Precocious British Industrialization: A General Equilibrium Perspective

N. F. R. Crafts and C. Knick Harley

Department of Economic History
London School of Economics
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Department of Economic History
London School of Economics
Houghton Street
London, WC2A 2AE

Tel: +44 (0)20 7955 6399
Fax: +44 (0)20 7955 7730

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N. F. R. Crafts
(London School of Economics)
and
C. Knick Harley
(University of Western Ontario)

1. Introduction

The British industrial revolution created an industrial economy. While casual discourse conflates industrialization and economic growth, Britain was remarkable primarily for the pronounced structural change that occurred rather than for rapid economic growth. Uniquely the British labour force became highly industrialized even prior to the move to free trade in the 1840s. On the eve of the abolition of the Corn Laws the share of agriculture in employment had already declined to levels that were not reached in France and Germany until the 1950s.

Table 1 reports levels of agricultural employment in other European countries at dates when, later on, they reached the British real income level of 1840. In every other case the share of agriculture was much larger. This reinforces the claim that precocious industrialization was a key aspect of British economic development. It also means that, in Patrick O'Brien's words, Britain was 'something of a special and less of a paradigm case' (1986, p. 297). The aim of this paper is to explore how Britain became such an outlier.

An argument that has endured through the decades is that British industrialization reflects the unusual ability of its agricultural sector to raise productivity. Looking at the period 1500-1800, Wrigley pointed out that 'In a closed economy…a substantial rise in the proportion of the population living in towns is strong presumptive evidence of a significant improvement in production

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[1] Draft chapter for Leandro Prados de la Escocura (ed), British Exceptionalism: A Unique Path to the Industrial Revolution (Cambridge University Press).

per head in agriculture, and may provide an indication of the scale of the change. Sufficient information is now available to justify an initial application of this line of thought to early modern England' (1985, p. 684). Although, Wrigley's numbers have been refined by Allen (2000, Tables 2 and 8) the estimates still show the pattern from which the inference was drawn. Whereas between 1500 and 1800 in France the agricultural population fell from 73 to 59 per cent of the total while agricultural labour productivity was unchanged, in England agricultural population fell from 74 to 35 per cent of the total and agricultural labour productivity rose by 43 per cent.

Table 1. Agricultural Share in Total Employment at British 1840 Real Income Level (%)

	Agricultural Employment	Year
Austria	64.1	1890
Belgium	44.4	1860
Britain	22.2	1840
Denmark	44.8	1890
Finland	64.6	1930
France	44.1	1890
Germany	39.9	1890
Greece	53.7	1930
Hungary	53.0	1930
Italy	55.4	1910
Netherlands	37.4	1860
Norway	39.5	1910
Portugal	48.4	1950
Spain	56.1	1920
Sweden	53.5	1900
Switzerland	42.4	1870

Sources: Labour force data from Bairoch (1968) except for France from Dormois (1997); income levels from Maddison (2001).

A variant on this stresses the role played by agrarian institutions. In particular, capitalist farming came to dominate in Britain while small-scale family farming prevailed in most continental European countries during nineteenth century industrialization. O'Brien re-stated the point thus: 'British families left the countryside…essentially because the institutions of capitalist agriculture will not retain as much redundant labour...the evolution of [Britain's] peasantry into a virtually wage-dependent labour force…can be contrasted with the tenurial systems not only of France, but of Italy, Germany, Spain, and other parts of Europe as well' (1996, p. 226).

These views would not surprise many earlier writers but fell out of favour in the 1950s and 1960s when it was widely argued that the main impetus to industrialization of the labour force came from demographic rather than agricultural change. Landes summarized this counter-claim as follows: 'the agricultural revolution associated with the enclosures increased the demand for farm labour…the rapid growth of population created a surplus of labour in the countryside much of which found its way into the new urban centres' (1969, pp. 115-6). As it stands, this argument is not entirely persuasive. The substantial growth of the industrial labour force relied on increasing agricultural labour productivity such that each agricultural worker could feed more urban workers as time passed. By 1850 labour productivity in agriculture was almost three times the level of 1700 (Allen, 1994).

While population growth alone seems inadequate to explain Britain's precocious industrialization, the suggestion that progress in agricultural technology was not central can be made more plausible by recognizing that Britain was an economy open to international trade instead of adopting Wrigley's closed economy perspective. By the industrial revolution period, if not earlier, this seems appropriate. Thus, Williamson, who developed a formal model of the nineteenth century British economy, argued that the structural changes of the industrial revolution were a consequence of much faster technological advance in

industry than in agriculture: 'Unbalanced productivity advance [was] the primary supply-side force driving industrialization and urbanization' (1985, p. 89).

