years by dividing census annual earnings by Rees' hourly earnings. Intervening years interpolated.

Figure 18

Labor Productivity in Cotton Spinning and Weaving combined



Data sources: US *Census of Manufactures*, various years and Wood (1903, p. 302).

Labour productivity was computed as

price*yards per lb*(lbs of yarn woven+relprice*lbs of yarn sold)/employment

Price was 1 for UK and .9 for USA in view of differences in the quality of the product. US cloth was made of coarser yarn than British cloth. Average yarn count in Britain was in the range 40-50, while average count in USA was on the order of 20. (Temin 1988, Harley 1992a). American cloths sold at lower average price per yard. Harley (1992a, pp. 566, 581) pointed out that *The Economist* reported the price of 'red end long cloth,' a fabric comparable to typical US cloth, in its weekly market reports in the 1850s, as well as print cloths typical of British production. The price per square yard of the American-style cloth was 90% or less of the price of typical British cloths.

yards per lb was taken to be 4 in the United States and 5 in Britain in view of the different qualities of cloth made. These ratios are born out by the incomplete data in the sources.

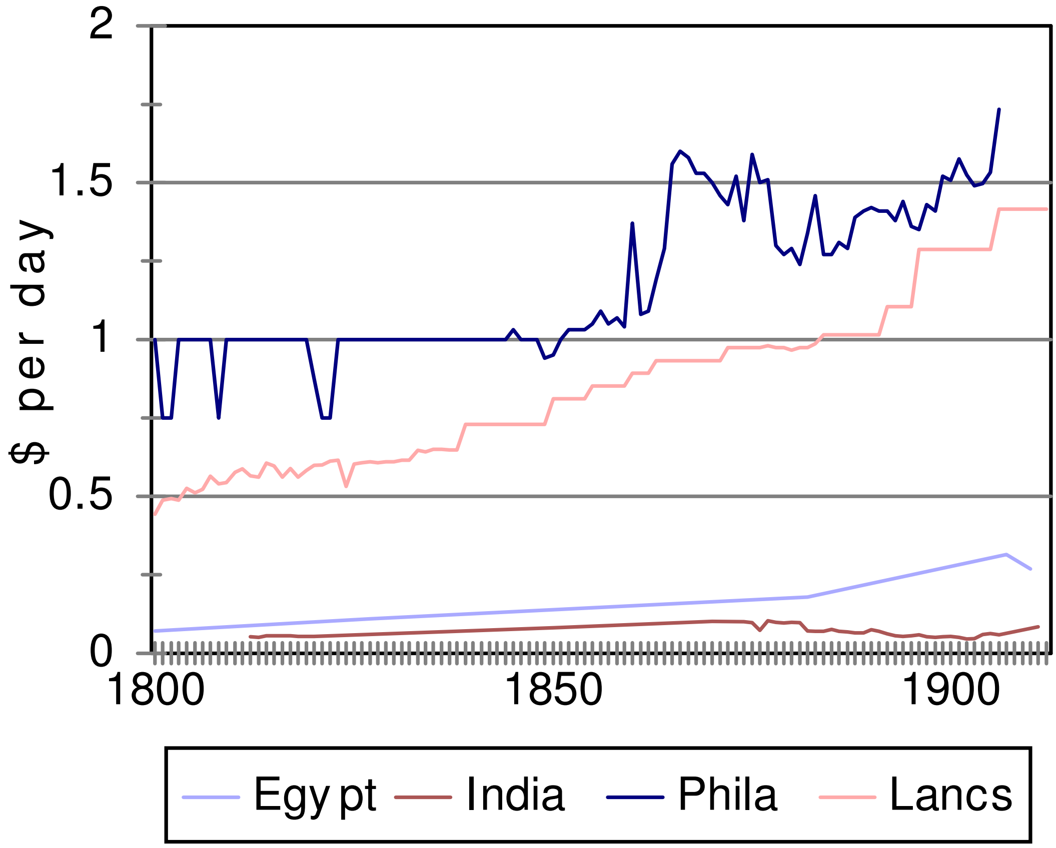
lbs of yarn woven and lbs of yarn sold were computed by dividing the weight of cotton spun into the two categories. In the case of the USA 85% of spun cotton was assumed to have been woven; in the case of Britain the proportion was 75%. These proportions were representative of the years for which they could be computed in the two countries. Wood reported the weight of cotton spun in Britain. For the USA, it was computed as 90% of the weight of cotton consumed by cotton mills, as this was the typical fraction in those years for which it could be computed.

Relprice was the price per pound of yarn relative to the price per pound of cloth made from the yarn. This equalled .75 for much of the nineteenth century, and that price was used throughout.

Employment in the USA was total employment in cotton mills. Wood reports the number of employees in cotton spinning mills, power weaving mills, and hand loom weavers. Employment was the sum of the three for the series showing the productivity of the whole sector. Labor productivity in the factory sector alone was computed by excluding the weight of yarn woven by hand from the calculation as well as the number of handloom weavers. In addition, employment in spinning mills was reduced in proportion to the weight of cotton yarn woven in power mills plus the weight of yarn sold as final product all relative to the total production of yarn.

Figure 19

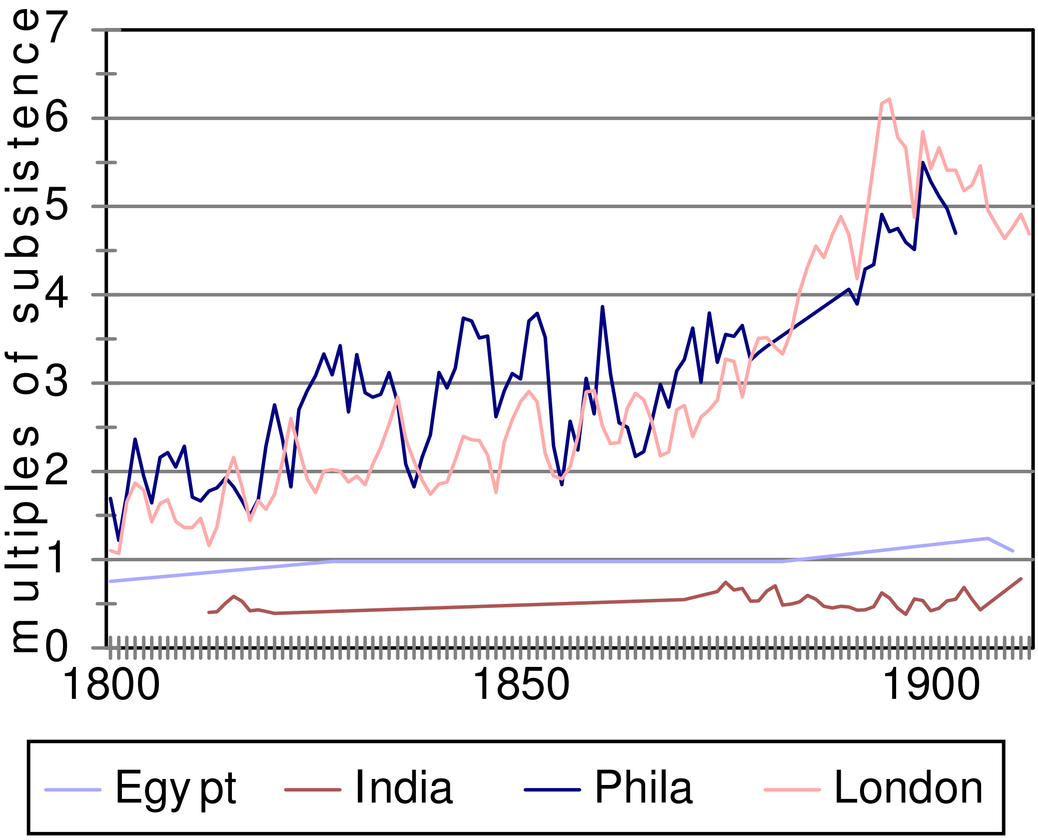
Laborers' Wages at the Exchange Rate



Source:
Philadelphia and Lancashire: as already reported.
India: see Allen (2007).
Egypt: Artin (1907, p. 125, ourvrier), Girard (1824), Wilkinson (1835, p. 286)

Figure 20

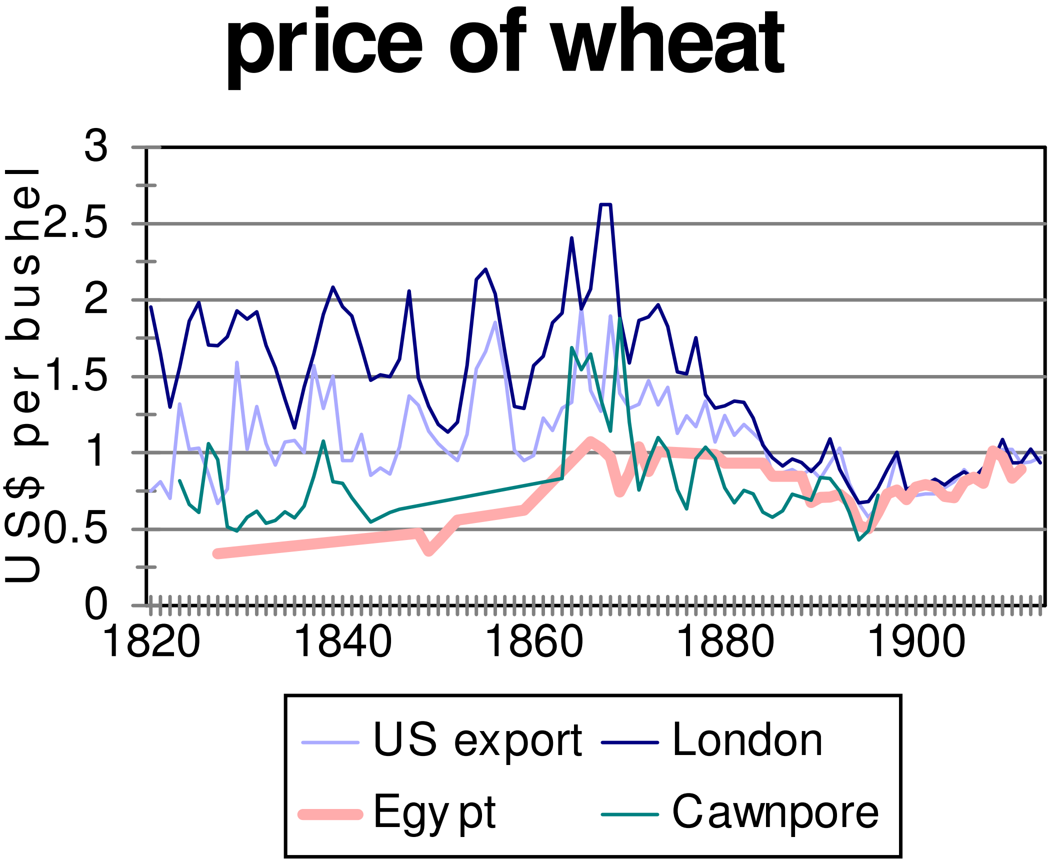
Real Wages as Multiples of Subsistence



sources:

Philadelphia and Lancashire: as already reported.
London: See Appendix.
India: see Allen (2007, p. 29, ftn. 1). The cost of living was recomputed using the basket in Table 1.
Egypt:
prices from Artin (1907, p. 118-30), Girard (1824), Wilkinson (1835, p. 283-5). Flour price in 1800 was extrapolated from Wilkinson's price for 1827 in proportion to change in wheat price.
Fuel–using the market price of charcoal in the normal calculation produces an unreasonably expensive budget. Vallet (1911, p. 61, 107) reports that most households paid a baker to bake their bread rather than buying fuel and doing it themselves. I have followed Vallet's lead and assessed the fuel charge 10% of the price of the flour.

Figure 21



sources:
USA average price per bushel of exported wheat–US Stat Abst
London–gazette price from Mitchell and Deane (1971, pp. 488-9)
Cawnpore– Montgomery (1849, Appendix VI), *Statistical Abstract Relating to British India*, various years (available on http://dsal.uchicago.edu/statistics/)
Egypt–Owen (1969, pp. 80, 126, 263), Stat Abst Foreign Countries, 1888-97/8 and 1900-10/11.

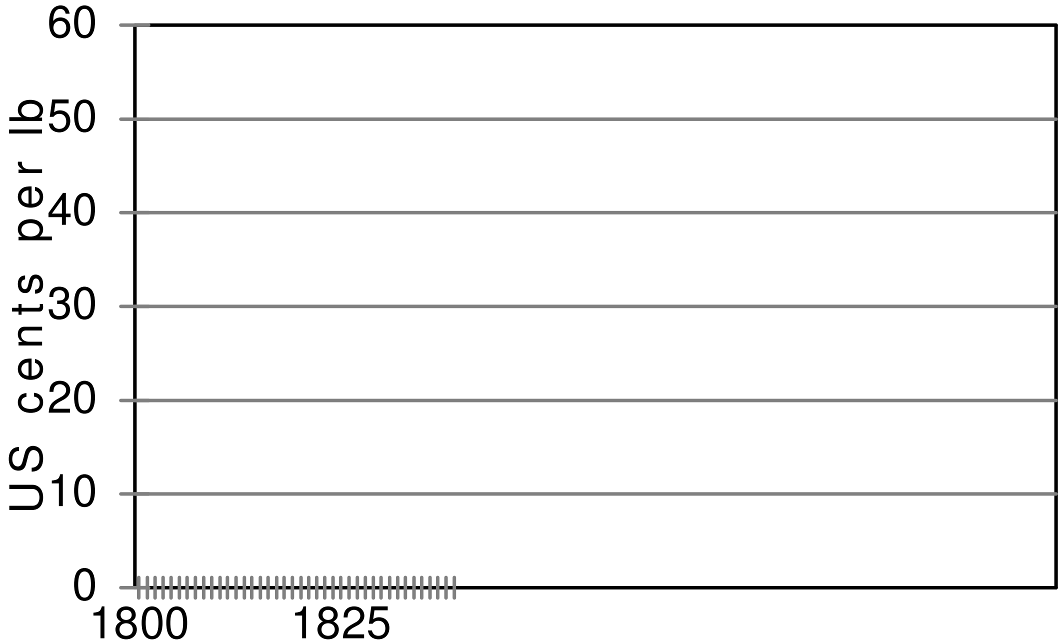
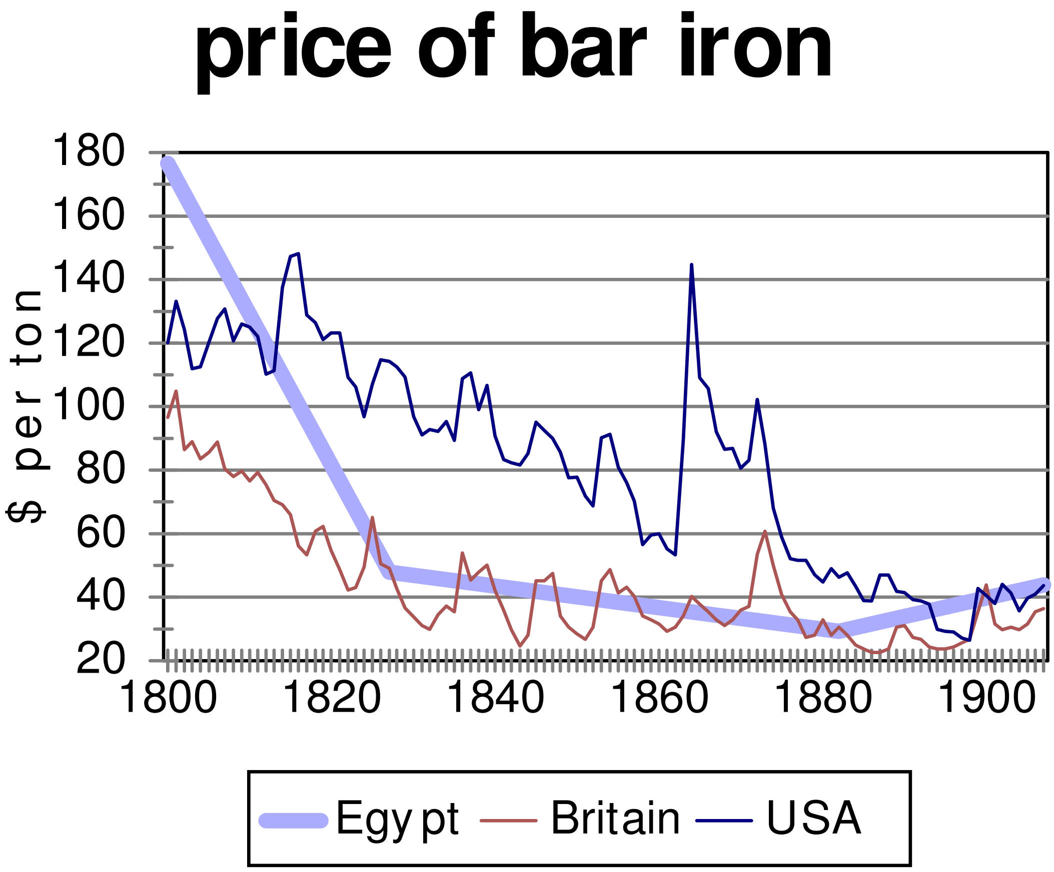
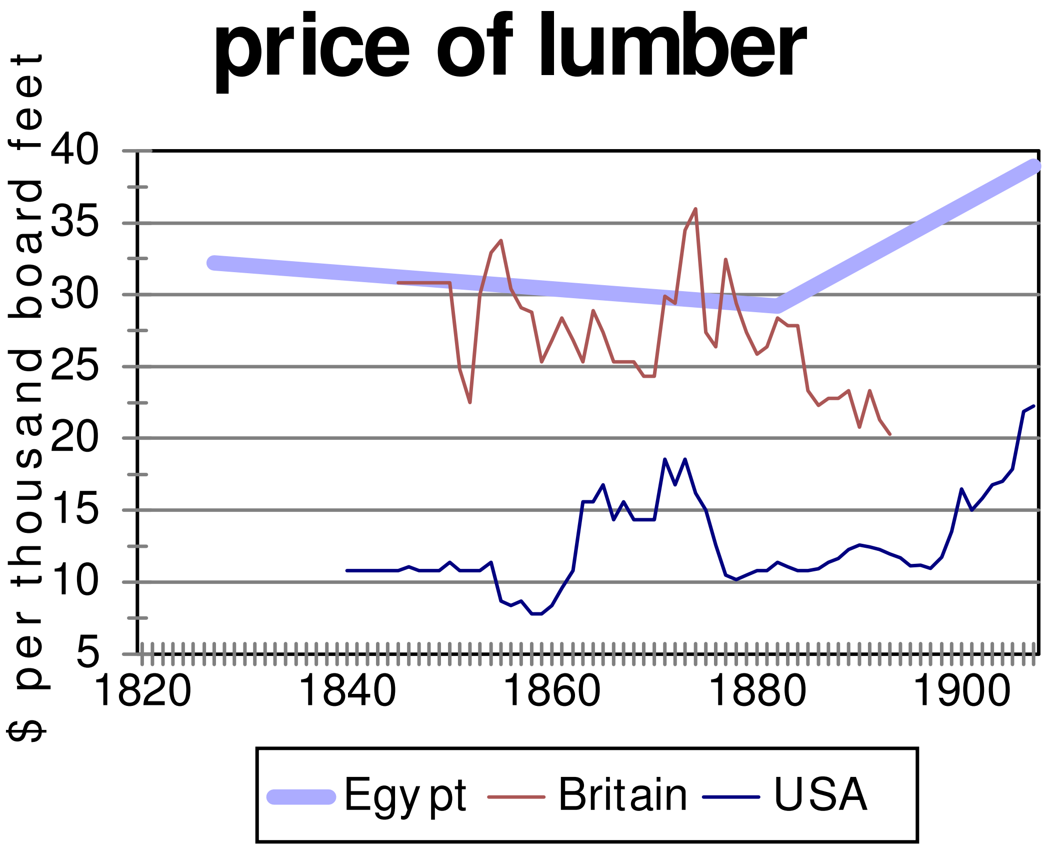