His analysis implied that a faster rate of agricultural productivity improvement tended to slow down industrialization because agriculture would have been more able to withstand import competition. Rapid agricultural advance could even have converted it to a sector exporting to the rest of the world. Williamson's model does, not, however, support the suggestion that population growth was responsible for rapid industrialization. On the contrary, his model predicts the opposite. He sees population growth driving down unskilled wages and 'in response to an augmented labour supply, labour-intensive agriculture expands far more rapidly, which implies de-industrialization and a trade contraction' (1985, p. 142).

The effects of agricultural productivity performance need, however, to be analyzed in the context of the whole economy. This was clearly understood by leading economists of the time, particularly David Ricardo who discovered the concept of comparative advantage. He wrote in 1817 that 'a country possessing very considerable advantages in machinery and skill, and which may therefore be enabled to manufacture commodities with much less labour than her neighbours, may in return for such commodities, import a portion of the corn required for its consumption, even if its land were more fertile and corn could be grown with less labour than in the country from which it was imported' (1971, p. 154). This has resonance for mid-nineteenth century Britain which had a substantial lead over its European rivals in agricultural labour productivity yet imported over 20 per cent of its agricultural consumption. These trade flows were associated with Britain's dominant position in cotton textile exports based on a huge lead in labour productivity in that sector (Crafts, 1989).

This review of the literature has established some useful guidelines for the development of a satisfactory understanding of Britain's precocious industrialization. It is clearly important to take account of the roles of increased population and technological advance in an open economy general equilibrium

perspective. Attention has to be given to interactions between agriculture and industry bearing in mind that international trade offered opportunities for importing consumption goods and exporting production that modified the relationship between domestic production and consumption. Repercussions of population growth, for example, will be felt on labour markets, product markets and the balance of external payments. Prices will rise and fall in response to excess demand and supply respectively. Labour allocation, production and trade will respond to incentives created by price movements to create a new balance between supply and demand.

The historiography clearly does not offer a consensus on the origins of Britain's unusually pronounced industrialization. In this paper, we explore the issues with the aid of a computational general equilibrium (CGE) model that facilitates a quantitative analysis of the competing claims. The model is a slightly modified version of the one that we have used to address the question of whether the 'Crafts-Harley' view of the sectoral dispersion of productivity increase during the industrial revolution is consistent with the pattern of British trade in industrial products (Harley and Crafts, 2000). As such we know that it is capable of broadly replicating the transformation of the economy between 1770 and 1841 in response to changes in factor endowments and productivity and is explicitly designed to examine adjustments in international trade. The model has two key features that we believe had not been adequately appreciated in previous work. First, British population grew rapidly but land resources did not. Second, Britain was large relative to world markets especially for its main exports so that expansion of exports tended to lower prices such that revenue grew much less quickly than export volume.

In this paper, we address the following questions explicitly in order to analyze both the direction and the magnitude of their impact on the industrialization of employment during the period of the industrial revolution. What were the implications of population growth ?
What was the effect of improvements in agricultural techniques ?

How important was the lead that Britain established in industrial technology ? Would things have been different if peasant farming had persisted as in France ?

As it turns out, our answers to these questions do not amount to an endorsement of any single position from the historiography. They do, however, provide considerable support for the emphasis placed on agrarian institutions by Patrick O'Brien.

2. A Primer on General Equilibrium in an Open Economy

A general equilibrium approach emphasizes the fact that an economy allocates resources among a range of alternative uses to produce a particular mix of goods. The allocation of resources and the mix of production will change systematically as underlying technological and market conditions change. The value of adopting an open economy general equilibrium perspective can be simply illustrated using diagrams based on the concept of the production possibility frontier which will be familiar to many students from elementary economics. The exposition that follows will also help to establish intuitions that aid the interpretation of the detailed numerical results that we present later in the paper.

Figures 1 to 3 (on pages 28-29) display permutations of a production possibility frontier (PPF) diagram where the two axes show the output of agricultural and industrial goods per person. If the economy is organized efficiently it will be on the PPF where more of one good can only be obtained by having less of the other. The slope of the PPF represents the marginal opportunity cost of one good in terms of the other, i.e., how much extra industrial output can be gained by giving up one unit of agricultural production. In equilibrium, this will be equal to the ratio of the prices of the two goods since at the margin when productive resources could be switched from one good to the other the revenue that would accrue must be the same, i.e., $\Delta A \times p_a = \Delta I \times p_i$ and $\Delta I / \Delta A = p_a / p_i$.

This is shown at point C in Figure 1. At this point prices would be represented by the line AB with slope p_a/p_i. Line AB is also just tangential to an indifference curve drawn for a representative consumer whose slope is the rate at which that consumer is willing to substitute one good for the other while maintaining a constant level of satisfaction.