US cents per lb
60
50
40
30
20
10
0
1800
1825

Figure 24



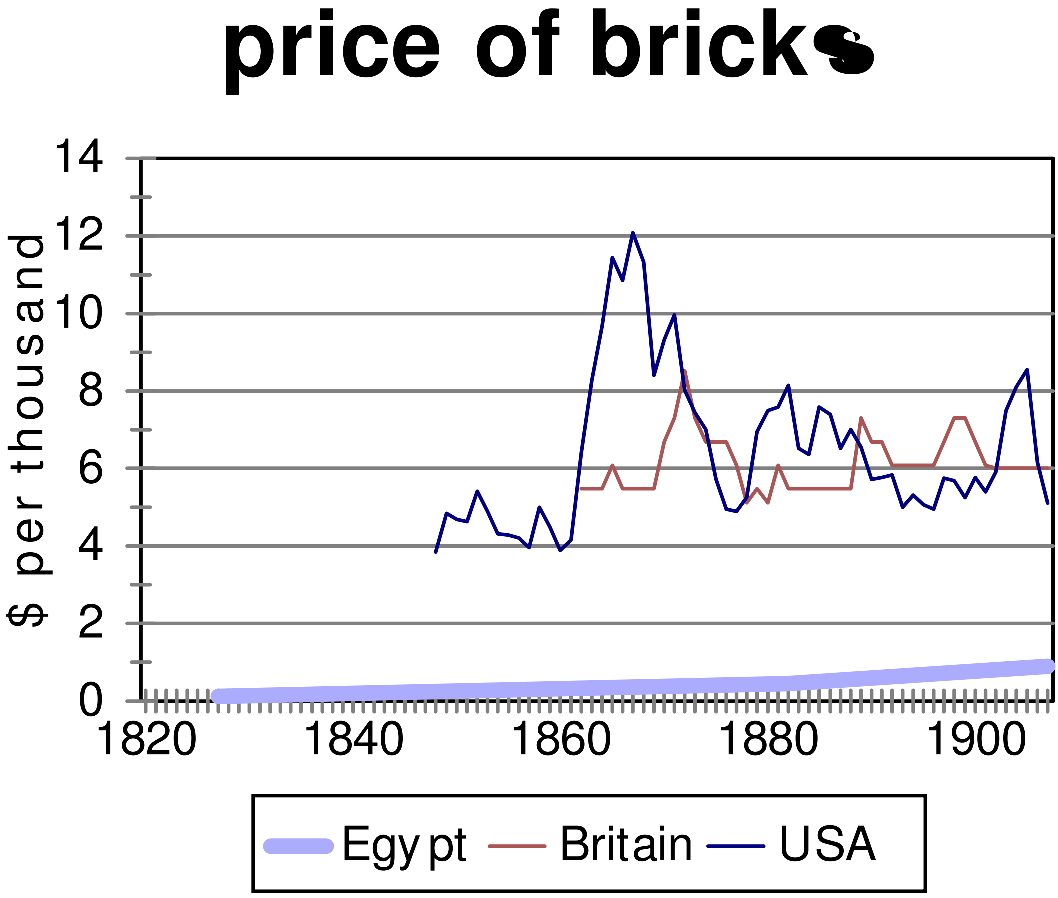
sources:
Britain and USA as in Figure 8.
Egypt–Artin (1907, p. 122).

Figure 25



sources:
Britain and USA as in Figure 4.
Egypt–Artin (1907, p. 118, bois de construction), Wilkinson (1835, p. 285). Prices reported for a 10 foot plank, which I assumed to be one inch thick and one food wide.

Figure 26



source:
sources:
Britain and USA as given previously.
Egypt–Artin (1907, p. 119, briques cuites), Girard (1824, pp. 199-207), Wilkinson (1835, p. 285). The prices of baked rather than sun dried bricks were used.

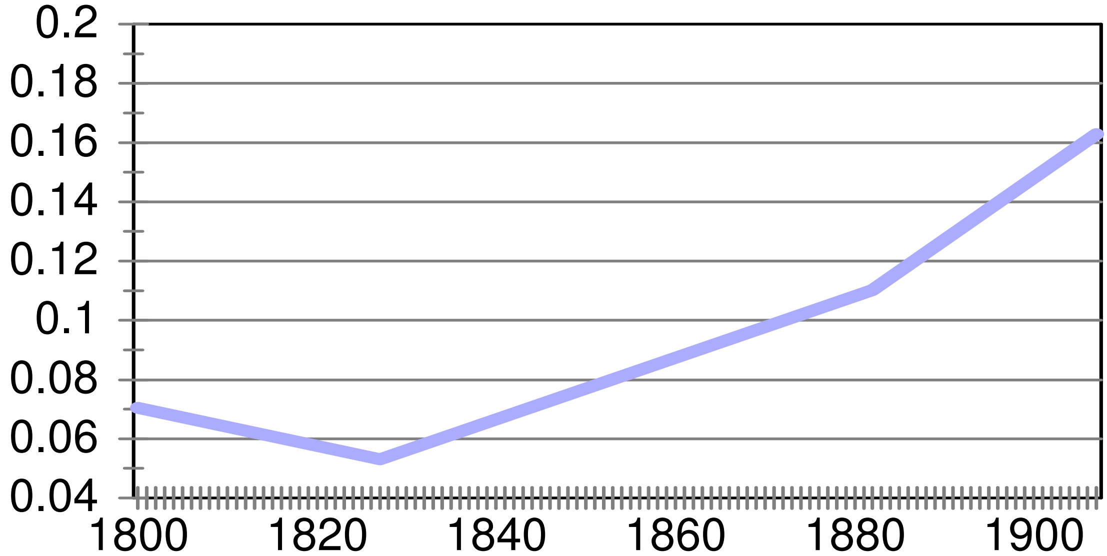
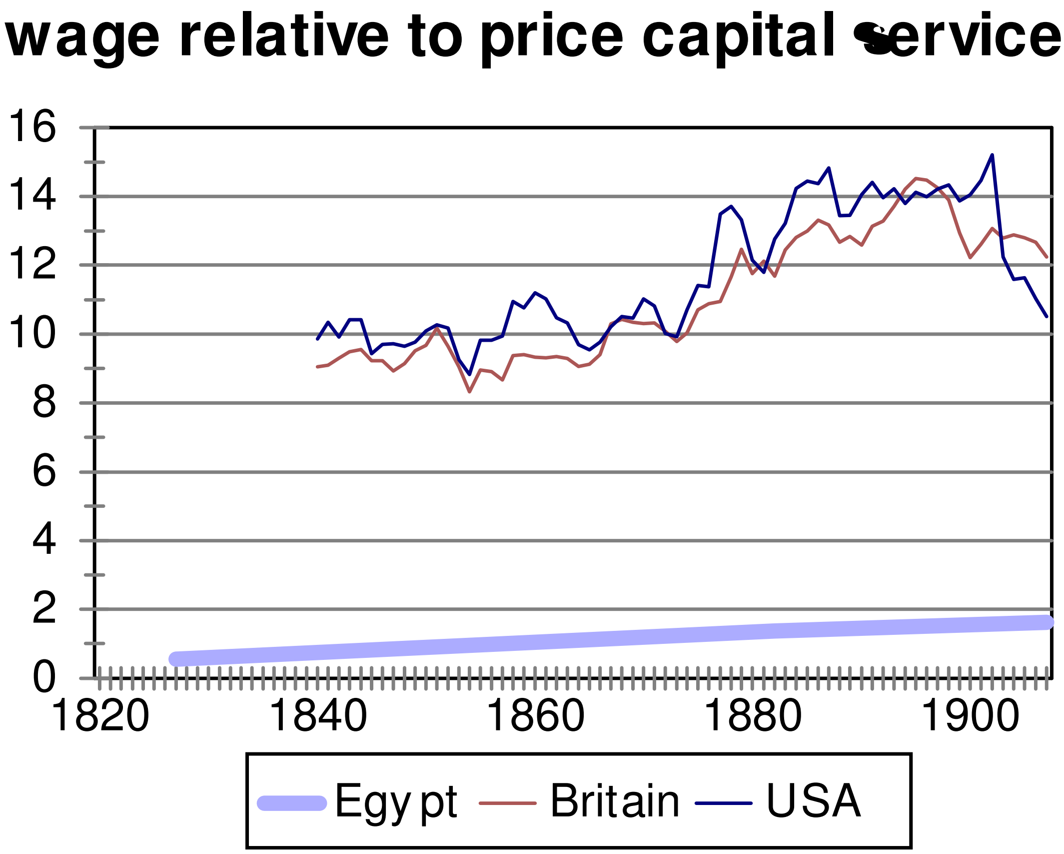

0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
1800
1820
1840
1860
1880
1900

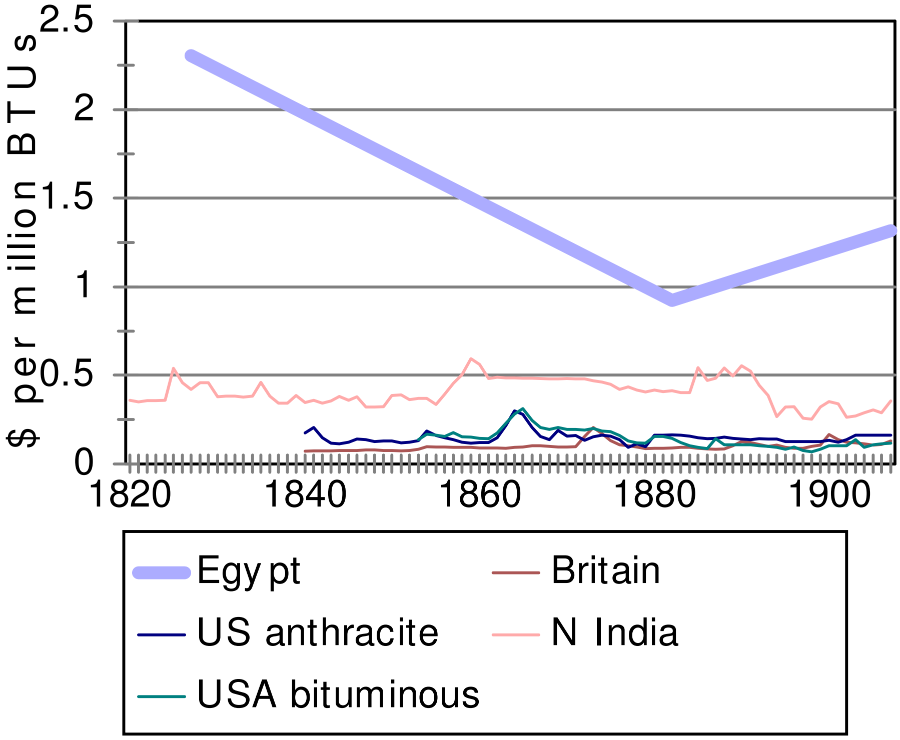
Figure 28



computed as previously.
Egyptian interest rate assumed to be 24% based on Wilkinson (1835,.p. 286–'interest of money, with security')

Figure 29

Price of Energy



sources:
Britain and USA as given previously.
Egypt–Artin (1907, p. 119), Girard (1824), Wilkinson (1835, p. 283). The price is based on the price of charcoal in Cairo. One can also compute the price from imported coal from 1889 to 1911 from import quantities and values in UK, *Statistical Abstract of Principal & Foreign Countries*.. This was a cheaper source of energy than charcoal but still twice the cost of coal energy in Britain.
India–
1761-1860:firewood in Pune.from Divekar, et al. (1989, Appendix).
1873-1910 firewood in Calcutta from *Prices and Wages in India*, 1893, 1910.


20
15
10
5
0
1820

Data Appendix: Sources for English cost of Living Index

flour

1700–1877: The underlying series is Kirkland's (1917). Its level is close to that of the naval victualling and Greenwich Hospital series reported by Beveridge (1939, 574-5 and 721-3). Comparison with some short series for retail sales in shops indicates that shop prices were about 8% higher, and the Kirkland series was increased by that proportion. (See the Manchester prices for 1810-25 for 'good seconds' in 12 lb contains in *Tables of Revenue, Population, and Commerce*, Parliamentary papers, 1833, Vol. 41, p. 165, and WRP, p. 235 (hotel prices) for 1858-69.)
1878-1902: WRP, p. 236 (households, per 7 lbs).
1903-13: Flour price extended with flour price index in UK, Board of Trade (1925, Vol. III, p. 21).

peas

1712-1902: price of peas, Greenwich hospital (Beveridge 1939, pp. 292-4, McCulloch 1880, pp. 1138-40, WRP, p. 102)
1903-13: extrapolated forward with price of haricot beans (See Allen 1994, p. 133-4).

beef
1712-1868: Greenwich Hospital 'flesh' (Beveridge 1939, pp. 293-5, McCulloch 1880, pp. 1138-40)
1869-1913: extrapolated forward with Clark's (2004) beef price series.

butter
1729-1902: Greenwich Hospital (McCulloch 1880, pp. 1138-40, WRP, p. 139)
1903-13: See Allen (1994, p. 133-4).

fuel
1700-1800: average of London coal price series and northern fuel price series. The northern fuel price series was a weighted average of a northern wood and northern coal price series. The weights shifted smoothly from 50% coal, 505 wood in 1700 to 100% coal in 1800.
1800-1913: average of London coal and northern coal price series
London coal price series: 1700-1830: coal delivered to Westminster school, Mitchell and Deane (1971, pp.479-80). Extrapolated forward with series for best coals at ships' side, London, and Wallsend, Hetton in London series from Mitchell and Deane (1971, pp. 482-3).

Northern coal price set equal to one quarter of London price.

Northern wood price–price of charcoal at blast furnace from Hyde (1977, pp. 39, 44, 58, 59, 79).

lamp oil
1700-1808: train oil Beveridge (1939, pp. 670, 672, 674, 680)
1809-1856: train oil Tooke and Newmarch (1928, Vol. II, p. 407, Vol. III, p. 297, Vol. IV, pp.

429-30, Vol. VI, pp. 163, 405-5).
1857-1876: train oil Aldrich I, pp. 211)
1877-1913: See Allen (1994, p. 133-4).

candles
1712-1867: Greenwich Hospital (Beveridge 1939, pp. 293-5, McCulloch 1880, pp. 1138-40)
1870-1913: See Allen (1994, p. 133-4).

soap
1700-68: Beveridge (1939,p. 667) many interpolations.
1769-1839: candle series
1840–1869: export price of soap from WRP, p. 207 increased by 25%, the mark-up implied by overlap with series for 1870-1913.
1870-1913: See Allen (1994, p. 133-4).

cloth
1700-1783, fustian, d/yd:
1783-1840: printer's cloth, Harley (1998, p. 78)
1841-1913: extrapolated forward with average price per yard of British exports of white or plain cotton cloth, Ellison (1886, Table 2).

Sources Referred to with Abbreviations

Hist Stat =*Historical Statistics of the United States: Millenium Edition*, Cambridge, Cambridge University Press, on line.

Saurerbeck =Sauerbeck (1886, 1907), Editor of the Statist (1918, 1938).

UK Stat Abst =United Kingdom, Board of Trade, *Statistical Abstract for the United Kingdom*, London, HMSO, various years.

US Stat Abst=United States of America, Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States*, Washington, Government Printing Office, various years.

WRP= United Kingdom, Board of Trade, *Report on Wholesale and Retail Prices in the United Kingdom in 1902, with comparative statistical tables for a series of years,* House of Commons Parliamentary Papers, 1903, Vol. 68.

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The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective
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Accessed: 23/04/2014 00:14

sometimes uses productivity data as part recent trend to convergence mainly an equilibration process among nations, or is it a sign of decline in the importance of nationalities and borders?

As we see it, the recent literature on these topics contains three broad perspectives, often implicit. One, associated

saliency of nation-states as technological and economic entities.

We do not claim that these three frameworks are neatly distinguishable, and we certainly do not claim to have answered our own questions definitively. But we believe there is value in posing of technological development and communication have become more oriented

to professional peer-group communities, which have themselves become increasingly international. technology has be

vantages, we present our diagnosis of how and why the twin leads have de-

clined since the late 1950s, and our views of what might lie ahead.

choices rather than to differences in the in plant and equipment. Thus "technol went a step further. Robert C. Allen (1983) describes this process of "collective invention" in some detail, in his study of British Bessemer steel producers in the Cleveland district, and Elting Morison (1974) describes a similar process among American Bessemer producers. The interdependencies went well beyond mere aggregation of achievements over time. As demonstrated in Ross Thomson's account of the origins and diffusion of the sewing machine (Thomson 1989), the success of new technical breakthroughs required that they mesh with prevailing complementary technologies, and that they fit into a complex chain of contingent production and exchange activities, from raw material to [redacted]

their scope has been largely defined by national borders. Why should this have been so?

In the first place, for reasons of geographical proximity. The networks described by Allen, Morison, and Thomson all involved inventors and tinkerers living in the same general area and having intimate contact with each others' inventions if not each other. Second, to the extent that technological communications networks follow in the tracks of previously established linguistic and cultural communities, it would be entirely natural for technologies to have something of a national character. Such a primary basis might well be reinforced by the existence of centralized or uniform national [redacted]

and mass marketing offered by the national rail and telegraph networks. These included new branded and packaged

consumer products (cigarettes, canned

goods, flour and grain products, beer, dairy products, soaps and drugs); mass-produced light machinery (sewing ma-

was intimately connected with the rise of the country to world leadership in the production of coal, iron ore, copper, pe-

troleum, and virtually every other major

industrial raw material of that era. To cite one important example, the breakthrough in the steel industry coincided materials. Not only did the capital stock itself embody domestic materials, but "high-throughput" methods, to maximize

tion, imply high ratios of physical materials and fuels to labor. For these reasons, although they were highly profitable given the economic conditions in the United States, American technologies were often not well adapted to other localities. Robert Allen (1979, p. 919) estimates that in 1907–09 the ratio of horsepower to workers was twice as large in America as in either Germany or Great Britain. On the other hand American

total factor productivity in this industry was only about 15 percent ahead of Great

or Germany. Per capita income had also surpassed that of Great Britain and was well ahead of continental Europe. Ameri-

ably homogeneous, and internal transportation and communications systems were well developed. Perhaps because of their relative freedom from traditional class standards, American consumers readily took to standardized products, a development which came much later in Europe. Further, this large American market was effectively off limits to European producers because of high prevailing levels of tariff protection. Although

the size of the U.S. domestic market may have been partially offset by the greater was not based on highly sophisticated product design or factory technology, but in the efficiency of its production, sales, and service organization (Fred Carstensen 1984, p. 26). Singer's ventures abroad came relatively early; but in general, the interest of American firms in foreign markets emerged belatedly, only after they had established national distribution networks (Mira Wilkins 1970). Here again, we should not think of organizational strength as an *alternative* but as a complement to advanced technology. As Alfred Chandler has argued, modern corporate enterprise tended to arise in sectors which had undergone prior technological transformation, and the new organizational form served to make more effective use of these new technological possibilities (Chandler 1977). Chandler's new comparative work, *Scale and Scope*, emphasizes that the United States had far more of these new technically and managerially advanced corporate institutions much earlier than any other country. Chandler's account of the "organizational capabilities" within large American firms is compelling and persuasive, but we would place more emphasis than he does on system-wide features of the economy, and on the ongoing development of the technology itself. The large American companies were not just efficiently streamlined organizations; they were

cated, middle managers, a phenomenon that seems to have been almost exclusively American. In his recent book Lazonick (1990) argues that American management increasingly took control of the job floor at this time, in contrast to Britain, where management had little control over the details of work. The "scientific management" movement was singularly American, and closely associated with the professionalization of management. In a fascinating recent paper, Kogut (1992) stresses the importance of basic principles of management and organization, which he argues take on a strikingly national character, or at least used to. He proposes that it was the style of management and organization, far more than the simple economies of scale and scope, that led to the pre-eminence of American corporations in the early years of the twentieth century, although the former was essential to the latter. In his empirical examination of American corporations that establishes overseas branches, Kogut found many large companies, but also some middle-sized ones. Almost all of them, however, were marked by strong adherence to the management and organizational principles described above, which formed a distinctly American style.

We note here that relatively little of the American performance during this era was based in science, nor even on

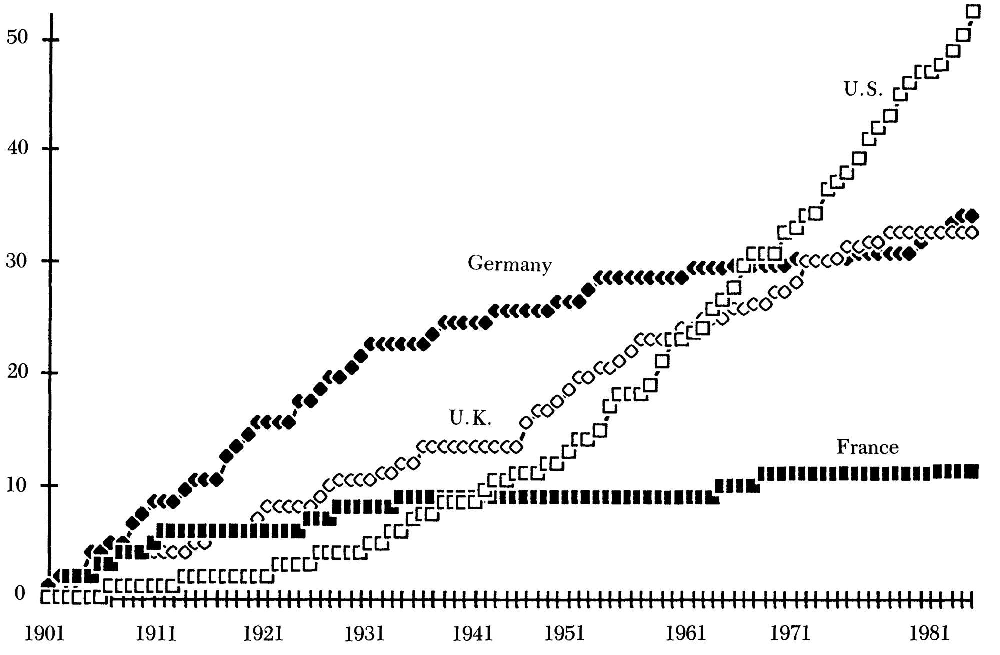


Figure 2. Cumulative Nobel Prizes in Physics and Chemistry, 1901–1990

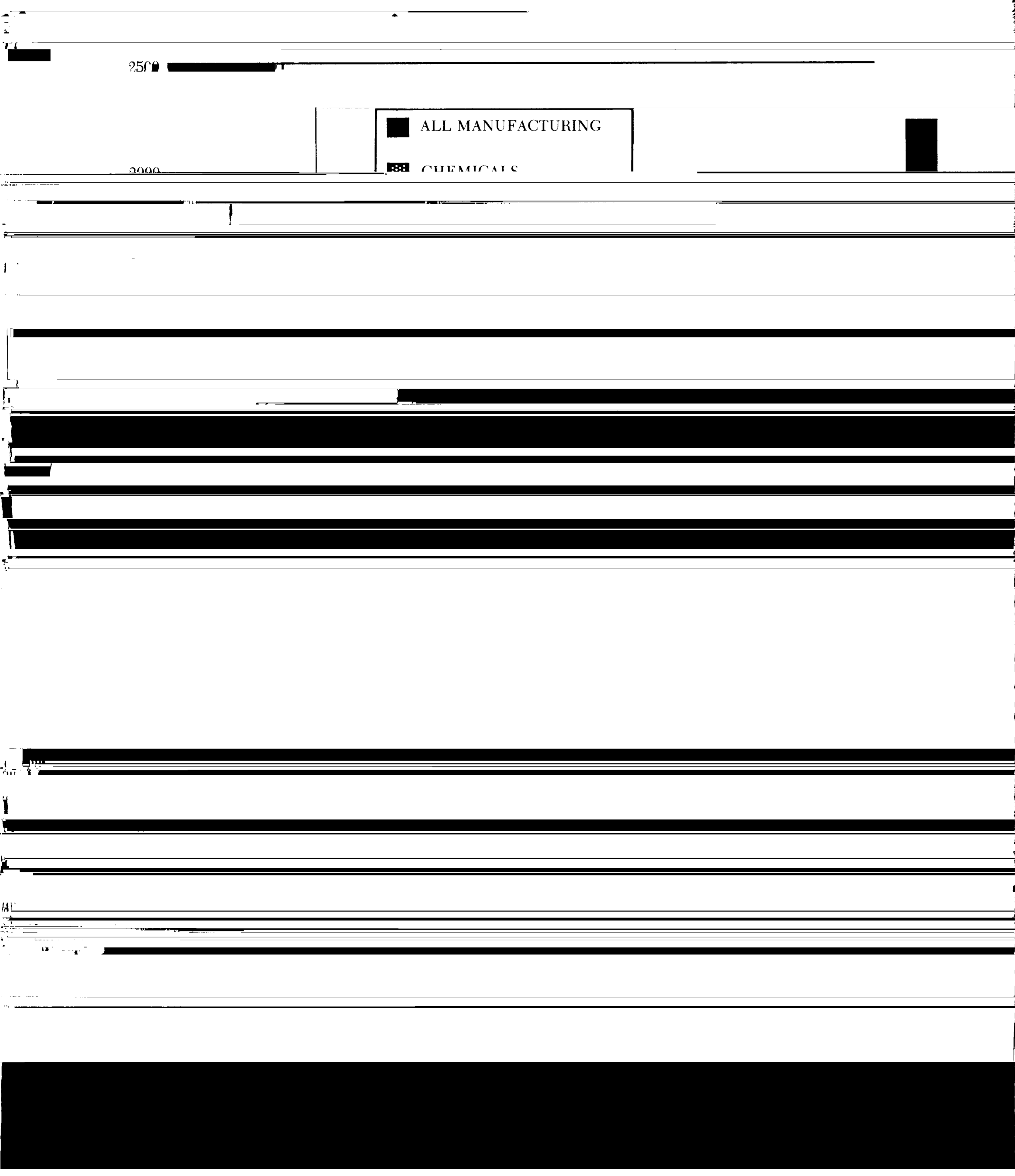
able petroleum by-products was carried out by people with only a smattering of chemical education (Nathan Rosenberg 1985, p. 43). Many of the industries in which American strength was clearest in productivity across the range of mass production industries. This lead in manufacturing combined with highly productive American agriculture to support wage rates and living standards higher ogy characterized by scale economies, capital intensity, standardization, and the intensive use of natural resources. Though the United States was not the world leader in science nor in the use of science-based technologies at that time, the country had developed much of the private organization and public infrastructure needed to operate effectively in the science-based industries that were coming into prominence.

Federal government support for uni-

practical arts dates from the Morrill Land Grant College Act of 1862. Though this act led directly to the founding of several major state universities and the strength-

openly belittled, and the areas of applied science which did show some strength in the nineteenth century were mainly those linked to state-specific economic interests, such as geology and industrial chemistry (Robert Bruce 1987). Nonetheless, by the turn of the century a network of research universities had come into being, striking an institutional balance between the demand for immediate usefulness and the ethos of academic independence espoused by the emerging

Geiger (1986), the main elements in this balance were the provision of large-scale undergraduate teaching as a means of financing research and graduate training;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R&D laboratories and had developed the capacity to produce a full range of industrial chemicals and a wide range of fine chemicals (Noble 1977; Hounshell and John Smith 1988). These companies were able to draw upon the newly emerging specialty of chemical engineering, an

American professional hybrid. They were

thus organizationally well positioned to take advantage of the cutoff of trade with the Germans during World War I, and to respond to the need to provide a variety of products for the military. The abro-

ples of innovations which were European in origin, but whose development progressed most rapidly in the United States because of the scale economies accessible in the American market (Hans-Joachim Braun 1983).

III. *The Interwar Period*

In the 1920s and 1930s, American industry consolidated its position of leadership in mass production industries, while joining these longer-term strengths to organized research and advanced train-

Figure 4. Shares of World Motor Vehicle Exports, 1907–1934

Source: James Foreman-Peck (1982, p. 868).

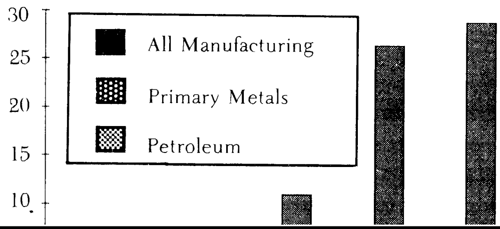
terials, and fuels. The distinct lead of American producers over French and British rivals really dates only from the

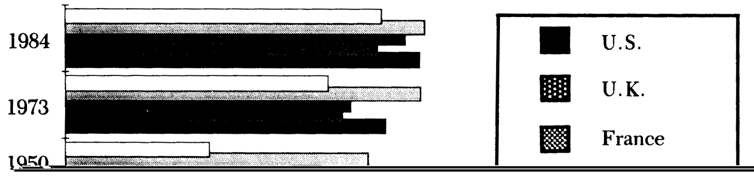
American methods would surely have continued, however, either by imitation or by direct foreign investment, if it had not been interrupted by World War II.

In many ways a more lasting and significant basis for technological leadership was established in those industries that were able to marry mass production

[illegible]

search, such as the electrical industries and chemical engineering. Though the fundamental scientific breakthroughs in electricity had come earlier, the interwar period saw the realization of this potential through full electrification of factories and households. Paul David (1989) has called attention recently to electrification as an example of an innovation whose ment only in 1920. The American surge was also closely associated with a shift in the basic feedstock for chemical plants from coal to petroleum, a primary product in which the U.S. dominated world production. As technology developed, the production of organic chemicals was

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which that training is integrated into the process of improving the technology of operating firms. In interwar America that [illegible]

coordination was advanced to a high state of refinement, as the curricula of educational institutions came to be closely adapted to the requirements of the "positions" that graduates would be taking. [illegible]

and vice versa (Lazonick 1990, pp. 230–32). A 1921 survey made note of the "progressive dependence [of corporations] upon higher education institutions as sources of employee supply . . . the [illegible]

have the requisite "social capabilities." Abramovitz (1986) has suggested that these include, prominently, a well-edu- [illegible]

cated work force including competence at the top in the major sciences and technologies of the era, adequate firm management and organization, and financial institutions and governments capable of [illegible]

keeping their fiscal and monetary houses in order. It is arguable that during the interwar period the major European economies were not significantly outmatched by the United States in these [illegible]

American scene, were less attractive to European firms facing their own home markets. Convergence is far from an automatic phenomenon. It requires not only that the lagging nations have requisite social capabilities, but also that their firms face an economic and political environment conducive to adopting technology used in the leading country. Rather than refining procedures for testing the "convergence hypothesis" as a universal tendency, it seems more fruitful to exam-

are advanced through community efforts. But to a far greater extent, chemical and electrical technologies, and nowadays fields like aircraft and semiconductors, require university-trained scientists and engineers, engaged in teamwork aimed to achieve new and better production process designs, through activities that have come to be called research and development. As a result, possession of university training, and involvement in organized R&D define the relevant tech-universities doing world class research. But the U.S. was not dominant in high technology industries.

B. *The Surge of Investment in R&D*

tists and engineers.

The expansion of supply was also supported, and in part propelled, by major increases in demand, from several sources. A small but important fraction was employed by the rapidly expanding

World War II changed the context. Victory brought a new sense of confidence and pride in America's strength, an awe for the power of science and technology engendered by their role in win-

U.S. university research system. The scientists and engineers who had engaged in the war effort had striking success in their argument that university science warranted public support, and during the


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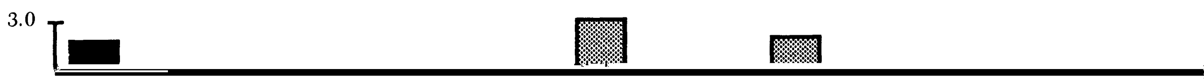
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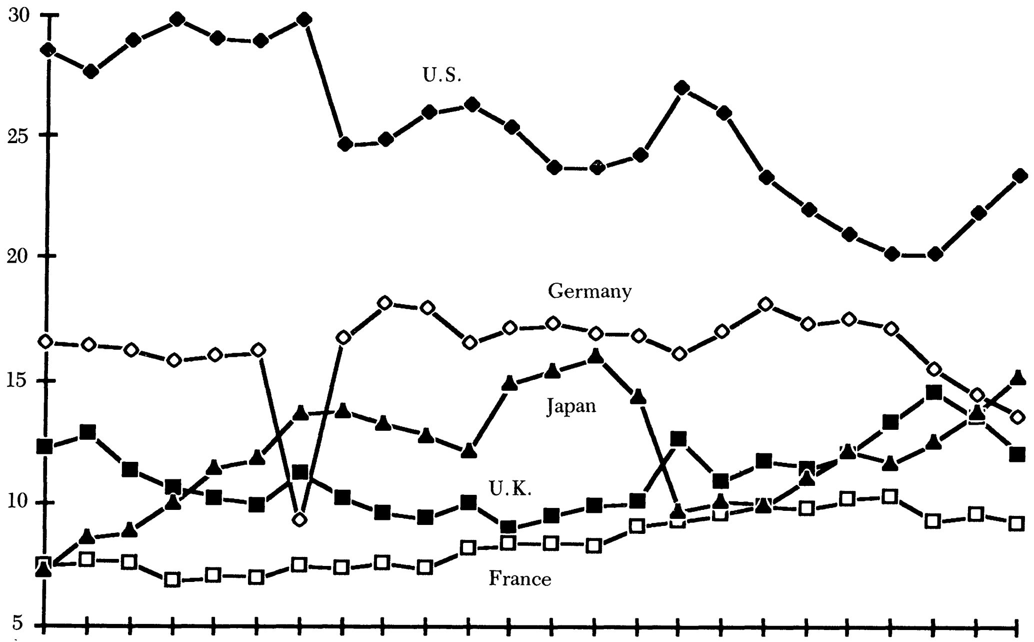
U.S. funded research aimed at developing a rapid computer. It is clear enough that during and shortly after the war, by which time the feasability of electronic computers had been established, the United States vastly outspent other governments in bringing this embryonic technology into a form that was operational in terms of military needs. Several major research universities were involved in the effort, notably MIT. IBM and AT&T participated actively. Early assessments were that the nonmilitary demand for computers would be small. It was apparent by 1960, however, that nonmilitary demand would be large, and it also turned out that the design experience that the major U.S. companies had had in their work on military systems was were of high value to the military set companies up to produce items for civilian products.