Point C is the best outcome for an economy closed to international trade since it lies on the highest indifference curve that can be reached given the constraints of technology and resources represented by the PPF. Now suppose that the PPF in Figure 1 relates to an economy which can trade with the rest of the world but is too small to have any influence on world prices. If prices on world markets are such that p_a/p_i is lower than would have prevailed in the closed situation, then the economy will shift resources from producing agricultural goods to producing industrial goods. In the diagram this is illustrated by a move round the PPF to produce at D. D is tangential to the XY line whose slope is the world price ratio. This move represents an increased specialization in the production of industrial output. International trade occurs at the prices embodied in the XY line. The economy sells industrial goods and purchases agricultural goods so the consumer can now reach a higher indifference curve at E. The differences between the amounts consumed and produced of each good are agricultural imports and industrial exports, DZ and EZ, respectively. The higher is p_i relative to p_a the more specialized the economy will become in industrial production and the greater will be the consumer's gains from trade.

Now suppose that population increase reduces the economy's land endowment per person. The maximum agricultural output per person the economy can produce falls but maximum industrial output per person is unchanged. This case is shown in Figure 2. The reduction in agricultural land per capita shifts the PPF per person inwards along the agricultural goods axis. In the absence of trade, per person consumption of both goods will fall to point F with a higher relative price of agricultural products. With trade at unchanged international prices XY, the economy will shift resources to produce more of the

industrial good and less of the agricultural good at G. Per person consumption of both goods declines (at H) but by much less than in the absence of trade. Industrial exports increase from EZ to HJ and agricultural imports from DZ to GJ.

Figure 3 represents a case where technological progress has raised the economy's industrial (but not agricultural) production capabilities. The PPF is extended along the industrial goods axis but not the agricultural goods axis. With unchanged world prices, the open economy moves to production at N with more industrial and less agricultural output while consumption is at M where exports and imports are now higher at MP and NP, respectively.

Figure 4 summarizes the key implications of the previous three figures. Williamson's (1985) arguments about the implications of unbalanced productivity advance, noted in section 1 above, fall directly within this context. However, the exposition from these figures is incomplete because it refers to a 'small open economy', i.e., where world prices are unaffected by anything that this economy does. We feel that this is inappropriate in the case of Britain during the industrial revolution.

Figure 4. Specialization in A Small Open Economy

Specialize More in Exportable	*Specialize Less in Exportable*
Relative price of exportable rises	Relative price of importable rises
Production possibility of importable falls	Production possibility of importable rises
Production possibility of exportable rises	Production possibility of exportable falls
Exports and imports rise	Exports and imports fall

Note: in rows 2 and 3 imports and exports rise by the same amount but not in row 1.

To understand the importance of this point, return to Figure 1. If we now consider a large economy entering international trade with supplies and demands that influence world prices, the analysis needs to be modified somewhat. We have seen that with unchanged prices the economy moves to point D. If the economy is large, increased demand for agricultural imports might raise international agricultural prices. This price change is represented by a rotation of the XY line to a less steep gradient. The higher international agricultural price would lead to an equilibrium in which the move round the PPF does not go as far as D. The economy ends up at a point somewhere intermediate between C and D. Similar qualifications would be necessary for Figures 2 and 3 if world prices are affected by changes in the PPF.

This exposition of an elementary general equilibrium analysis for an open economy has worked through some simple 'five-finger exercises'. The objective has been to generate some heuristic insights that will be useful in considering the results of simulations of the CGE model in the following sections. A key message for the industrial revolution period that should now be readily comprehensible is as follows: 'When productivity grew very fast in Britain's exportable textiles, had productivity not increased at all in agriculture it would have been appropriate to specialize still more in textiles and import more food' (Crafts, 1985, p. 137).

3. An Initial Simulation of the CGE Model

Figures 1 to 3 provide useful introductions to the general equilibrium workings of an economy undergoing changes in openness, population and technology but they also have serious limitations. In particular, while the diagrams provide useful insights into the qualitative directions of change, they are poor guides to the quantitative magnitudes. Equally important, the diagrams cannot cope with economies with more than two goods. For some purposes,

aggregating economic activity this drastically may be acceptable but it seems inappropriate for understanding the industrial revolution. Our interpretation of technological change in this period has stressed the diversity of technological histories among manufacturing industries and that rapid advance concentrated in textiles and metals was crucial to the British experience (Harley and Crafts, 2000). It is also important to recognize that by 1841 the service sector employed 35 per cent of the labour force and accounted for over 40 per cent of national income.

It is possible to represent more complex economies using computational general equilibrium (CGE) models in which consumption and production relationships are embodied in mathematical equations. The equations are chosen to correspond to actual numerical values so that the model provides quantitative as well as qualitative results. This paper explores the British industrial revolution using a CGE model that is an extension of the one set out in Harley and Crafts (2000). Most importantly, we replaced a single representative consumer with three classes (wealth-holders, urban labour and rural labour) and modelled much of the demand for services as dependent on the distribution of goods from producers to consumers.