By the mid 1960s the American lead in the new high technology industries, like the old lead in mass production industries, was widely taken as a fact of life, a source of pride for Americans, and of concern to Europeans, but not readily subject to change. Jean Jacques Servan Schreiber pointed to the U.S. lead with alarm, arguing that if Europeans did not act quickly to catch up, they would be permanently subservient to the Americans. His diagnosis of the sources of American strength was rich and complex, if in places ironically amusing in the face of subsequent developments. He pointed not only to American investments in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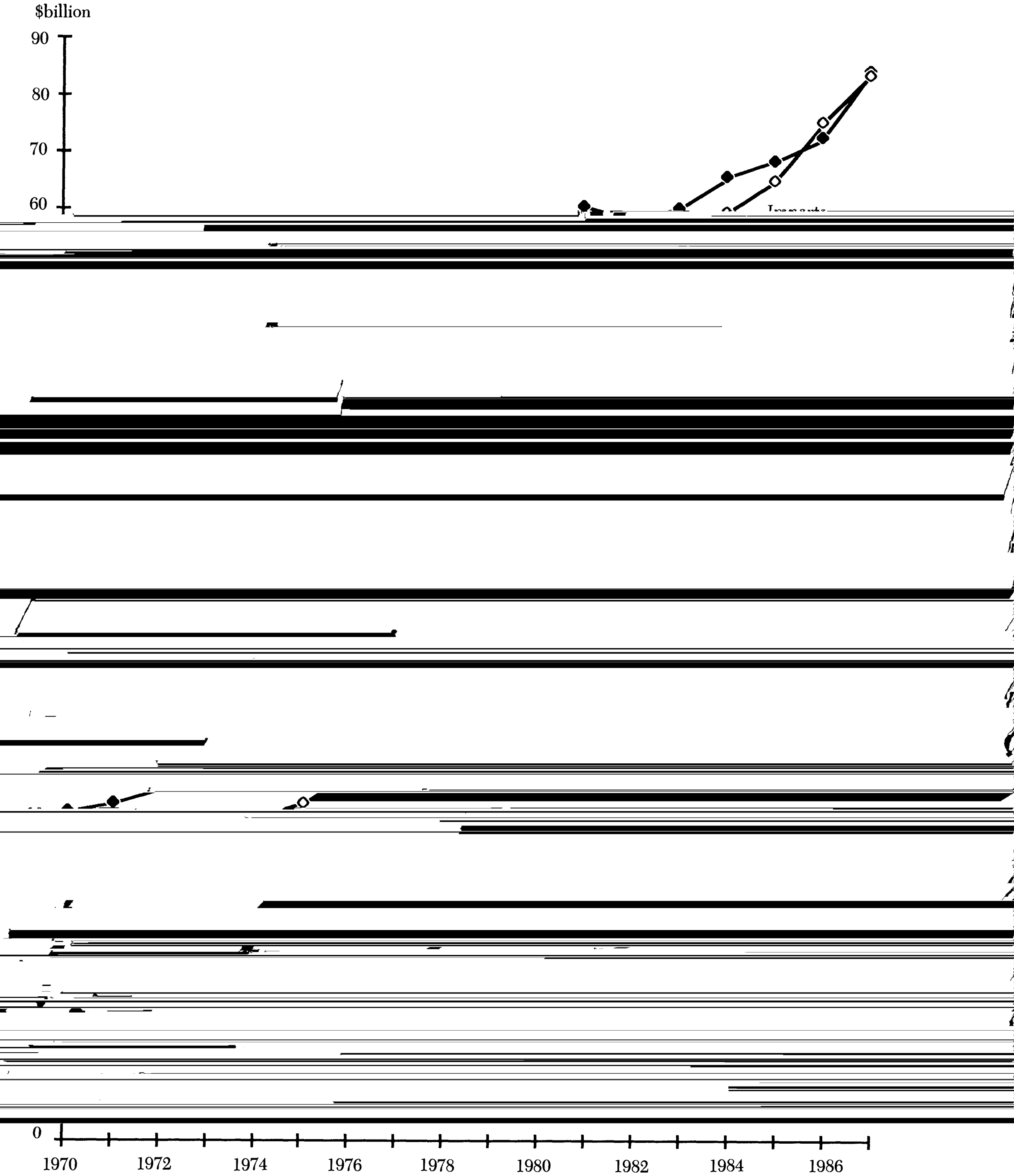

Figure 11. U.S. Trade in High-Technology Products, 1970–1987

Source: U.S. National Science Board (1989, Appendix Table 7–14)

since the late 1960s. That is so, but it is also true of the major European countries and the U.S. rate has partially recovered since 1980. We do not know what forces

on national patenting show a similar pattern. By and large U.S. export shares have persisted in industries where U.S. patenting has held up, and declined export and patenting leader in many industries connected with agricultural products and others based on natural resources.

Thus beneath the surface of general productivity convergence, there is a much more variegated picture. U.S. performance continues to be strong in several of the most R&D intensive industries, and those connected to natural resources. It has declined in many of the industries—like automobiles, consumer electrical products, and steel making—where the U.S. had a dominant world

icant rise in the percentage of manufactured products exported and imported in virtually all major industrial countries. Between 1960 and 1980, U.S. imports roughly doubled as a fraction of GNP. In France, Germany, and the U.K. taken as a group, the ratio of imports to GNP increased by about fifty percent. It grew by a quarter in Japan. All of these ratios were substantially higher for manufacturing alone. Thus, over this period, efficient companies producing attractive products increasingly faced a world rather than a national market. At the companies have done the same, on a larger scale.

The internationalization of business

tion of international trade statistics. For

tions have often tried to keep national technologies within their borders, however futile these efforts may often have

gists from different countries have com-

Internationalization of business is an

important part of this story. It is not just that foreigners can learn what American engineers can learn by going to American

universities. European engineers can ob-

in their home countries and purchase

States in making those big investments

in education and training, and R&D. The convergence in scientists and engineers in R&D as a fraction of the workforce,

and in R&D as a fraction of GNP, shown in Figures 8 and 9, is an essential part

of, and a complement to, the internation-

There are several reasons for the diminished importance of military R&D as a source of technological advantage outside the military field. First, while ini-

tially civilian demands for computers, semi-conductors, and jet aircraft had lagged behind military demands by the

mid-1960s the civilian market for these

new and stemmed from investments in higher education and in research and development, far surpassing the levels of other countries at that time. Several fac-

tors lay behind the erosion of these twin leads. The most basic of these is that over the post World War II era, commodity

and resource trade, business and finance "public good," allowing only that there

may be some friction in moving it around. Instead, as we have argued,

much of what is involved in mastering a

technology is organization-specific in-

vestment and learning. Hands-on tech-

good than a public good. For that reason, if the economic conditions and incentives facing firms in different countries differ

technology that will stay contained

within national borders for very long in a world where technological sophistica-

tion is widespread and firms of many na-

tionalities are ready to make the invest-

ment needed to exploit new generic

A closely related observation is that a well-educated labor force, with a strong cadre of university trained engineers and educational levels at leading universities

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rator than capital-intensity or wage levels, which one might take to be more fundamental). What is striking is the decline over time in this relative intensity, entirely concentrated on the import side. Here we have another likely contributor to the trend toward the Leontief Paradox. Employment of women and child workers in American manufacturing was concentrated in only a handful of industries: canning, preserving, and freezing on the one hand, and textiles and apparel on the other. The first remained a strong net export category, but in the second, the growth of imports was increasingly stifled by tariff barriers, particularly after the 1922 Fordney-McCumber tariff.

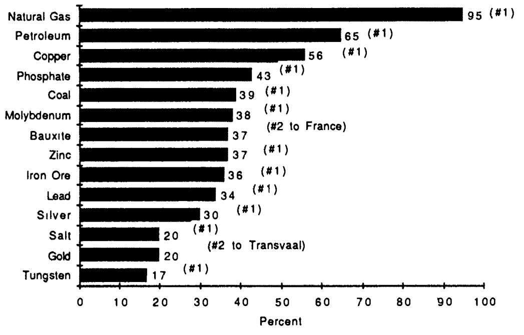
Easily the largest factor-intensity differentials were in nonreproducible natural resources, as shown in Table 3. Recall that these are weighted averages for manufactured goods alone and exclude entirely exports of agricultural goods and crude materials. We still find not only that U.S. exports had far higher natural resource content than imports but that this trend was growing both absolutely and relatively over *precisely the historical period when the country was moving into a position of world industrial preeminence*. Using the more inclusive index of direct and indirect use, the resource intensity of manufacturing exports grew by 64 percent to its peak, and even after a slight decline, the 1928 level was still nearly 50 percent higher than that of 1879. The figures confirm a little-noticed analysis by Robert E. Lipsey (1963): "The composition of manufacturing exports has been changing ceaselessly since 1879 in a fairly consistent direction—*away from products of animal or vegetable origin and toward those of mineral origin*" (p. 59; emphasis added).

Table 3 also clearly shows that the resource intensity of imports was growing as well, and that signs of a reversal in the relative balance are detectable even in 1928. By 1940, the historic U.S. specialization had virtually disappeared. This is the modern trend identified first and most clearly by Vanek (1963), of no small importance for interpreting recent American industrial history. But because of his choice of dates and coverage, Vanek missed the fact that the declining phase had been preceded by a long epoch of rising natural resource intensity, of no less importance in interpreting the country's place in the industrial world.

B. *Regression Analysis*

Simple factor-intensity comparison between exports and imports is not conclusive in the presence of more than two factors (Edward Leamer, 1980). An apparent pattern of specialization may merely represent the effect of a third factor, acting as a complement or substitute for one of the other two. This section therefore follows the general format of Crafts and Thomas (1986) and earlier studies in the international trade literature by regressing the net trade balance for each industry against measures of factor intensity. On no account should the coefficients be viewed as structural estimates within a Heckscher-Ohlin framework (compare Leamer and Harry P. Bowen, 1981). They are best considered as descriptive summaries of trade patterns in a multifactor setting, a way of pointing out areas of distinctive strength and tracking changes over time. Because the industry or commodity groupings are inevitably arbitrary, R^2 levels by themselves are not particularly meaningful; but t-tests on individual coefficients are a reasonable standard for confidence in that factor's contribution, and R^2 comparisons across years should reflect changes in the tightness-of-fit according to factor content. Following Crafts and Thomas, all reported standard errors were recomputed according to the procedure suggested by Hal White (1980) to adjust for heteroskedasticity in the error structure. The effect generally is to reduce the larger t-ratios, so that what is reported here is a conservative version of the account that leaps from the data using ordinary-least-squares. The results are robust to changes in precise variable definitions and to transformations of the coefficients into factor shares at various discount rates. Trade values have been deflated by export and import price indices (Lipsey, 1963, pp. 142–143; 1913 = 100) so that coefficients may be compared across years.

CHART 3. U.S. MINERAL OUTPUT, 1913: PERCENTAGE OF WORLD TOTAL



Source: Smith (1919), using data from U.S. Geological Survey (1913).

of world totals in 1913. The 95 percent of world natural gas and 65 percent of world petroleum were perhaps of somewhat less economic moment in 1913 than they would be at a later date. But copper, coal, zinc, iron ore, lead, and other minerals were at the core of industrial technology for that era, and in every single case the United States was the world's leading producer by a wide margin. In an era of high transport costs, the country was *uniquely* situated with respect to almost every one of these minerals. Even this understates the matter. Being the number one producer in one or another mineral category is less important than the fact that the *range* of mineral resources abundantly available in the United States was far wider than that in any other country. Surely the link between this geographical status and the world success of American industry is more than incidental. Cain and Paterson (1986) find that between 1850 and 1919, material-using technological biases were significant in nine of twenty American sectors, including those with the strongest export performance, such as petroleum, metals, and machinery.

Resource abundance was a background ingredient in many other distinctively American industrial developments. Continuous-process, mass-production methods, closely associated with modern forms of corporate organization in the analysis of Chandler (1977), were characterized by "high throughput" of fuel and raw materials relative to labor and production facilities (compare Michael Piore and Charles Sabel, 1984). Oliver Williamson (1980) notes that cheap, reliable sources of energy and heat were crucial to this development. Coal was of strategic early importance as a direct source of heat and power, and at a later point as a source of thermal energy for electricity, essential to the efficiency of the moving assembly line and other quasi-flow processes. Alex Field (1987) points out that organizational innovations of this type may be considered "capital-saving" overall, even though firm-level capital requirements were high. In export markets, contemporary comments emphasized non-price competition and particularly the short delivery lags on the part of U.S. suppliers (Nicholas, 1980, pp. 581-587). Quick delivery is a feature one would expect to see where exports have a "vent-for-surplus" quality, because of the length of a production run on a standardized item. In addition, American producer and consumer goods were often specifically designed for a resource-abundant environment. Some of the adjustment problems of U.S. auto companies in recent years stem from their decades of specialization on large, fuel-using cars. There was a parallel problem facing U.S. locomotive manufacturers in the 1920s, who found their foreign sales handicapped by their design for standard-gauge rails, heavy motive power, and heavy train loads (*Markets of the United States*, p. 71).

The emergence of cheap American steel at the end of the nineteenth century was particularly important. Whereas S. J. Nicholas (1980) suggested that the fall in relative U.S. machinery prices was misleadingly proxied by iron and steel prices, it may be that the world success of American engineering goods was buoyed by exactly that development. Table 6 shows the major role played by iron and steel exports over the half-century under discussion. If we aggregate the three headings under which iron and steel products were listed, we find that their share of U.S. manufacturing exports grew steadily, from 5.5 percent in 1879 to 37.5 percent in 1929. If we add in one other

The British Industrial Revolution in Global Perspective:

How Commerce Created
The Industrial Revolution and Modern Economic Growth

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The Industrial Revolution is one of the most celebrated watersheds in human history. It is no longer regarded as the abrupt discontinuity that its name suggests, for it was the result of an economic expansion that started in the sixteenth century. Nevertheless, the eighteenth century does represent a decisive break in the history of technology and the economy. The famous inventions–the spinning jenny, the steam engine, coke smelting, and so forth–deserve their renown[1], for they mark the start of a process that has carried the West, at least, to the mass prosperity of the twenty-first century. The purpose of this essay is to explain why they occurred in the eighteenth century, in Britain, and how the process of their invention has transformed the world.

The last sentence introduces an important theme of this essay, which is the Britishness of the industrial revolution. Until recent decades, this was axiomatic: The industrial revolution started in Britain with the inventions that created factory textile production, the shift to coal and coke in the iron industry, and the perfection of the steam engine. Economic growth on the continent occurred when these innovations were adopted there. This schema was first called into question by national income studies which indicated that the pace of economic growth in France was not very different from that in England despite the differences in economic structure–hence, the thesis of O'Brien and Keyder (1978) that there were "two paths to the twentieth century." This critique has gathered force with the recent emphasis on the Scientific Revolution, a pan European phenomenon, as the cause of the Industrial. While these contributions broaden our understanding of the industrial revolution, it is our contention that it really was fundamentally British.

Explaining the industrial revolution is a long standing problem in social science, and all manner of prior events have been adduced as causes (Hartwell 1967, Mokyr 1999). The role of political structure–parliamentary checks on the executive, the security of property rights, the flexibility of the legal system–is at the centre of much current discussion. According to this view, the dramatic changes of the late eighteenth century can be traced back to the Glorious Revolution of 1688 that consolidated parliamentary ascendancy, minimal government, and secure property rights. Supposedly, these legal changes created a favourable climate for investment that made the industrial revolution possible (North and Weingast 1989, De Long and Schleifer 1993, LaPorta, Lopez-de-Silanes, Schleifer, Vishny 1998, Acemoglu, Johnson, and Robinson 2005). This interpretation, however, has some weaknesses: Studies of banking and interest rates fail to detect any structural break after 1688, so the improved investment climate is not manifest in anything financial (Clark 1996, Epstein 2000, Quinn 2001). Property rights were at least as secure in France–possibly, in China for that matter–as in England (Hoffman, Postel-Vinay, Rosenthal 2000, Pomeranz 2000). Indeed, one could argue that France suffered because property was too secure: Profitable irrigation projects were not undertaken in Provence because France had no counterpart to the private acts of the British parliament that overrode property owners opposed to the enclosure of their land or the construction of canals or turnpikes across it

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[1] There has been a debate about the breadth of technological progress during the industrial revolution with Crafts (1985), Harley (1999), Crafts and Harley (1992, 2000) arguing that productivity growth was confined to the famous, revolutionized industries in the period 1801-31, while Temin (1997) has argued that many more industries experienced productivity growth. Whatever one believes about 1801-31, it is clear that many non-revolutionized industries experienced productivity growth between 1500 and 1850. The incentives to invent discussed in this paper applied to all industries, not just the famous ones I discuss here.

(Rosenthal 1990, Innes 1992, 1998, Hoppit, Innes, Styles 1994). The Glorious Revolution meant that "despotic power was only available intermittently before 1688, but was always available thereafter" (Hoppit 1996, p. 126). Finally, taxes were higher in Britain than across the Channel (Mathias and O'Brien 1976, 1978, Hoffman and Norberg 1994, Bonney 1999). In any event, it was a long stretch from the excise tax on beer or the cost of foreclosing on a defaulting mortgagor (not actually a cheap process in eighteenth century England) to Watt's invention of the separate condenser. An explanation of the technological breakthroughs has to be more focussed on technology than is usual in constitutional discussions.

The industrial revolution was fundamentally a technological revolution, and progress in understanding it can be made by focussing on the sources of invention. This subject has been opened up for economists by the researches of Joel Mokyr (1990, 2002) , and I will examine his views on macroinventions, the scientific revolution, and the industrial enlightenment. While Mokyr takes us forward by emphasizing the social context in which invention occurred and the importance of information flows, we can sharpen our understanding by concentrating on the incentives faced by inventors and the context in which they worked. This approach indicates that the reason the industrial revolution happened in Britain, in the eighteenth and nineteenth centuries, was not because of luck (Crafts 1977) or British genius or culture or the rise of science. Rather it was Britain's success in the international economy that set in train economic developments that presented Britain's inventors with unique and highly remunerative possibilities. The industrial revolution was a response to the opportunity.