The CGE model works out the impact of changes in factor endowments and technology on output and prices by calculating new equilibria that balance demand and supply for goods and factors of production and equalize the money value of imports and exports. The structure of the model is predicated on the standard assumptions of neoclassical economics and Britain in the industrial revolution is modelled as a large economy, i.e., one whose output decisions do affect world prices.

Table 2 reports some of the results of a first simulation of the model with a view both to providing some familiarity with its workings and also to making clear that being open to international trade makes a substantial difference. The model was initially calibrated to replicate the British economy of 1841 in its key features. Most benchmark values are reported in column 1 as a base of 100 to

facilitate comparisons. The sectoral shares in value added and employment, however, are reported as actual percentages.

Table 2. CGE Simulation of 1841 Economy with Volume of Agricultural Imports Constrained to 1770 Level.

	1841 Benchmark	*Simulated Value (capital not adjusted)*	*Simulated Value (capital adjusted)*
Agricultural Imports	100	15	15
Industrial Exports	100	58	63
Agricultural Output	100	108	110
Industrial Output	100	90	99
Value Added in Agriculture (%)	22	28	28
Value Added in Industry (%)	35	30	30
Agricultural Employment (%)	22	26	26
Industrial Employment (%)	41	37	37
Price of Agricultural Goods	100	116	121
Price of Industrial Goods	100	93	91
Real wages	100	94	99
Real land rents	100	151	167
Real return on capital	100	93	82
Capital Stock	100	100	118
GNP/person	100	102	108

The simulation provides insights into the difference between a closed and open British economy. During the industrial revolution the British economy responded to changes in technology, demography and capital accumulation by relying increasingly heavily on agricultural imports. To illustrate the effect of trade we solved a variant of the model in which the volume of agricultural

imports was reduced to the level of 1770, about 15 per cent of the actual 1841 amount. Columns 2 and 3 of Table 2 show what would have happened if the economy had not been able to increase agricultural imports by limiting foreign supply to only 3.6 per cent instead of 24 per cent of 1841 benchmark agricultural consumption. It will be useful to refer to Figure 1 to get a feel for the responses that the model predicts while considering the detailed results in Table 2.

The counterfactual proposed is equivalent to the imposition of an even higher level of protection for domestic agriculture than existed in the early nineteenth century. Since the simulation does not eliminate trade, it would represent a situation where the relative price line rotated to a position intermediate between XY and AB. In Figure 1 this would move the equilibrium to a point on the PPF between D and C where agricultural prices would be higher relative to industrial prices than at D, while industrial output is smaller and agricultural output is greater than at D. While the simulations reported in Table 2 are more complex than this, the flavour of these responses is clearly visible.

The simulation in column 2 of Table 2 shows that if international trade had been severely restricted the economy would have been considerably less industrialized notwithstanding the technological progress of the industrial revolution period. The counterfactual industrial employment and value added shares are 37 per cent and 30 per cent, respectively, compared with 41 per cent and 35 per cent in the 1841 benchmark. The relative price of agricultural goods at 121/91 is about a third higher and agricultural output is 8 per cent greater and industrial output 10 per cent lower than in the benchmark. The economy is less able to exploit its comparative advantage in industrial production.

An interesting, and at first sight perhaps surprising, feature of this simulation is that this restriction of trade raises GNP per person by 2 per cent, although real wages fall by 6 per cent. The key to this result is that during the industrial revolution Britain was a big country in terms of world trade. Accordingly, Britain faced a downward sloping demand curve for its industrial exports. Restricting imports would reduce Britain's specialization in industrial

production and thus reduce the supply of exports to the world market. A higher price would be obtained for the remaining exports and this is equivalent to the exercise of market power. In other words, Britain could move the international terms of trade in its favour, i.e., British export prices would increase relative to the prices of goods produced in the rest of the world. In fact, because Britain was the major supplier of its main exports, the impact on prices could be very substantial.

It is well-known that in such circumstances imposing what the economics literature calls an 'optimal tariff' will make the home country better off.[2] The economic history literature has long accepted that this argument applies to early nineteenth century Britain and that in these terms its adoption of free trade in the 1840s reduced real national income (McCloskey, 1980; Irwin, 1988). There is no suggestion that the restriction that is imposed in Table 2 was 'optimal' in this sense but it does have a similar income-increasing effect. In the simulated equilibrium of column 2 of Table 2 the volume of Britain's exports falls by 42 per cent but, because their relative price rises by about a third, the volume of imports falls by a little under 30 per cent. British imports cost significantly less to purchase in terms of the home economy's resources.

Restricting trade raises agricultural prices and this pushes up the rent of agricultural land substantially. This raises the share of property incomes and lowers the share of wages in national income, a point that was not lost on the protagonists in the struggle over the abolition of the Corn Laws. This would naturally have implication for savings and capital accumulation in an economy where the saving rate from wage income was probably negligible and certainly much lower than those from rents and from profits (Horrell, 1996; von

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[2] Of course, there are several other potential effects of protecting domestic producers that might also be considered. These include the possibility that with reduced import competition home producers are less energetic in controlling production costs and that protection encourages a waste of resources in the pursuit of rewards from lobbying politicians, seeking favourable treatment in procuring imports etc. etc. It should not be assumed that a move from free trade to restricted trade generally raises economic welfare. Indeed we believe that, in general, the opposite is the case.

Tunzelmann, 1985). Economic theory suggests that the stock of assets accumulated by the propertied class would maintain a constant ratio with their income and the simulation of column 3 in Table 2 adopts this assumption.

Allowing the capital stock to adjust in this way in response to the changed distribution of income raises the counterfactual capital stock relative to the 1841 benchmark by 18 per cent. Accordingly, production possibilities across all sectors of the economy expand and the PPF shifts out. The increased capital per person entails a further increase in GDP per person to 108 in this counterfactual. The higher level of capital and the shift of income to high-income consumers are responsible for the trivial ultimate decline in industrial output relative to the benchmark.

In the context of industrial-revolution Britain we believe that taking account of the impact of changes in the distribution of income for savings and capital accumulation is appropriate. Indeed, this has been the traditional assumption in the literature. Therefore, in the tables that follow we only report simulations incorporating capital adjustment.[3]

Does this example have much historical relevance? The answer is surely yes for at least two reasons. First, the industrial revolution saw a sustained political struggle over the extent of agricultural protectionism, i.e., over how far the economy would be allowed to take advantage of the gains from international trade which only saw the landed interest finally defeated with the abolition of the Corn Laws in 1846 (Barnes, 1961). Second, as O'Brien (1989) has underlined, failure to defeat Napoleon would in all likelihood have curtailed British trade and thus have pushed the allocation of resources in the direction of the closed economy case. Thus, in the simulations that follow, on each occasion, we report results with trade free to adjust fully and results where agricultural imports are constrained to the 1770 level.

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[3] This way of modelling the 'capital adjustment' would not, however, be appropriate in many other circumstances. In particular, it would be inappropriate in a fully globalized world in which capital markets allow countries to have unlimited access to foreign savings.

4. Simulating the Effects of Population Growth and Technological Progress.

At this point we return to the claims of the historiography that relates to factors promoting the unusual degree of industrialization in the British economy. Our approach will be to present the results of a series of simulations of the CGE model designed to illuminate these arguments. In this section we explore successively the impact of holding the population at its 1770 size (about 45 per cent of its 1841 level), of eliminating post-1770 total factor productivity growth in agriculture, and of restricting the advance in British industrial technology to the rate achieved in the rest of the world.

Table 3 reports the results of a simulation in which population is reduced to 45 per cent of its actual 1841 level. This is equivalent to there being no population growth between 1770 and 1841. Figure 2 is the reference point for these results but the counterfactual considered is the reverse of that discussed earlier.

In the case where trade adjusts fully, the counterfactual elimination of post-1770 population growth is significantly de-industrializing. Agricultural employment rises by nearly a third from 22 per cent of the labour force in the 1841 benchmark to 29 per cent while industrial employment falls by an equivalent amount from 41 to 34 per cent. This is somewhat similar to the move from G to D in Figure 2 but here we are considering a large not a small economy and this occurs despite a rise in the relative price of industrial goods. This result mainly arises because our model has strongly diminishing returns to labour in agriculture. When population pressure is reduced, labour productivity increases, rents fall and the sector can afford to attract a bigger share of the labour force even though relative prices have moved against it. In addition, the lower agricultural goods price increases per capita agricultural consumption well above its 1841 level.

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Table 3. Simulated 1841 Economy with 1770 Population

	1841 Benchmark	*Trade Adjusting*	*1770 Agricultural Imports*
Agricultural Imports	100	62	15
Industrial Exports	100	42	29
Agricultural Output	100	70	82
Industrial Output	100	41	38
Agricultural Employment (%)	22	29	34
Industrial Employment (%)	41	34	30
Price of Agricultural Goods	100	77	86
Price of Industrial Goods	100	111	105

Note: "trade adjusting" in this and the following tables means that volumes of both imports and exports are free to respond to market signals and the economy is fully open to international trade.