What commercial success did for Britain was to create a structure of wages and prices that differentiated Britain from the continent and, indeed, Asia: In Britain, wages were remarkably high and energy cheap. This wage and price history was a fundamental reason for the technological breakthroughs of the eighteenth century whose object was to substitute capital and energy for labour. Scientific discoveries and scientific culture do not explain why Britain differed from the rest of Europe. They may have been necessary conditions for the industrial revolution, but they were not sufficient: Without Britain's distinctive wage and price environment, Newton would have produced as little economic progress in England as Galileo produced in Italy.

There were, however, important features of British popular culture that distinguished the country from much of the continent, and those features–greater literacy and numeracy–underpinned the technological achievements of the eighteenth century. They were not autonomous movers, however, but were themselves consequences of the economic development that preceded the industrial revolution and that produced the high wage, cheap energy economy. Underlying the technological breakthroughs of the industrial revolution was Britain's commercial and imperial expansion of the seventeenth and eighteenth centuries, which was the cause of the peculiar wage and price pattern. The state policies that mattered most were Mercantilism and Imperialism.

The working assumption of this paper is that technology was invented by people in order to make money. This idea has important implications. First, inventions were investments where future profits had to offset current costs. The technical discoveries were either new products or reductions in the cost of making existing products. In either case, the profitability calculation governing invention depended on the prices of the products and the prices of the various inputs. As we will see, labour was particularly expensive and energy particularly cheap in Britain, so inventors in Britain were led to invent machines that substituted energy and capital for labour. Second, the balance between the profits and the costs of an invention depended on the size of its market. The scale of the mining industry in eighteenth century Britain was much greater than anywhere else, so the return to inventing improved drainage machinery (a.k.a. the steam engine) was greater in Britain than in France or China. Third, patents that allow the inventor to capture all of the gains created by his invention raise the rate of return and encourage invention. Indeed, North and Thomas (1973) have argued that it was better property rights for knowledge that explain the inventions of the industrial revolution. However, the English patent law was enacted in 1624 and attracted little interest for much of the seventeenth century, so the explanation of the inventions of the eighteenth turns on the greater incentive to invent rather than on a change in law that met an existing, latent demand for patenting.[2] Fourth, in the absence of patents, the incentive to invent was limited to the gains the inventor could realize in his own firm, and these were likely to have been small. Firms could increase the return to inventing by learning from each other. In that case, they divided the costs and pooled the gains. Indeed, collective invention was important before private invention took off in the eighteenth century and has remained a complement to the present day (Allen 1983, Epstein 1998, 2004, Nuvolari 2004a, 2004b).

Britain–a high wage, cheap energy economy

Since invention was an economic activity, its pace and character depended on factors that affected business profits including, in particular, input prices. Why the industrial revolution happened in eighteenth century Britain is easier to understand if we compare wage rates and energy prices in the leading economies of the day. In these comparisons, Britain stands out as a high wage, cheap energy economy.

Our views of British wages are dominated by standard of living debate. Even optimists who believe the real wage rose in the Industrial Revolution accept that wages were low in the eighteenth century. They were certainly lower than they are today, but recent research in wage and price history shows that Britain was a high wage economy in four senses:

1. At the exchange rate, British wages were higher than those of its competitors.
2. High silver wages translated into higher living standards than elsewhere.
3. British wages were high relative to capital prices.
4. Wages in northern and western Britain were exceptionally high relative to energy prices.

These trends are illustrated in Figures 1-4. These figures were constructed from databases of wages and prices assembled from price histories written since the middle of the nineteenth century. The typical price history is based on the archives of an institution that lasted for hundres of years–colleges and hospitals are favourites. The historian works through their accounts recording the quantity and price of everything bought or sold and draws up tables of the annual averages. Usually prices are found for a range of agricultural and food stuffs as well as cloth, fuel, candles, building materials, implements, and a miscellany of other items. Wages and salaries are often also recorded. The commodities are measured in local weights and measures, and prices are stated in local units of account, and these must be converted to international standards. Prices histories have been written for

[2]On the operation of the English patent system, recent research includes: Dutton (1984), MacLeod (1986, 1988), Nuvolari (2004a), Khan (2005), Khan and Sokoloff (2006).

many European cities, and the research is being extended to Asia. By putting all of this material in the computer, international comparisons are becoming possible for the first time, and they are redefining our understanding of economic history. In particular, they throw new light on the origins of the Industrial Revolution, as we shall show.

Figure 1 shows the history of nominal wages of building labourers in leading European and Asian cities from the middle ages to the industrial revolution. The various units of account in which the data were recorded have been converted to grams of silver since silver coins were the principal medium of exchange. The figure shows that the divergence in nominal wages was minimal in Europe at the end of the late middle wages. There was little wage inflation subsequently in eastern Europe. Wages in western Europe rose during the price revolution (1550-1620). Thereafter, there was a three way split with silver wages falling in southern Europe, levelling out in the Low Countries, and continuing to rise in London. From the late seventeenth century onwards, London wages were the highest recorded.

Figure 1

London wages rose above those elsewhere in Britain in the sixteenth century. By the late seventeenth, however, wages in southern English towns like Oxford were rising to close the gap. Wage movements in northern England were more erratic: In the late seventeenth century builder's wages in cities like York were as high was those in Oxford. Wage growth ceased in the north in the early eighteenth century, however, so the region fell behind the south in nominal wages although the level was still higher than in most parts of the European continent. Fast wage growth towards the end of the eighteenth century brought the north to the same level as the south, however, and all parts of England had exceptionally high silver wages (Gilboy 1934, Allen 2001, 2003).

Comparisons with Asia further emphasize the high wages in eighteenth century Britain. In Beijing, Canton, Japan, and Bengal, labourers earned between one and two grams of silver per day–less than half the wage in central or eastern Europe and a smaller fraction of earnings in the advanced economies of the northwest of the continent (Özmucur and Pamuk 2002, Allen 2005, Allen, Bassino, Ma, Moll-Murata, van Zanden 2005, cf. Allen, Bengtsson, Dribe 2005).

Did Britain's high nominal wages translate into high living standards or were they offset by high prices in Britain? To explore this issue, welfare ratios have been computed for leading cities. Welfare ratios are defined to be full time annual earnings[3] divided by the cost

[3]European building workers were paid by the day, and I assume that 250 days was a full year's work, making allowance for Sundays, religious holidays, and erratic employment.

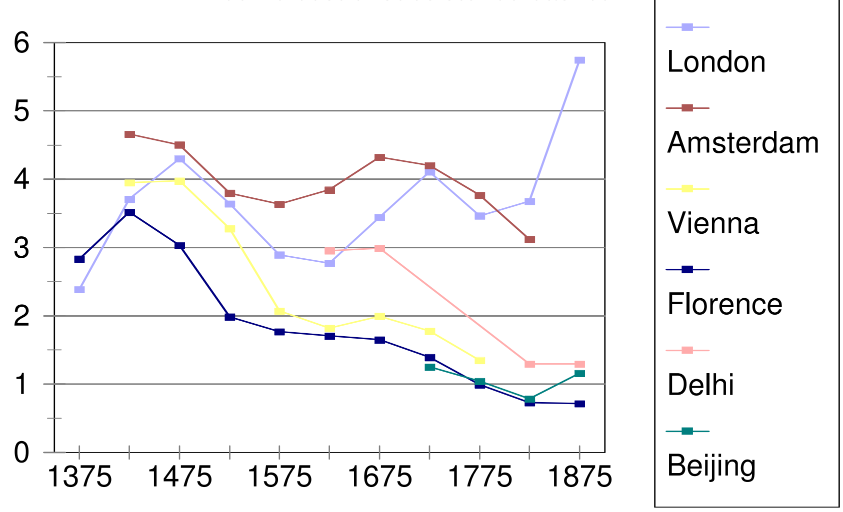
of a basket of consumer goods sufficient to keep a family at a specified standard of comfort–in this case at minimal subsistence. Baskets are constructed with most spending on the grain that was cheapest in each locality (e.g. oats in northern Europe, polenta in Florence, sorghum in Beijing, millet in Delhi). Very small portions of meat, peas or beans, butter or oil, cloth, fuel, and housing are also included. Consumption is set at the low level of 1920 kilocalories per day for an adult male with other family members proportioned accordingly. Calculations with baskets corresponding to a more affluent lifestyle have also been undertaken, and the relative rankings are unchanged.

Figure 2 plots the welfare ratios for the cities in Figure 1. The population decline caused by the Black Death meant that real incomes were high everywhere in the fifteenth century. Welfare ratios in London and the Low Countries were trendless across the early modern period, although there were oscillations in the series. Moreover, fully employed workers in these regions earned three to five times the cost of the subsistence lifestyle. They spent their extra income on a superior diet (with bread, beer, and much more meat) and more non-food consumer goods including some of the luxuries of the 'consumer revolution' of the eighteenth century (Shammas 1990, McKendrick, Brewer, and Plumb 1982, de Vries 1993, Fairchilds 1993, Weatherill 1996, Berg and Clifford 1999, Berg 2005). In contrast, real living standards fell dramatically across the continent, reaching a level of about one. In eighteenth century Florence and Vienna, fully employed building workers earned only enough to maintain their families at rock bottom subsistence. There was no surplus for bread, meat, beer, or wine let along imported luxuries. Real wages also fell sharply in provincial England in the sixteenth century, but even at the trough labourers in Oxford earned at least 50% more than bare bones subsistence. The nominal wage inflation of the late seventeenth century meant that welfare ratios in Oxford were between 2.5 and 3.0 in the eighteenth century.

Figure 2

Subsistence Ratio for Labourers

income/cost of subsistence basket



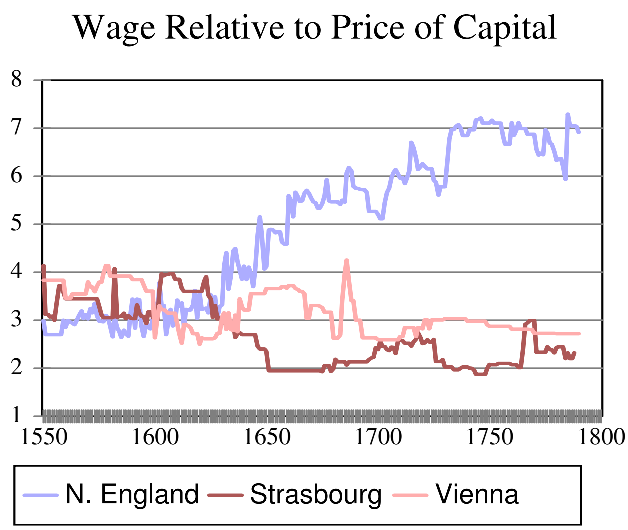
If we extend the comparisons of living standards to Asia, English performance looks even more impressive. Low silver wages in the East were not counterbalanced by even lower food prices. Welfare ratios for labourers in Canton, Beijing, and Japan were about one in the eighteenth and nineteenth centuries–as low as those in the backward parts of Europe. Mass demand for manufactures was very limited across Asia, since most consumer spend was directed towards basic necessities.

Many Asian wages are based on monthly earnings, and I assume employment for twelve months.

The earnings of craftsmen (carpenters, masons, and so forth) followed the same trends as labourers in all countries. Skilled workers, however, earned more than the unskilled, so their welfare ratios were higher everywhere. Craftsmen in London or Amsterdam earned six times what was required to purchase the subsistence basket, while their counterparts in Germany or Italy only 50% more than that standard. Craftsmen in northwestern Europe spent much of their surplus income on more food and better quality food. Nonetheless, the mass market for consumer goods was much larger in Britain and the Low Countries than in most of Europe.

A third sense in which Britain was a high wage economy was in terms of the wage rate relative to the price of capital. Figure 3 plots the ratio of a building labourer's daily wage relative to an index of the rental price of capital in northern England, Strasbourg, and Vienna. The rental price of capital is an average of price indices for iron, nonferrous metals, wood, and brick multiplied by an interest rate plus a depreciation rate. Strasbourg and Vienna were chosen since there are long series of wages and prices for those cities, and their data look comparable to those of most of Europe apart from the Low Countries. The series are 'PPP adjusted' so that we can compare across space as well as over time.

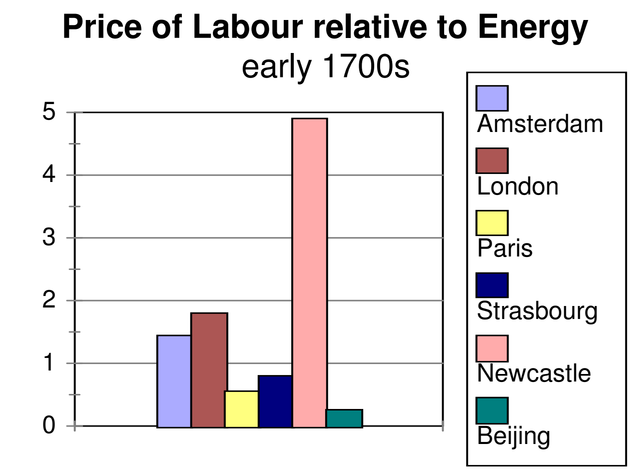
Figure 3



The ratio of the wage relative to the price of capital was trendless and similar in all cities from 1550 to 1650. Then the series diverged. In England, labour became increasingly expensive relative to capital from 1650 onwards. This rise reflects the inflation of nominal British wages at the time. In contrast, the ratio of the wage to the price of capital declined gradually in Strasbourg and Vienna across the seventeenth and eighteenth centuries.

The different trajectories of the wage-rental ratio created different incentives to mechanize production in the two parts of Europe. In England, the continuous rise in the cost of labour relative to capital led to an increasingly greater incentive to invent ways of substituting capital for labour in production. On the continent, the reverse was true: Factor price movements led businesses to search for ways of substituting increasingly cheap labour for capital. It was not Newtonian science that inclined British inventors and entrepreneurs to seek machines that raised labour productivity but the rising cost of labour.

Figure 4



Finally, there is a fourth sense in which labour was costly in industrializing Britain. That involves a comparison of wages to the price of fuel. Figure 4 is bar graph of the ratio of the building wage rate to the price of energy in the early eighteenth century in important cities in Europe and Asia. In this ratio, the price of a kilogram of fuel was divided by its energy content, so energy prices are expressed as grams of silver per million BTUs. The ratio is calculated for the cheapest fuel available in each city–coal in London and Newcastle, peat in Amsterdam, charcoal or fire wood in the other cities.

Newcastle stands out as having the highest ratio of labour costs to energy costs in the world. To a degree the high ratio reflects high British wages, but the low cost of coal was the decisive factor. Indeed, a similar ratio characterized the situation on all of the British coal fields and in the industrial cities (Sheffield, Birmingham, and so forth) built on them. The only place outside of Britain with a similarly high ratio of labour to energy costs was probably the coal mining district around Liège and Mons in present day Belgium. The high cost of labour relative to fuel created a particularly intense incentive to substitute fuel for labour in Britain. The situation was the reverse in China were fuel was dear compared to labour. The Chinese invented very large kilns for firing their pottery because such kilns had a high ratio of volume to surface area and so conserved heat. The reverse was true in Britain where kilns were small and thermally inefficient.

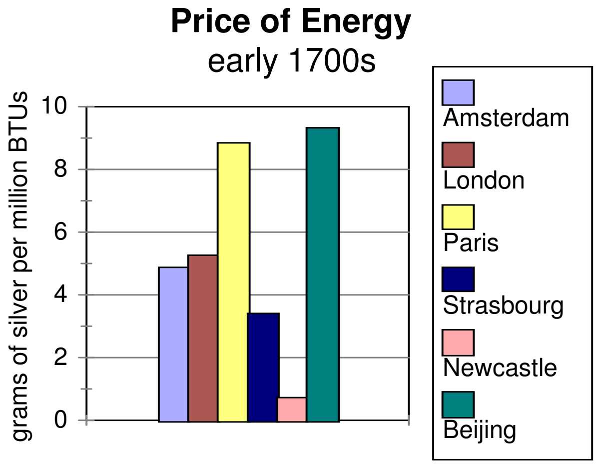
Why were British wages and prices unique?

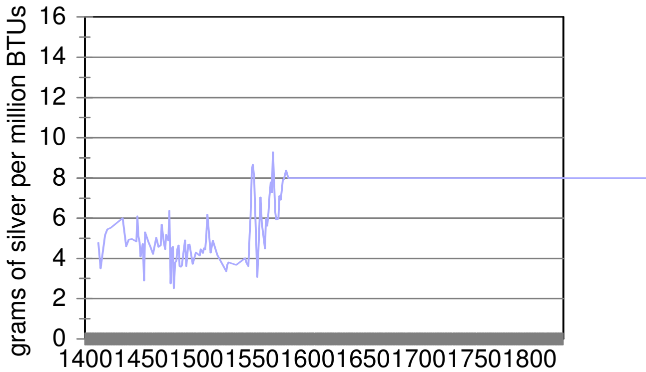
Britain's unusual wages and prices were due to two factors. The first was Britain's success in the global economy, which was in part the result of state policy. The second was geographical–Britain had vast and readily worked coal deposits.

In pre-industrial Europe, real wages moved inversely to the population. As Figure 2 indicates, the real wage rose in Britain and Italy after the Black Death of 1348/9, which cut the population by about one third. As population growth resumed, the real wage fell in most of Europe between the fifteenth century and the eighteenth. The Low Countries were an important exception to this trend. Real wages fell in rural England in the sixteenth century, but London bucked the trend in the same way as Antwerp and Amsterdam, and, indeed, as we have seen, living standards rose generally in southern England from 1650 onwards. Why were England and the Low Countries successful?

The superior real wage performance of northwestern Europe was due to a boom in international trade. The English boom began with the export of 'new draperies' in the late sixteenth century. These were light woolen clothes made in East Anglia and exported to the Mediterranean through London. Between 1500 and 1600, the population of London grew from about 50,000 to 200,000 in response to the trade-induced growth in labour demand. During the Commonwealth, Cromwell initiated an active imperial policy, and it was continued through the eighteenth century (O'Brien 2006). In a mercantilist age, imperialism was necessary to expand trade, and greater trade led to urbanization. Between 1600 and 1700, London's population doubled again, and by 1800 it approached one million. In the eighteenth century, urbanization picked up throughout England as colonial trade increased and manufacturing oriented to colonial markets expanded. Between 1500 and 1800, the fraction of the English population living in settlements of more than 10,000 people increased from 7% to 29%. The share of the workforce in agriculture dropped from about 75% to 35%. Only the Low Countries, whose economies were also oriented to international trade, experienced similarly sweeping structural transformations. In the eighteenth century, the Dutch and the English had much more trade per capita than other countries in Europe. Econometric analysis shows that the greater volume of trade explains why their wages were maintained (or increased) even as their populations grew (Acemoglu, Johnson, Robinson 2005, Wrigley 1987, O'Brien 1999, Ormrod 2003, Allen 2000, 2003).

Figure 5


Price of Energy
early 1700s
grams of silver per million BTUs
10
8
6
4
2
0
Amsterdam
London
Paris
Strasbourg
Newcastle
Beijing


grams of silver per million BTUs
16
14
12
10
8
6
4
2
0
1400
1450
1500
1550
1600
1650
1700
1750
1800

1932)–and shipments of coal from Newcastle to London began their rapid growth. The take-off of the coal industry was, thus, due to the growth of London. Since this was due to the growth of international trade, the exploitation of Britain's coal resources were the result of the country's success in the global economy as well as the presence of coal in the ground.

The Dutch cities provide a contrast that reinforces the point (Pounds and Parker 1957, de Vries and van der Woude 1997, Unger 1984). The coal deposits that stretched from northeastern France across Belgium and into Germany were as useful and accessible as Britain's. With the exception of the mines near Mons and Liège, they were largely ignored before the nineteenth century. The pivotal question is why city growth in the Netherlands did not precipitate the exploitation of Ruhr coal in a process parallel to the exploitation of Northern English coal. Urbanization in the Low Countries also led to a rise in the demand for fuel. In the first instance, however, it was met by exploiting Dutch peat. This checked the rise in fuel prices, so that there was no economic return to improving transport on the Ruhr or resolving the political-taxation issues related to shipping coal down the Rhine. Once the Newcastle industry was established, coal could be delivered as cheaply to the Low Countries as it could be to London, and that trade put a ceiling on the price of energy in the Dutch Republic that forestalled the development of German coal. This was portentous: Had German coal been developed in the sixteenth century rather than the nineteenth, the industrial revolution might have been a Dutch-German breakthrough rather than a British achievement.

Why Britain's unique wages and prices mattered: Substituting Capital for Labour

Britain's high wage, cheap energy economy was an important determinant of the pace and character of technical change. There were both demand and supply links, and I begin with the former. In analyzing these, it is useful to distinguish between product and process innovations, for they were influenced by different features of the price structure.

Historians of consumption have emphasized product innovations as a cause of the industrial revolution (Berg 2005). Trade with Asia brought new products to Britain–cotton fabrics, Chinese porcelain, coffee and tea. Britain's high wages meant that the demand for these goods was not confined to the middle classes but included skilled workers and even labourers, so the market was far broader than in much of Europe. British manufacturers attempted to make these goods or imitations of them in order to meet that demand. Cotton textiles is a famous example we will consider later. There was also much product innovation in porcelain as English manufacturers (Wedgewood is the most famous) developed materials and designs that could compete with the Chinese (Young 1999). To an important extent, the industrial revolution was an exercise in import substitution.

Process innovations were important in their own right, and much of the product innovation also involved redesigning production processes to suit British conditions. What mattered was the wage of labour relative to the prices of capital and energy. Britain's high–and rising wage–induced a demand for technology that substituted capital and energy for labour. At the end of the middle ages, there was little variation across Europe in capital-labour ratios. As the wage rose relative to the price of capital in Britain, it was increasingly desirable to substitute capital for labour and that is what happened. Sir John Hicks (1932, pp. 124-5) had the essential insight: "The real reason for the predominance of labour saving inventions is surely that...a change in the relative prices of the factors of production is itself a spur to innovation and to inventions of a particular kind–directed at economizing the use of a factor which has become relatively expensive." Habakkuk (1962) used this insight to argue that high wages led Americans to invent labour saving technology in the nineteenth century, and a similar situation obtained in eighteenth century Britain.[4] Economists have since debated how to formalize these ideas (David 1975, pp. 19-91, Temin 1971, Ruttan 2001, Ruttan and Thirtle 2001, Acemoglu 2003). One problem is that businesses are only concerned about costs in toto–and not about labour costs or energy costs in particular–so all cost reductions are equally welcome. I will not review the debate here. Instead, I will show that invention in the British Industrial Revolution was consistent with Hick's observation, while the subsequent perfection of technology looks more like a neutral process. The following generalizations apply to many inventions including the most famous:

1. The British inventions were biased. They were labour saving and energy and capital using.

Thanks to Adam Smith, the pin factory is the most famous production process of the eighteenth century. Smith argued that high productivity was achieved through a division of labour among hand workers. It is very likely that he derived his knowledge from Diderot and d'Alembert's *Encyclopédie* (1765, Vol. V, pp. 804-7, Vol. XXI, 'épinglier') since both texts divide the production process into eighteen stages, and that cannot be a coincidence.[5] Indeed, Smith seems to have used the *Encyclopédie* for the exact purpose that Mokyr suggests–to find out about the latest technology.

There is a difficulty, however. The *Encyclopédie*'s account is based on the production methods at l'Aigle in Normandy. This was not the state-of-the-art practise as carried on in Britain. The first high tech pin factory in England was built by the Dockwra Copper Company in 1692, and it was followed by the Warmley works near Bristol in midcentury. (Hamilton 1926, pp. 103, 255-7). The latter was a well-known tourist destination (Russell 1769), and Arthur Young visited it. Both mills were known for their high degree of mechanization, and they differed most strikingly from Normandy in the provision of power. In L'Aigle, machines were powered by people turning fly wheels that looked like spinning wheels. In contrast, the Warmley mill was driven by water power. Since the natural flow of the stream could not be relied on, a Newcomen steam engine was used to pump water from the outflow of the water wheel back into the reservoir that supplied it. "All the machines and wheels are set in motions by water; for raising which, there is a prodigious fire engine, which raises, as it is said, 3000 hogsheads every minute." (Young 1771, p. 138.) Powering the mill in this way immediately eliminated the jobs of the wheel turners (their wages amounted to one sixth of the cost of fabricating copper rod into pins) and probably other jobs as well. Many French workers, for instance, were employed scouring pins. This activity was done with large machines driven by water power at English needle factories at the time.[6] Arthur Young observed that the Warmley works "are very well worth seeing." It is a pity that Adam

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[4]Fremdling (2004, pp. 168-9) entertains this possibility, as does Mokyr (1993, pp. 87-89), who also raises many objections to it.

[5]Peaucelle (1999, 2005, 2006) has examined Smith's sources very carefully and identified several additional French publications that he argues Smith relied on. All of these sources describe production in Normandy.

[6]Early eighteenth century water-driven scouring machinery is still in operation and can be seen at the Forge Mill Needle Museum, Redditch.

Smith relied on the French *Encyclopédie* to learn about the latest in technology rather than travelling with Arthur Young.

Why did the English operate with a more capital and energy intensive technology than the French? L'Aigle was on a river, and water power drove a forge in the town, so geography was not a bar (indeed, the steam engine at Warmley shows that water power was possible almost anywhere if you were willing to bear the cost of a steam engine). The Swedish engineer R.R. Angerstein (1753-5, p. 138) visited Warmley in the 1750s and noted that "the works uses 5000 bushels of coal every week, which, because they have their own coal mines, only costs three Swedish 'styfwer' per bushel," which was about half the Newcastle price.[7] In addition, English wages were considerably higher than French wages. Innovation in pin making is an example of factor prices guiding the evolution of technology.

2. As a result of 1, cost reductions were greatest at British factor prices, so the new technologies were adopted in Britain and not on the continent.

One of the big themes in the history of the industrial revolution is the lag in adopting British technology on the continent. There has been a tendency to regard the inventions of the industrial revolution as such marvellous improvements that only a fool would ignore them. Coke smelting is an important example, and Landes (1969, pp. 216, 528) attributed its slow diffusion on the continent to entrepreneurial failure. However, a close study of the economics shows that coke smelting was not profitable in France or Germany before the mid-nineteenth century (Fremdling 2000). Continuing with charcoal was rational behaviour in view of continental factor prices. This result looks general; in which case, adoption lags mean that British technology was not cost-effective at continental input prices.

3. The famous inventions of the industrial revolution were made in Britain rather than elsewhere in the world because the necessary R&D was profitable in Britain (under British conditions) but unprofitable elsewhere.

Research and development was expensive, and it was fundamental to inventing in the eighteenth century. Consequently, inventions were undertaken only when the R&D benefits exceeded the costs. If the French or Germans did not adopted an invention when it was freely available, then it brought them no benefit, and there would have been no point in expending resources to have invented it. If we ask why coke smelting, or the spinning jenny, or the steam engine were invented in Britain rather than in China or France, the adoption lags imply that the rates of return to these R&D projects were zero outside Britain. To understand invention, we do not have to entertain the arcane questions that arise in cultural discussions of the topic: Did Chinese science have a sufficiently developed concept of the vacuum to allow the conceptualization of the low pressure steam engine? Was French engineering theoretically inclined while British was empirical? The answer lies in different economic conditions that led different countries to invent different kinds of technology.

4. Once British technology was put into use, engineers continued to improved it, often by economizing on the inputs that were cheap in Britain. This made British technology cost-

[7] I am thank Martin Dribe for help in deciphering the Swedish stwyfer.

effective in more places and led to its spread across the continent later in the nineteenth century.

As British technology evolved, capital and energy intensities declined. Chapman (1970, p. 253) observed that "the mechanical genius of Lancashire was directed towards a reduction of plant costs, which fell from £2 per spindle at the height of the Arkwright era to less than £1 a spindle by 1836." It was the same story with steam power: The first Newcomen engines were profligate in their use of fuel. Smeaton improved them in the mid-eighteenth century cutting the use of coal. Watt's separate condenser saved more fuel. The high pressure steam engine, and the Cornish engine reduced energy use much further (Nuvolari 2004a). By the mid-nineteenth century, steam engines could be used in France even though coal was expensive since they did not use much of it. The culmination of this process was compound condensing marine engines that finally made steam ships cheaper than clipper ships on the very long routes from the Pacific to Britain (Harley 1971).

Three idealist explanations

The theory advanced here explains the technological breakthroughs of the industrial revolution in terms of the economic base of society–natural resources, international trade, profit opportunities. Through their impact on wages and prices, these prime movers affected both the demand for technology and its supply. An alternative approach traces the inventions of the industrial background back to the realm of ideas and culture. This view is advanced by cultural historians like Margaret Jacob (1988, 1997) and Larry Stewart (2004) and by economists like Joe Mokyr (2002). His writings have been highly influential in putting technological history at the centre of debate and in emphasizing the importance of networks and communication channels for understanding invention. However, the history of wages and prices as well as the detailed investigation of famous inventions (to be considered shortly) both suggest that economic evolution exerted a stronger influence on invention than autonomous changes in culture or ideas.

There are three distinct idealist explanations of the industrial revolution that need to be considered:

1. The technological breakthroughs were 'macro-inventions,' i.e. acts of genius or serendipity rather than responses to economic incentives.
2. The technological breakthroughs were applications of scientific discoveries that were made for scientific rather than economic reasons.
3. The industrial revolution was the result of the spread of scientific culture that made people more experimental, more numerate, and more systematic in their study of technology. This cultural change was due to the success and example of Newtonian science.

These possibilities affected the supply of technology rather than its demand. The first two increased the supply of technology by providing engineers with Big Ideas to develop. The third improved the ability of engineers to turn ideas into commercial applications.

Consider macro-inventions first. These differ from micro-inventions, which are "the small incremental steps that improve, adapt, and streamline existing techniques already in use, reducing costs, improving form and function, increasing durability, and reducing energy and raw material requirements." Microinventions are "more or less understandable with the help of standard economic concepts. They result from search and inventive effort, and respond to prices and incentives." In contrast, macroinventions embody "a radical new idea, without clear precedent" and emerge "more or less ab nihilo." They "do not seem to obey obvious laws, do not necessarily respond to incentives, and defy most attempts to relate them to exogenous economic variables. Many of them resulted from strokes of genius, luck or serendipity" (Mokyr 1990, p. 13.) Mechanical spinning is a pre-eminent example. (Mokyr 1993, p. 20).

Stress on pure genius is hard to square with my discussion of wages, prices, and the incentives they created for inventing technology, for that analysis treats all of the inventions of the industrial revolution as micro-inventions. Which were they: micro or macro? The tests are: (a) to see whether mechanical spinning, for instance, emerged 'ab nihilo' or whether it was a development of existing ideas and (2) to see whether its 'invention' involved a development program that made sense in terms of economic opportunities. When we perform these tests, we see that the famous inventions of the industrial revolution look more like micro-inventions than macro-inventions.

How about scientific discovery as a source of eighteenth century technology? This is a favourite theme of university presidents and vice chancellors, and, indeed, has been argued by proponents of scientific research since the seventeenth century. In 1671, Robert Boyle developed the argument. "Inventions of ingenious heads doe, when once grown into request, set many Mechanical hands a worke, and supply Tradesmen with new meanes of getting a liveleyhood or even inriching themselves." There were three ways by which "naturalists" could improve technology. "The first [was] by increasing the number of Trades, by the addition of new ones." The pendulum clock and scientific instruments were Boyle's examples. "The second [was] by uniteing the Observations and Practices of differing Trades into one Body of Collections," so that techniques used in one trade could be transferred to another. "And the third [was] by suggesting improvements in some kind or other of the Particular Trades." Cornelius Drebbel's invention of turkey red dye was an example, but what particularly excited Boyle were the possibilities of inventing "engines" to mechanize production. "When we see that Timber is sawd by Wind-mills and Files cut by slight Instruments; and even Silk-stockings woven by an Engine...we may be tempted to ask, what handy work it is, that Mechanicall contrivances may not enable men to performe by Engines." Boyle thought that there were more possiblities here "than either Shopmen or Book men seem to have imagined" and experimental scientists would discover them. (Boyle 1671, Essay 4, pp. 10, 20.)

Was Boyle right? The impact of scientific discovery on t [illegible] in China or in the middle ages); the second explains why it happened in Britain rather than France.

Mokyr (2002, p. 29) gives a succinct statement of the first stage claim.

> I submit that the Industrial Revolution's timing was determined by intellectual developments, and the true key to the timing of the Industrial Revolution has to be sought in the scientific revolution of the seventeenth century and the Enlightenment movement of the eighteenth century. The key to the Industrial Revolution was technology, and technology is knowledge.

Mokyr coined the term Industrial Enlightenment to describe the features of the Enlightenment that linked the Scientific Revolution of the seventeenth century to the Industrial Revolution of the eighteenth and nineteenth. The Industrial Enlightenment emphasized the application of the scientific and experimental methods to the study of technology, the belief in an orderly universe governed by natural laws that could be apprehended by the scientific method, and the expectation that the scientific study of natural world and technology would improve human life. These ideas were popularized until they eventually permeated the culture. The channels through which this was done included professional scientific societies like the Royal Society, and the publication of books like the *Encyclopédie* that described manufacturing processes (although the tale of pin-making gives us pause). Popular scientific societies and lectures also played a role in disseminating the new approach to technology and nature.

According to Mokyr (2002, p. 29), the industrial enlightenment explains "why the Industrial Revolution took place in western Europe (although not why it took place in Britain and not in France or the Netherlands.)" This must be so when the pre-eminent example of knowledge diffusion is Diderot and d'Alembert's *Encyclopédie*. Britain's lead over France is attributed to a difference in the engineering cultures of the two countries: The French were supposedly theoretical, while the British were practical. This is the second stage claim.

With a theory so multi-faceted, it is hard to reach a definitive judgement: The theory stimulates, but there are many grounds for reservation. The theory posits European and national cultures that make little allowance for class or social status differences in attitudes. What exactly were the links between Cambridge dons like Newton and artisan inventors like Abraham Darby or James Hargreaves? This problem was apparent to eighteenth century writers. In <u>The Fable of the Bees</u>, Mandeville (1724) remarked:

> They are very seldom the same Sort of People, those that invent Arts, and Improvements in them, and those that enquire into the Reason of Things: this latter is most commonly practis'd by such, as are idle and indolent, that are fond of Retirement, hate Business, and take delight in Speculation: whereas none succeed oftener in the first, than active, stirring, and laborious Men, such as will put their Hand to the Plough, try Experiments, and give all their Attention to what they are about.

To close the gap between high science and artisan technology, the culturalists propose coffee houses giving popular science lectures. Who attended these events and what they heard are less than clear. The minutes of the Chapter Coffee House society, which met between 1780 and 1787, have been published (Levere and Turner 2002), and they provide a rare peek inside. They warrant attention since the history of the society provides "hard evidence of the interplay between science and technology, and industrial revolution." But does it? 60% of the 55 members were Fellows of the Royal Society and only five had a connection to manufacturing. Of those five, only one ever attended a meeting. The Chapter Coffee House was not science communicating with industry. It was science talking to itself. There probably were some occasions when high science addressed the hoi polloi, but the suspicion must be that Mandeville was right: these were separate spheres.

More suspicion that the Industrial Enlightenment was mainly an upper class cultural phenomenon with little relation to production comes from the study of its twin–the Agrarian Enlightenment. This involved many of the same themes as the Industrial Enlightenment–except applied to farming rather than manufacturing–and, indeed, many of the same people, once returned to their country houses at the close of the London season. These were the celebrated improving landlords of England, who enclosed their estates, turned their home farms into experimental stations, patronized Arthur Young (a great collector of farming data), published reports of new crops and cultivation methods, and promoted improved farming among their tenants. This was the enlightenment project applied to agriculture, but, unfortunately for the cultural theory, it had little effect on agricultural productivity (Wilmot 1990). The impact of the Agrarian Enlightenment was inherently limited because it was a movement among the gentry and aristocracy, not among the farmers who actually tilled the land. The books were written by landlords, for landlords. The King could play at being Farmer George, but there was little connection with real production. Was the Industrial Enlightenment as ineffective?