Column 4 of Table 3 combines eliminating the population growth after 1770 and a constraint on agricultural imports (thus limiting exports of the manufacturing sectors where technological change had been most rapid) and illustrates the combined effect of population growth and trade. Constraining agricultural imports to the 1770 level (as in column 2 of Table 2) with the much smaller population leads to more de-industrialization than does just population change. The agricultural share rises from 29 per cent in column 2 to 34 per cent (and up from 26 per cent with limited trade but unchanged population in Table 2 column 2). In terms of Figure 2, with the economy closed to trade expansion, production has moved from F to C but with quite a marked rise in the relative price of industrial goods (steepening of the AB line) from 91/121 to 105/86. Allowing trade fully to adjust reduced this effect but the relative price of industrial goods still rises by 44 per cent. Again, however, the severity of the

diminishing returns in the agricultural sector and the increase in agricultural consumption stimulated by lower food prices is such that, compared with F, the equilibrium point C has much greater agricultural output but relatively little increase in industrial output.

The simulations in Table 3 show clearly that the population growth of the industrial revolution era stimulated industrialization. In terms of our earlier literature review, this supports the position advanced by Landes (1969) but not that of Williamson (1985). Williamson's argument is undermined by the fact that agriculture is always an importable and by the strongly diminishing returns which ensue in the agricultural sector as demographic pressure intensifies in our model. Population growth also tends to shift the distribution of income in favour of capital and land especially in the less open economy case thereby leading to more savings and a higher capital to labour ratio in the economy as a whole.

Nevertheless, it hardly seems plausible that demography fully accounts for precocious British industrialization of employment. Although population grew about twice as fast during the British industrial revolution as in continental Europe (Tranter, 1994, pp. 37-8), Table 3 indicates that this would account for only around 3 percentage points difference in the share of agriculture in the labour force in 1841.

Table 4 reports the results of simulations in which there are no advance in total factor productivity in agriculture after 1770. This is equivalent to raising each of the required factor inputs (land, labour and capital) per unit of output by 50 per cent in 1841. This case can also be considered with reference to Figure 2. Suppressing post-1770 technological improvement in agriculture in this way corresponds to the maximum agricultural production point on the PPF moving in toward the origin.

Table 4. Simulated 1841 Economy with 1770 Agricultural Technology

	1841 Benchmark	*Trade Adjusting*	*1770 Agricultural Imports*
Agricultural Imports	100	142	15
Industrial Exports	100	132	66
Agricultural Output	100	59	73
Industrial Output	100	103	98
Agricultural Employment (%)	22	19	26
Industrial Employment (%)	41	45	38
Price of Agricultural Goods	100	109	151
Price of Industrial Goods	100	96	82

Here the results of the simulations are rather different depending on whether trade adjusts. In the simulation in which trade is allowed to adjust (column 2 of Table 4) we see that imports paid for by industrial exports replace some inefficient agriculture. Agricultural employment falls from 22 to 19 per cent of the labour force while industrial employment has risen by an equivalent amount from 41 to 45 per cent. National income and real labour income fall substantially (about 15 per cent) reducing demand for all goods. As a big country, Britain experiences a small change in relative prices with agricultural prices rising but the main effect of lower agricultural productivity is a large increase in agricultural imports. The outcome is reasonably similar to the move from D to G in Figure 2. In this trade adjusting case, the distribution of income moves against property because land is significantly less productive. In response, the capital stock is 16 per cent lower than in the benchmark.

If agricultural imports, along with agricultural productivity, are kept constant at the 1770 level, there is a bigger impact on real labour income which falls by about 50 per cent. GNP, however, falls only about a third as much as when imports increase (about 5 per cent) because property incomes and, in

consequence, the capital stock increase. The structure of employment changes only modestly. Agriculture employs 26 per cent of the labour force, up from the actual 22 per cent but the same as in column 2 of Table 2 where trade is also constrained. Industrial employment at 38 per cent is somewhat below the 1841 level but slightly higher than in the trade constrained case of Table 2. This is similar to the move from C to F in Figure 2 and is accompanied by a rise in the relative price of agricultural goods from 121/91 to 151/82. In this case, income shifts a bit toward property and the capital stock is 6 per cent higher than in the benchmark.

Table 4 bears out Williamson's (1985) predictions. In the open economy of industrial revolution Britain, if productivity growth had been more unbalanced in favour of industry, industrialization would have been enhanced. It would have been appropriate to specialize more in exportables like cotton textiles whose exports rise in the counterfactual by about 40 per cent. However, the overall impact is not dramatic; a substantial change in counterfactual agricultural productivity causes only a modest fall in the share of the labour force in agriculture.

Table 5 explores the effect of Britain's lead in industrial technology by simulating what the economy would have looked like if the rate of post-1770 technological progress in British industry were reduced to that in the rest of the world. This amounts to increasing the required primary inputs in cotton production by 50 per cent, in metal production by 20 per cent and in other textiles by 5 per cent. This can be understood in the context of Figure 3 but with the reverse shift as the industrial goods end point of the PPF moves toward the origin.

Table 5. Simulated 1841 Economy with No British Lead in Industrial Technology

	1841 Benchmark	Trade Adjusting	1770 Agricultural Imports
Agricultural Imports	100	62	15
Industrial Exports	100	60	47
Agricultural Output	100	103	109
Industrial Output	100	75	76
Agricultural Employment (%)	22	24	26
Industrial Employment (%)	41	40	38
Price of Agricultural Goods	100	101	113
Price of Industrial Goods	100	113	106

As would be expected, in column 2 of Table 5, we find that, relative to the benchmark case, with full trade adjustment the reduction in industrial technological advance is de-industrializing. Once again, however, the effects are quite modest. Agricultural employment rises from 22 to 24 per cent of the labour force. This is similar to a move from N to D in Figure 3 but with some offset from the large country effect on relative prices which shift in favour of industrial goods. Lower profits from lower productivity reduce the capital stock by 8 per cent. Restricting agricultural imports (column 3) results in greater de-industrialization but the structure of the economy is almost the same as occurs when restrictions of imports act alone (Table 2, column 2).

Table 5, like Table 4, supports the position put forward by Williamson (1985). With an economy that can take full advantage of international trade, a greater imbalance in productivity growth towards industry causes a more industrialized labour force. But since in Britain, while productivity growth was skewed towards exportable manufactures, notably textiles, there was also significant advance in agriculture, an extreme degree of unbalanced technological

progress does not seem adequately to explain precocious British industrialization. Broadly speaking, most of Northern Europe adopted improved crop rotations leading to substantial gains in arable yields such that the level of total factor productivity in French and Irish agriculture in 1841 was not far below that of Britain (Crafts, 1989, pp. 422-3). So the unusual aspect of British technology was industrial rather than agricultural and Table 5 suggests that this only explains about 2 percentage points of the 1841 industrialization of employment.

5. Capitalist versus Peasant Farming

In 1841 the share of the labour force in agriculture in Britain was some 25 percentage points below the level that regression methods suggest was normal for a nineteenth century European country at the same income level (Crafts, 1985, p. 62). The simulations above show that both unusually strong population pressure and unbalanced productivity growth can explain only a relatively small part of this gap between the British experience and the 'European Norm'.

Early modern British agriculture was remarkable less for its technological leadership than for the emergence of an agrarian structure based on capitalist farming. British agriculture, with its landlords, tenants and wage labourers on large holdings, contrasted with family or peasant farming elsewhere. As was noted earlier, this has been re-asserted by O'Brien (1996) as a major reason for the much greater industrialization of the British labour force. This section examines the plausibility of such an argument in terms of our CGE model.

Cohen and Weitzman (1975) presented a simple theoretical model to justify predictions along these lines. The model relies on the assumption that peasant workers receive wages based on the average product of the household while in profit-maximizing capitalist agriculture workers are paid wages equal to their marginal product. The difference that this makes for a given technology is shown in Figure 5 (on page 29).

In the peasant case labour remains on the farm so long as the income of the farm allows the family to share total farm product and earn an income equal to that which could be earned in the labour market off the farm. Thus employment is at E where the average product of labour equals the market wage rate. This implies that rent is dissipated among the peasants. In the capitalist case, farmers hire labour to the point where marginal product of labour equals the market wage and employment is at d. This results in rent equal to the rectangle abcd which is made up of the difference at d between average product and the wage times the amount of employment. In comparison, the peasant family uses more labour, its members earn the equivalent to the market wage and it retains 'surplus labour' whose average and marginal product are below that in capitalist farming. Replacement of peasant by capitalist farming would lead to a reduction in farm employment and a transfer of income towards rents.

Figure 5 does not consider the wider (general equilibrium) implications for the economy as a whole of a move from peasant to capitalist agriculture. Cohen and Weitzman did an analysis of this kind. They found that a switch from peasant to capitalist farming resulted in the use of less labour intensive methods in agriculture, a rise in rents, and a net outflow of labour from agriculture to the rest of the economy. GDP increased as labour was used more efficiently but real wage rates declined as the displaced workers were absorbed by the labour market. Looked at the other way around, if peasant farming leads to the equalization of average product wages in agriculture with marginal product wages prevailing elsewhere in the economy, it leads to a more agricultural labour force than would be observed in the neoclassical equilibrium.

The Cohen and Weitzman model has three important limitations, however. First, it does not allow for the accumulation of capital to respond to the increase in property income. Second, it is essentially a closed economy model. Third, it is abstract rather than quantitative and deals only in directions of change not magnitudes. We can address all these issues using our CGE model. Our simulations distribute labour between the capitalist and peasant sectors using the

assumption that small family farmers equalize the average product of labour to the market wage.

Allen (1992) described a 'landlords' revolution' in eighteenth century England that amounted to the 'disappearance of the yeoman', i.e., to the virtual elimination of small-scale family farming. Identifying peasant farms as those with less than 60 acres while capitalist farms had over 100 acres, he argued that, while in 1688 the peasantry occupied almost two-thirds of the land, by 1800 the proportion had fallen to only about 10 per cent (1992, p. 85). Moreover, his analysis of farm surveys clearly reveals the classic result that farms of under 50 acres used substantially more labour per acre and have higher output per acre than capitalist farms of 100 acres or more. Accordingly, the move to large farms lay behind the gains in agricultural labour productivity during the eighteenth century (1992, pp. 211-225).