It is important to distinguish between popular culture and elite culture and ask how they were related. Cultural historians see popular culture changing in response to high science, an elite cultural activity. In contrast, I contend that popular culture evolved in response to changes in the economy. The growth of international trade led to much greater urbanization in northwestern Europe. Jobs in trade, manufacturing, and commerce required skills that agriculture had not demanded. Literacy rates in medieval Europe were much higher in cities than in the countryside for this reason, so literacy rose with urbanization. The high wage economy of the commercial centres also aided the accumulation of human capital by making it easier for people to pay for education and knowledge. Beyond that, the invention of printing sharply reduced the price of books leading to much greater effective demand for both useful knowledge and pleasure (van Zanden 2004a, 2004b, Reis 2005). The same factors probably boosted numeracy (Thomas 1987). Knowledge of arithmetic and geometry was important to keep accounts and navigate ships. In his path breaking epidemiological study of London, Graunt (1662, p. 7) attributed his calculations not to science but to trade: "It depends upon the Mathematiques of my Shop-Arithmetic." The much greater level of human capital in the eighteenth century than in the middle ages is an important reason why the industrial revolution did not happen earlier.

Do differences in human capital explain why the industrial revolution occurred in Britain rather than France? Literacy in France as a whole was lower than in Britain, but France was a bigger country with a larger population and considerable diversity. Literacy in northern France was about as common as in Britain, and so human capital differences may not have been important. Indeed, it is not clear that there was much difference in inventiveness between eighteenth century Britain and France. There are certainly many examples of the French inventing. Why do we think the British had a more pragmatic engineering culture than the French? Because it was Brits who first smelted iron with coke, invented the steam engine, and discovered how to spin with machines. In the rest of this essay, I will show that these differences in behaviour were due to differences between the countries in the profitability of doing R&D. If that argument is accepte

How much creativity did coke smelting require? What engineering problems did it pose?

Coke smelting did not depend on any scientific discovery nor did it require an act of genius. In fact, it required almost no thought at all. Coal was a much cheaper source of energy than wood, and attempts were made to substitute the cheaper fuel in most applications during the seventeenth century. If coal was being burnt to heat the house, why not chuck it into the blast furnace instead of expensive charcoal? And, indeed, there are many examples of people doing just that in the seventeenth century. Dud Dudley was an early pioneer who claimed in his book *Metallum Martis* (1665) to have successfully smelted iron with coke, and he had the iron goods around his house to prove it. Others followed, and there is no reason to believe that they failed. The problem was that the process was not economic. Most iron in the seventeenth century was refined into wrought iron, and pig iron smelted with coal contained too much sulfur for this to be successful. This was a typical problem in substituting coal for wood: the coal introduced impurities, so new technology had to be invented to eliminate them. Wrought iron was not successfully made from mineral fuel pig iron until the middle of the eighteenth century.

Abraham Darby I is usually credited with the invention of coke smelting, but, as noted, he did not conceive the idea. Darby probably learned about coke smelting from Shadrach Fox, who had a contract to supply the Board of Ordnance with cast iron shot in the 1690s. This iron was probably smelted with coke, and the Fox's furnace was the one at Coalbrookdale that Darby later leased. The furnace blew up in 1701, and Fox smelted some more iron with coal or coke at the Wombridge Furnace. Darby leased the Coalbrookdale from Fox in 1708, rebuilt it, and set off on his career smelting coke iron (King 2003, p. 52).

The link from Fox to Darby solves several puzzles–why Darby never patented coke smelting (although he patented a casting process) and how he had the confidence to use coke from the very inception of his business. He seems to have known the process would work technically, for he did no experimenting with coke nor does he seem to have had a back-up plan to use charcoal if coke smelting failed. Also, Shaddrock Fox's experience showed that coke iron was suitable for castings, which was the application Darby had in mind.

Darby's R&D project

Indeed, Darby's contribution to 'inventing' coke smelting was in finding a commercially viable application for the material. In about 1702, Darby and other Quakers established the Baptist Mills Brass Works near Bristol. Most brass was then fabricated by drawing it into wire or by hammering sheets into pots, kettles, and such like. Casting was traditionally limited to church bells and canon. However, by the late seventeenth century, the Dutch were casting many other products using sand moulds and reusable patterns. In 1703, Darby set up his own foundry and tried to cast iron pots with sand moulds, but he was unsuccessful. In 1704, he went to the Netherlands to study sand casting. He brought back some Dutch workers and got them to try casting iron, but they were also unsuccessful. However, an English apprentice, John Thomas, believed he could do it, and Darby paid him until he was successful in 1707. This was Darby's principal R&D project, and it resulted in a patent for casting iron with sand molds. Darby's partners in Baptist Mills did not want to pay for this research, but he found a new financial backer in Thomas Foudney.

When Darby leased the Coalbrookdale furnace from Shadrach Fox, his plan was to smelt pig iron and cast iron pots with sand moulds. Not only were the castings successful, but the silicon in the coke iron rendered it more fluid than charcoal iron, so it proved possible to m

It took almost a century from the perfection of coke smelting at Coalbrookdale until its use was widespread on the continent. During that period, the technology was well known and freely available but not adopted. Since it conferred no benefit to French or German producers, there would have been no point in developing it in those countries. It was not the impracticality of the engineering culture that explains the lack of attention to coke smelting. Inventing the process would not have paid.

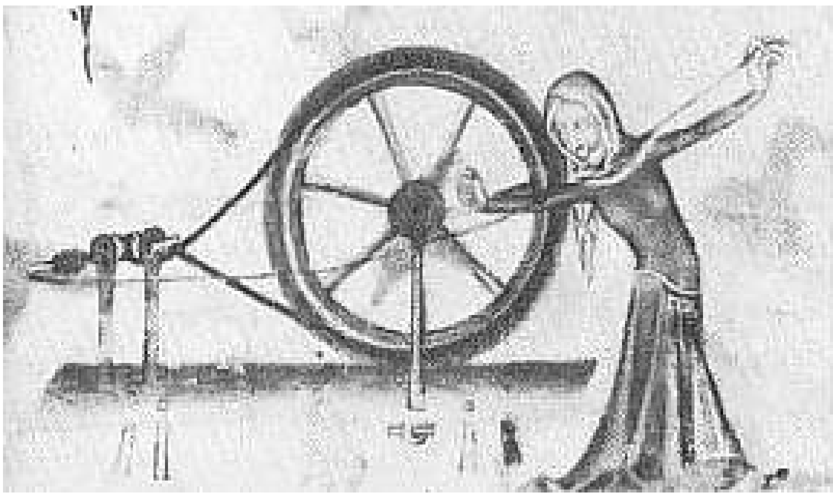
The invention of cotton spinning machinery

How much creativity did mechanical spinning require? What engineering problems did it pose?

The spinning jenny and water frame were not based on scientific discoveries. Were they instead 'macro inventions' that required enormous leaps of the technological imagination? To know, we must see if the spinning machines really did spring ab nihilo or whether they had genealogies that indicate less dramatic departures from previous practice. I begin with hand spinning to highlight the technical problems that Hargreaves and Arkwright faced.

Figure 7 shows a spinning wheel in operation. The raw cotton was first carded to produce a roving, which was a loose length of cotton fibres. The two key operations in spinning were drawing out the roving so it became thinner and then twisting it to impart strength. In the late medieval period, this was done with a 'spinning wheel'. It consisted of three parts–the wheel itself, the spindle, and the string that acted as a belt to connect the wheel to the spindle. Sometimes a treadle was connected to the wheel so that the spinster could turn it with her foot; otherwise she used her right hand. She held the roving in her left hand, and its other end was attached to the horizontal spindle. The wheel was spun, and the spindle rotated. The spinster pulled back the roving so that it thinned out and then moved her hand to the left. This allowed the thread to slip off the end of the spindle each time it rotated. Each time that happened, the thread was twisted once. When enough twist was imparted, the spinster moved her left hand to the right, so it was once again between her and the spindle. In this position, the thread was wound onto the spindle. The process was repeated as the next few inches of roving were pulled away from the spindle to be thin out in turn.

Figure 7



It is hard to see anything that came ab nihilo in Hargreaves' spinning jenny. It was little more than a spinning wheel on its side with several spindles connected by belts to a common wheel. Indeed, the story is that Hargreaves conceived the jenny when he saw a spinning wheel fall over and continue spinning while it was on the ground. A sliding frame replaced the spinster's left hand and drew the rovings away from the spindles. The difficulty, as with most eighteenth century technology, lay in working out of the details of the linkages and rods that drew out the cotton roving. The spinning jenny was an engineering challenge. It did not require a scientific breakthrough or a great leap of imagination.

Arkwright's water frame was another spinning technique that was more portentous in its consequences and arguably more clever in its design. But, again, it was based neither on a scientific breakthrough nor on an original idea. Figure 8 shows a water frame, and Figure 9 is a close-up of the 'clockwork'. The rovings entered at the top. They then passed through three pairs of rollers. The rollers operated like mangels, pulling the cotton between them. The second pair spun at twice the speed of the first, and the third doubled the speed again. For this reason, the first pair of rollers simultaneously pulled the roving into the mechanism and at the same time held it back with respect to the second pair, which was spinning faster and tugging it forward. The cotton was, thus, stretched and thinned out as it went between the two pairs of rollers. The stretching was repeated between the second and third pairs of rollers since the third pair spun faster than the second. In this way, the water frame accomplished the first task in spinning–drawing out the fibre.

Figure 8

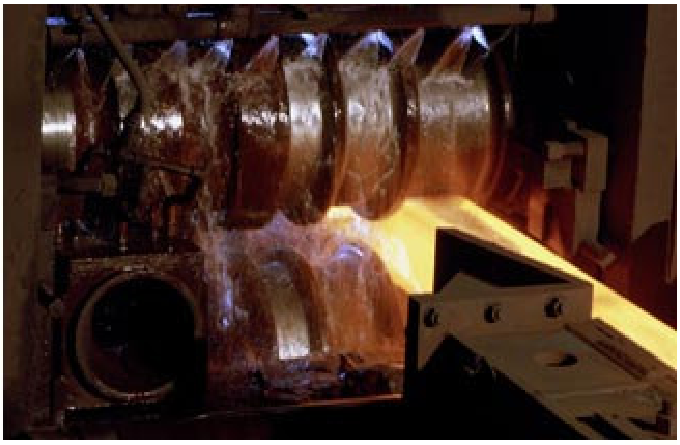
The second task was accomplished by the flyers, which spun around at the bottom of the frame, simultaneously twisting the fibre and coiling it on the bobbin.

Not much of this was original with Arkwright. The flyer, indeed, was an old device and none of the cotton inventors could take credit for it (another example of copying). The novelty of the water frame lay in the trains of rollers that drew out the cotton. This idea, however, was not Arkwright's either: Wyatt and Paul took out patents on the idea in 1738 and 1758. Much effort was put into perfecting the machine, licenses were sold, and they erected their own factory in Birmingham. It was not successful, although Matthew Boulton thought it might have been had it been well managed. The Wyatt and Paul R&D program was a failure.

Figure 9

If there were any macro inventors, they were Wyatt and Paul. But were they? The test of a macro-invention is whether it was conceived <u>ab nihilo</u> or whether it had a pedigree that shows that it involved only a small variation in practice. By that test, roller spinning was a micro-invention. Rollers were a general purpose

Figure 10



technology whose use was spreading in the early eighteenth century.[8] Rollers had a long history in metallurgy where bars, ingots, plates, and nails were shaped (Figure 10). Coin faces were pressed into gold and silver with engraved rollers. Indeed, the similarities between a metal rolling mill and roller spinning were so great that Rees (1819-20, II, p. 173) reports that Arkwright conceived of roller spinning when looking at a rolling mill. There are sixteenth and seventeenth century designs for corn mills using rollers. In the late seventeenth century, cast glass was rolled at Saint-Gobain and polished with a roller. Cloth was pressed by rollers under enormous weight in the calendering process. In 1696, the Paris mint was using rollers. In the late seventeenth century, 'milled' sheet formed by rolling lead replaced cast lead sheet. In 1670, the Dutch developed a roller device with spikes to tear up rags for paper making and in 1720 applied rollers to pressing paper. Rollers were also used to crush rock. Applying rollers to stretching cotton was no doubt clever, but the idea had a history. When he discussed Cort's invention of puddling and rolling, Mokyr (1993, p. 22) discounted it as a macro invention since rolling had a long history in metallurgy. The same argument applies to cotton. Rollers were in the air in the first half of the eighteenth century. Wyatt and Paul did not think them up from nowhere. Roller spinning was not a macro invention.

Hargreaves' and Arkwright's R&D projects

The challenge with roller spinning was making the idea work. Hargreaves faced the easier challenge. His first jenny was reportedly made with a pocket knife, but getting a design that could be operated satisfactorily took from 1764 to 1767 (Aspin and Chapman 1964, p. 13). Hargreaves began trying to realize money from his invention almost immediately by selling jennies. He moved to Nottingham. As he continued to improve the jenny he needed a financial backer. He first went into partnership with a man named Shipley and later with Thomas James (Aspin and Chapman 1964, 19, 22-3, 34-5). They established a spinning factory. In 1770, Hargreaves patented the jenny, but it was too late. His patent was challenged in court and eventually voided on the grounds that he had sold jennies before it was issued. Despite the widespread use of the jenny in the late eighteenth century, Hargreaves realized very little money from the invention.

Arkwright's challenge was far greater. Figure 11 shows Wyatt and Paul's diagram from their second patent, and it can be compared to the Arkwright machine to see the engineering problems involved. Both devices used a flyer to twist and wind the finished thread. Wyatt and Paul's diagram shows one pair of rollers, whereas Arkwright's frame had

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[8]Singer, et al. (1957, Vol. III, pp. 16-7, 32, 45, 47, 177, 238-9, 340-4, 414-5), Raistrick 1972, p. 91), Rowe (1983, pp. 8-10), Beveridge (1939, pp. 191-2, 287-9, 485-9, 652-6) Mokyr (1990, p. 60), Hunter (1930, pp. 170-1).

three. It was essential to have several in a series so that they could pull against each other. Wyatt and Paul did mentioned two pairs in the description of the machine in their first patent: Deciding the number of rollers was a development challenge, and it looks as though Wyatt and Paul went down a wrong alley in their R&D program by trying to develop a machine with only one set of rollers.

Figure 11

They never confronted, therefore, the other development challenges that Arkwright overcame in the 1760s. These included:

- The increase in speed from one set of rollers to the next. In the early water frame displayed in Strutt's North Mill, Belper rotation speed doubles from one train of rolls to the next.
- How to arrange the gears to connect the main power shaft to the rollers and coordinate their movements. The rollers and gears were produced as a module known as the 'clock work' in recognition of the apparatus that inspired it.
- The spacing between the rollers. The distance had to be slightly less than the length of a cotton fibre. That allowed stretching and thinning of the thread since a fibre that was past the grip of the first rollers and caught by the second pair could be pulled ahead of an adjacent fibre that was held by the first rollers but not yet in the grasp of the second. If the rollers were too close, all of the fibres would be gripped by both pairs, so there would be no stretching. If the rollers were too distant, the thread would be pulled apart: Proper operation required some fibres to be gripped by both rollers to prevent breakage, while others were held by one or the other pair for thinning. Thought and experimentation were required to work this out.
- The materials with which to make the rollers. One was grooved metal and the other wood covered with leather. They had to pull the fibre without catching.
- The pressure with which the top roller pressed down on the bottom one. This was regulated by hanging weights from the top ones, as shown in Figure 9. The optimal weight could only be determined by repeated trials.

The point of this discussion is to emphasize the real issues involved in 'inventing' mechanical spinning. The originality was not in thinking up the roller; rather, the challenges were the practical issues of making the roller work in the application. Wyatt and Paul spent some years on this, but did not succeed. Arkwright employed clockmakers over a five year period to perfect the design. We have no record of exactly what they did, but the comparison of the Wyatt and Paul design with Arkwright's frame highlights the problems they faced. These challenges could only be met by constructing models or experimental prototypes. 'Inventing' the water frame involved a significant R&D program.

The R&D program had very modern financial implications that are worth noting. First, the object was to make money for Arkwright, and patenting the invention was the essential step in securing that income. This was done in 1769. Second, there was the formidable problem of financing the R&D. Arkwright did what modern inventors do: he found venture capitalists–'projectors' in the language of the eighteenth century. His patent was jointly held with John Smalley and David Thornley, and each partner was committed to finance one third of the development costs. Quickly they ran out of money, and Samuel Need and Jedediah Strutt were brought in as partners. Strutt was an established ‘projector,’ who had already made a fortune financing improvements in frame knitting. Development work continued. Strutt himself suggested dusting the rollers with chalk to prevent the cotton from sticking to them. Several cam operated devices were added to wind the thread, raise and lower the bobbins and move the thread back and forth along the rollers to prevent a groove’s being worn in the surface. In 1774, Jedediah Strutt claimed that £13,000 had been spent on developing Arkwright’s device. This included the construction of buildings, which posed problems of layout and power transmission, and it indicates the scale of the finance required to turn the idea of roller spinning into the reality of a working cotton mill (Hills 1970, pp. 60-71).

Roller spinning was not unusual. If we examine the revolutionary inventions of the eighteenth century, we see that they were not based on revolutionary ideas. They were based on little ideas and often on copying products and practices from other places or industries. Success depended on solving the engineering problems in making the simple idea work. Edison famously remarked that ‘invention was 1% inspiration and 99% perspiration.’ Sweat was at least as important in the eighteenth century as it was in the late nineteenth. Mokyr (1993, p. 33) correctly observed that Britain ‘had a *comparative* advantage in *micro*inventions.’ The questions are where that advantage came from, and why it was activated.

What was the motive for mechanizing spinning?

Mechanical spinning was a child of globalization. India was the world’s greatest cotton textile producer, and the East India company imported vast amounts of printed cotton cloth. This was important for later developments, for it showed that there was a large British market. So much was imported, that wool and linen manufacturers succeeded in 1701 in having printed cotton fabrics excluded from Britain. The import of white cottons was still permitted, and printing was done in England. A small British production of cotton cloth ensued. In 1721, the ban was extended to all cotton fabrics: the domestic production and consumption of purely cotton fabrics was made illegal. “The Lancashire cotton industry...secured in 1736 a relaxation for goods of flax warp and cotton weft [called fustians], a relaxation which by custom (or subterfuge) came to cover the great bulk of the industry’s production and even, it is probable, the growing part of it that used hand-spun cotton twist for warps,” i.e. all cotton cloth (Fitton and Wadsworth 1958, p. 68). English cotton producers, thus, received ambiguous protection from Indian imports. Similar restrictions were imposed in other European countries. While offering domestic protection, the laws did permit the importation of Indian cottons for re-export, and that market boomed with the growth of the slave trade in the mid-eighteenth century, for cotton cloth was bartered with African chiefs for slaves. This was another market which British producers could hope to supply–if their costs were competitive.

Britain’s high wage economy affected the cotton industry in two respects. First, the high incomes of British workers underpinned the mass market in cloth that was revealed during the period of unrestricted imports (Lemire 1991, p. 55). Second, at the exchange rate, British wages were considerably higher than Indian wages. While distance provided some protection, English spinners could only compete in producing the coarsest yarn, which was the least labour intensive.

Lowering labour costs was the key to competitiveness. There was a large potential domestic market, and a vast foreign market supplied by India and other producers. Cost reductions promised a large increase in market share and immense fortunes for the successful innovators–both of which were realized through mechanization.

Why not France?

Globalization affected other European countries as it affected England. For much of the pre-industrial period, France had possessions in India and was flooded with Indian calicoes in the late seventeenth century. Their importation was banned in 1686. France also had new world colonies and was active in the slave trade where French ships carried about 40% of the volume of English ships (Curtin 1966, pp. 211-2). French producers had an African market, albeit a smaller one than the English. In 1786, when English production was already soaring as mechanized spinning spread, Britain imported 18 million pounds of raw cotton, while France imported 11 million (Crouzet 1985, p. 32). The French cotton market was substantial, and French manufacturers had opportunities to compete against Indian textiles in Africa like their British counterparts, a feature emphasized by Inikori (2002, pp. 427-51).

And yet the French not only failed to invent mechanized spinning, they did not adopt it even when it was freely available. This was not for lack of knowledge. John Holker was an English Jacobite, who fled to France in 1750 where he established himself as a cotton manufacturer. In 1754, he succeeded in being appointed Inspector General of Foreign Manufactures charged with importing successful foreign technology. In 1771 he sent his son to Lancashire to report on the new machines, and his son brought back a jenny. This was copied and made available to French producers; indeed, the state subsidized its use. It was installed in some large scale factories but was otherwise ignored by the cotton trade. In 1790, there were about 900 jennies in France compared to 20,000 in England (Aspin and Chapman 1964, p. 49). The disproportion was at least as great with water frames. About 150 large scale mills were in operation in Britain in the late 1780s. In France, there were only four and several of these were extremely small and not representative of British practice. (Wadsworth and Mann 1931, pp. 193-208, 503-6, Chapman and Butt 1988, pp. 106-11).

Why did the French ignore the new spinning machines? Cost calculations for France are not robust, but the available figures indicate that jennies achieved consistent savings only at high count work, which was not the typical application (Ballot 1923, pp. 48-9). In France, a 60 spindle jenny cost 280 livre tournois in 1790 (Chassagne 1991, p. 191), while a labourer in the provinces earned about three quarters of a livre tournois per day, so the jenny cost 373 days labour. In England, a jenny cost 140 shillings and a labourer earned about one shilling per day, so the jenny was worth 140 days labour (Chapman and Butt 1988, p. 107). In France, the value of the labour saved with the jenny was not worth the extra capital cost, while in England it was. French cost comparisons show that Arkwright's water frame, a much more capital intensive technique, was no more economical than the jenny. The reverse was true in England where water frames were rapidly overtaking jennies. The French lag in mechanization was the result of the low French wage.

Global competition was the impetus to invent mechanical spinning. The result was a biased technical improvement that benefited Britain with its high wage economy much more than continental producers like France.

Why the British rather than the French invented mechanical spinning

As we have indicated, both the jenny and the water frame required considerable expenditures in R&D to make them work. The same would have been true in France. Would these expenditures have been worthwhile in France? No–mechanized spinning brought no economic benefit there in view of the low wage. We need look no further to understand why the spinning jenny and the water frame were invented in England rather than France or, indeed, most other parts of the world.

Steam engine

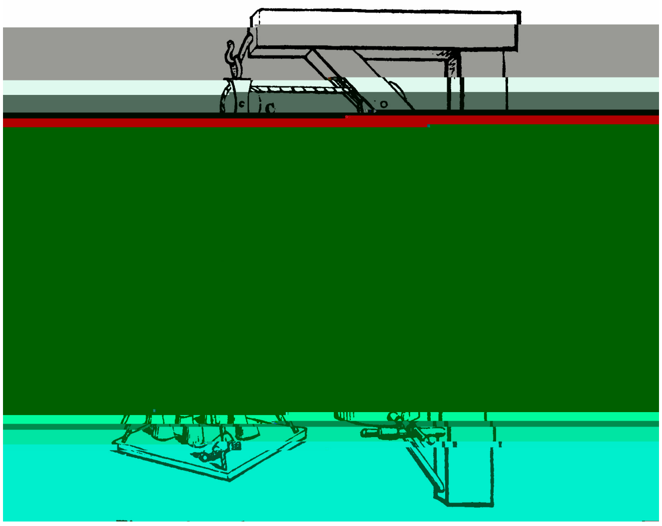
An idea from science

The steam engine presents a variation on the theme. Big Ideas did not have much to do with coke smelting or mechanized spinning, but the low pressure steam engine, developed by Newcomen and improved by Watt, was the best example of a scientific spin-off in the eighteenth century. It was based on the idea that the atmosphere had weight, which was a seventeenth century discovery and a hot topic in experimental physics. Even in this case, however, economic incentives were a key to the application of this new knowledge. Without the British coal industry, the steam engine would not have been developed.

The link from science to the steam engine was direct. The science began with Galileo, who discovered that a suction pump could not raise water more than about 34 feet–despite a vacuum existing above the column of water that had been drawn up to that height. Aristotle had said that nature abhorred a vacuum but only, it seemed, for 34 feet! Galileo suggested to Evangelista Torricelli, his secretary, that he investigate this problem. In 1644 Torricelli inverted a glass tube full of mercury and placed its bottom in a bowl of mercury. The mercury stabilized in the tube forming a column 76 centimeters high with a vacuum above it. This was the world's first barometer, and Toricelli concluded that the atmosphere had weight and pushed the mercury up the column. This was confirmed in 1648 by placing the barometer in a larger container and pumping the air out of it–the column of mercury collapsed and then reappeared as air was readmitted into the larger container.

A particularly important set of experiments was performed in Magdeburg by Otto von Guericke. In 1655, he put two hemispheres together and pumped the air out of the space they enclosed. It took sixteen horses to pull them apart. In another portentous experiment in 1672, von Guericke found that if the air was pumped out of cylinder A (Figure 12), the weights D rose as the atmosphere pushed the piston down into the cylinder. Evidently, the weight of the air could perform work.

Figure 12



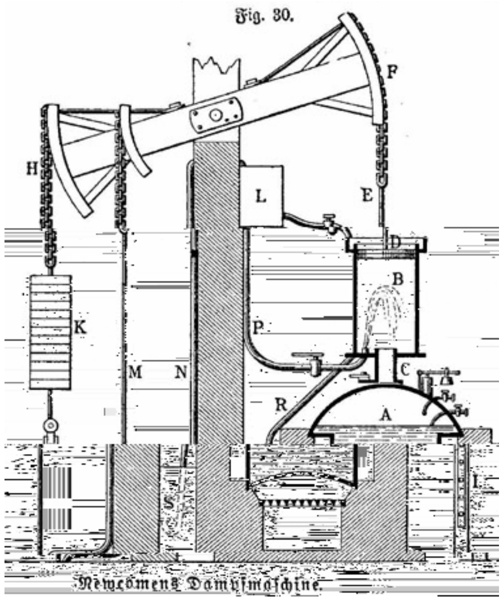
This idea had been anticipated by Christian Huygens in 1666 who used exploding gun powder to drive a piston up a cylinder. When it reached the top, the gases from the explosion were released creating a vacuum. Air pushed the piston down and raised the load. This design was not effective. However, his assistant, Denis Papin, realized that filling the cylinder with steam and then condensing it accomplished the same purpose. In 1675, Papin built the first, very crude steam engine.

The first practical application of steam technology was Savery's steam vacuum pump patented in 1698. It created a vacuum by condensing steam in a reservoir; the vacuum then sucked up water. The purpose of Savery's devise was draining mines, but it was not widely used, and it was not a steam engine.

But still an R&D project

The first successful steam engine was invented by Thomas New

Figure 13



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[9]Recent work on the development of the steam engine includes Hills (1989), Nuvolari (2004a), von Tunzelman (1978).

the engine. The top of the cylinder had to be sealed with a layer of water–nothing else worked. The dimensions of the balance and the weights of the engine's piston and the pump (K) had to be coordinated for smooth operation. Linkages between the beam and the valves had to be designed so that they would open and shut automatically at the correct moments in the cycle. No wonder it took Newcomen ten years to create an operating engine. It was a time consuming and expensive undertaking.

Like many practitioners of R&D, Newcomen hoped for a pay-off through patenting his creation. In this he was frustrated because the Savery patent was extended 21 years to 1733 and construed to cover his very different engine! Newcomen was forced to do a deal with the Savery patentees to realize any income at all.

A biased technical improvement that favoured the British

R&D costs mean that the link between Galileo and Newcomen was mediated by economics. Scientific curiosity and court patronage may have been reason enough for Torricelli, Boyle, Huygens and other scientists to devote their time and money to studying air pressure (David 1998), but Newcomen was motivated by prospective commercial gain. What was that gain? The object of the engine was to drain mines, so the demand for the technology was determined by the size of the mining industry. In 1700, England's lead was immense: It produced 81% of the tonnage in Europe and 58% of the value. Germany, which had been Europe's mining centre in the late middle ages, produced only 4% of the tonnage and 9% of the value in 1700. The change was all down to coal. Servicing the drainage needs of England's coal industry is one reason why steam engine research was carried out in England.

Coal mattered for a second reason as well. There were alternative ways of powering pumps–water wheels or horse gigs–so there was effective demand for steam power only if it was cost-effective. The early steam engines were profligate in their consumption of fuel, so they were cheap sources of power only if fuel was remarkably cheap. Desaguliers (1744, II, pp. 464-5), an early enthusiast of steam power, put the matter succinctly:

> But where there is no water [for power] to be had, and coals are cheap, the Engine, now call'd the Fire-Engine, or the Engine to raise Water by Fire, is the best and most effectual. But it is especially of immense Service (so as to be now of general use) in the Coal-Works, where the Power of the Fire is made from the Refuse of the Coals, which would not otherwise be sold.

The Newcomen engine was a biased technological improvement that shifted input demand away from animal feed and towards combustible fuel.

Free fuel overcame high fuel consumption, but, by the same token, the energy-intensity of the Newcomen engine restricted its use to the coal fuels. Since most of the coal mines were in Britain, so were most of the engines. At the expiry of the Savery-Newcomen patent in 1733, there were about 100 atmospheric engines in operation in England. By 1800, the total had grown to 2500 in Britain of which 60 - 70% were Newcomen engines.[10] In

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[10]Kanefsky and Robey (1980, p. 171). The uncertainty depends on how one classifies the engines of unknown type. As the production of Watt engines is reasonably well established, the unknown engines were probably Newcomen, and that choice yields the higher

contrast, Belgium, with the largest coal mining industry on the continent, was second with perhaps 100 engines in 1800.[11] France followed with about 70 engines of which 45 were probably Newcomen (installed mainly at coal mines) and 25 were Watt. The first steam engine was installed in the Netherlands in 1774, in Russia in 1775-7, and in Germany at about the same time. None seem to have been installed in Portugal or Italy (Redlich 1944, p. 122, Tann 1978-9, p. 548, 558). The Newcomen engine "was adopted in numbers only in the coal fields...The machines were, until well into the 19th century, so symbolically linked to the coal-fuel matrix in which they had come to maturity that they could not readily pass beyond its limits" (Hollister-Short 1976-7, p. 22). The diffusion pattern of the Newcomen engine was determined by the location of coal mines, and Britain's lead reflected the size of her coal industry–not superior rationality.

Why the steam engine was invented in Britain rather than France or China

Moreover, the diffusion pattern of the Newcomen engine indicates that it would not have been invented outside of Britain during the eighteenth century. Non-adoption was not due to ignorance: The Newcomen engine was well known as the wonder technology of its day. It was not difficult to acquire components, nor was it difficult to lure English mechanics abroad to install them (Hollister-Short 1976). Despite that, it was little used. A small market for engines implied little potential income for a developer to set against the R&D costs. The benefit-cost ratio was much higher for Newcomen than for any would-be emulator on the continent. Newcomen had to know about the weight of the atmosphere in order to make his engine work, but he also needed a market for the invention in order to make its development a paying proposition. The condition was realized only in Britain, and that is why the steam engine was developed there rather than in France, Germany, or even Belgium.

Why did the industrial revolution lead to modern economic growth?

I have argued that the famous inventions of the British industrial revolution were responses to Britain's unique economic environment and would not have been developed anywhere else. This is one reason that the Industrial Revolution was *British*. But why did those inventions matter? The French were certainly active inventors, and the scientific revolution was a pan-European phenomenon. Wouldn't the French, or the Germans, or the Italians, have produced an industrial revolution by another route? Weren't there alternative paths to the twentieth century?

These questions are closely related to another important question asked by Mokyr: Why didn't the industrial revolution peter out after 1815? He is right that there were previous occasions when important inventions were made. The result, however, was a one-shot rise in productivity that did not translate into sustained economic growth. The nineteenth century

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percentage.

[11]The total is very poorly established and is surmised from an estimate of 200 engines installed in France (then including Belgium) in 1810 made by Perrier, the first important French steam engine manufacturer (Harris 1978-9, p. 178).

was different–the First Industrial Revolution turned into Modern Economic Growth. Why? Mokyr's answer is that scientific knowledge increased enough to allow continuous invention. Technological improvement was certainly at the heart of the matter, but it was not due to discoveries in science–at least not before 1900. The reason that incomes continued to grow in the hundred years after Waterloo was because Britain's pre-1815 inventions were particularly transformative, much more so than continental inventions. That is a second reason that the Industrial Revolution was *British* and also the reason that growth continued throughout the nineteenth century.

Cotton was the wonder industry of the industrial revolution–so much so that Gerschenkron (1962), for instance, claimed that economic growth in advanced countries was based on the growth of consumer goods industries, while growth in backward countries was based on producer goods. This is an unfortunate conclusion, however, for the great achievement of the British industrial revolution was, in fact, the creation of the first large engineering industry that could mass produce productivity-raising machinery. Machinery production was the basis of three developments that were the immediate explanations of the continuation of economic growth until the First World War. Those developments were: (1) the general mechanization of industry, (2) the railroad, (3) steam powered, iron ships (Crafts 2004). The first raised productivity in the British economy itself; the second and third created the global economy and the international division of labour that were responsible for significant rises in living standards across Europe (O'Rourke and Williamson 1999).

The nineteenth century engineering industry was a spin-off of the coal industry. All three of the developments that raised productivity in the nineteenth century depended on two things–the steam engine and cheap iron. Both of these, as we have seen, were closely related to coal. The steam engine was invented to drain coal mines, and it burnt coal. Cheap iron required the substitution of coke for charcoal and was prompted by cheap coal. (A further tie-in with coal was geological–Britain's iron deposits were often found in proximity to coal deposits.) There were more connections: The railroad, in particular, was a spin-off of the coal industry. Railways were invented in the seventeenth century to haul coal in mines and from mines to canals or rivers. Once established, railways invited continuous experimentation to improve road beds and rails. Iron rails were developed in the eighteenth century as a result, and alternative dimensions and profiles were explored. Furthermore, the need for traction provided the first market for locomotives. There was no market for steam-powered land vehicles because roads were unpaved and too uneven to support a steam vehicle (as Cugnot and Trevithick discovered). Railways, however, provided a controlled surface on which steam vehicles could function, and colliery railways were the first purchasers of steam locomotives. When George Stephenson developed the Rocket for the Rainhill trials, he tested his design ideas by incorporating them in locomotives he was building for coal railways. In this way, the commercial operation of primitive versions of technology promoted further development as R&D expenses were absorbed as normal business costs.

Cotton played a supporting role in the growth of the engineering industry for two reasons. The first is that it grew to immense size. This was a consequence of global competition. In the early eighteenth century, Britain produced only a tiny fraction of the world's cotton. The main producers were in Asia. As a result, the price elasticity of demand for English cotton was extremely large. If Britain could become competitive, it could expand production enormously by replacing Indian and Chinese producers. Mechanization led to that outcome. The result was a huge industry, widespread urbanization (with such external benefits as that conveyed), and a boost to the high wage economy. Mechanization in other activities did not have the same potential. The Jacquard loom, a renowned French invention of the period, cut production costs in lace and knitwear and, thereby, induced some increase in output. But knitting was not a global industry, and the price elasticity of demand was only modest, so output expansion was limited. One reason that British cotton technology was so transformative was that cotton was a global industry with more price-responsive demand than other textiles.

The growth and size of the cotton industry in conjunction with its dependence on machinery sustained the engineering industry by providing it with a large and growing market for machinery. The history of the cotton industry was one of relentlessly improving machine design–first with carding and spinning and later with weaving. Improved machines translated into high investment and demand for equipment. By the 1840s, the initial dependence of cotton manufacturers on water power gave way to steam-powered mills (von Tunzelman 1978, pp. 175-225). By the middle of the nineteenth century, Britain had a lopsided industrial structure. Cotton was produced in highly mechanized factories, while much of the rest of manufacturing was relatively untransformed. In the mid-nineteenth century, machines spread across the whole of British manufacturing (one of the causes of the continuing rise in income). Until then, cotton was important as a major market for the engineering industry.

The reason that the British inventions of the eighteenth century–cheap iron and the steam engine, in particular–were so transformative was because of the possibilities they created for the further development of technology. Technologies invented in France–in paper production, glass, knitting–did not lead to general mechanization or globalization. One of the social benefits of an invention is the door it opens to further improvements. British technology in the eighteenth century had much greater possibilities in this regard than French inventions. The British were not more rational or prescient than the French in developing coal-based technologies: The British were simply luckier in their geology. The knock-on effect was large, however: There is no reason to believe that French technology would have led to the engineering industry, the general mechanization of industrial processes, the railway, the steam ship, or the global economy. In other words, there was only one route to the twentieth century–and it went through northern Britain.

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