Continental countries such as France were much less affected by developments of this kind. In the mid nineteenth century average farm size in France was about 30 acres compared with over 100 acres in Britain and farms of 100 acres or more accounted for only 29 per cent of French land at that time. In 1840, French agricultural labour productivity was 60 per cent whereas total factor productivity was about 84 per cent of the British level. Rather more of the labour productivity gap came from lower French land and capital to labour ratios resulting from the persistence of small farms than from lower crop yields (Crafts, 1989).

In the light of this literature, it seems relevant to model the general equilibrium implications of a switch from peasant (average product wages) to capitalist (marginal product wages) farming. This provides insights into both the consequences of the 'landlords' revolution' in English agriculture and the basis of precocious British industrialization. Table 6 presents the results of a simulation based on a switch from fully capitalist agriculture in the 1841 benchmark case to a situation with 2/3 of the land devoted to peasant farming. As in the earlier simulations, capitalists' assets (now reduced by land and

agricultural capital in the hands of peasant families) are assumed to adjust to maintain a constant ratio to their incomes. Since there are suggestions in the literature that a move to capitalist agriculture with better property rights may have encouraged innovation we assume somewhat lower total factor productivity in peasant agriculture at 80 per cent of the 1841 benchmark. This is in line with the discussion in Allen (1999) which suggests no more than a modest impact of this kind from the landlord's revolution. We have also assumed that capital in peasant agriculture was 20 per cent lower than on the same land in 1841; this is a land to capital ratio about halfway between the actual 1770 and 1841 levels.

Table 6. Simulated 1841 Economy with 2/3 Land in Peasant Farming

	1841 Benchmark	*Trade Adjusting*	*1770 Agricultural Imports*
Agricultural Imports	100	101	15
Industrial Exports	100	80	41
Agricultural Output	100	105	111
Industrial Output	100	69	55
Agricultural Employment (%)	22	47	57
Industrial Employment (%)	41	28	21
Price of Agricultural Goods	100	94	113
Price of Industrial Goods	100	113	94

Note: TFP in peasant agriculture is assumed to be 0.8 the actual 1841 level as is the capital to land ratio.

The results in Table 6 show that replacing capitalist with largely peasant farming has a big de-industrializing effect — much larger than that of any of the earlier counterfactuals that we have considered. The results are consistent with the predictions of Cohen and Weitzman (1975). The impact in the fully open

economy case is to more than double agriculture's share in the labour force to 47 per cent and to reduce industry's share by 13 percentage points. In this case there is also a noticeable effect on the services sector where employment falls by 12 percentage points. This occurs primarily because there is a much-reduced need for distribution services to bring food to an urban population. Income moves from property owners to peasants and labourers. Real wages fall by less than 5 per cent despite a fall in property owners' real incomes, and consequently of the non-agricultural capital stock, by over 40 per cent. This case also involves a move in production space from the PPF to a point within it — in Figure 1 this would be to the south west of D — and GDP falls by 22 per cent.[4]

In the case where agricultural imports are restricted to the 1770 level, Table 6 reports that agriculture's share in the labour force rises by 31 percentage points while industry's share falls by 16 percentage points compared with Table 2, column 2. Increased dependence on inefficient peasant agriculture increases the reduction in GDP to 26 per cent and lowers workers' welfare by a similar 4 per cent. While agricultural output increases slightly, industrial output falls by 44 per cent. In this simulation, Britain has moved all the way to the 'European Norm'.

Comparison of Tables 4 and 6 permits clarification of the relationship between productivity change in agriculture and industrialization. In Table 4 it emerged that, given that the British economy was based on capitalist farming, as it was by the mid-nineteenth century, improvements in agricultural technology that raise land and labour productivity slow down industrialization. From Table 6 we learn that a move from peasant to capitalist farming would raise labour productivity and at the same time would promote industrialization very significantly. Since this latter change was a large part of the exceptional

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[4] It is possible that other feedbacks from a move to peasant agriculture should be added in to the simulation. The most obvious would be to allow a move away from proletarianization of the labour force to reduce population size through later marriage and lower fertility, as argued by Goldstone (1986). In further simulations (not reported here) we have explored this possibility and we do not believe it would make very much difference to the results on deindustrialization reported in Table 6.

eighteenth century British experience, it seems right to conclude that agriculture did release labour as Allen (1992) and Wrigley (1985) supposed. The reason for this was a move to relatively large-scale farming rather than enclosure per se but, even so, the emphasis placed by Landes (1969) on population growth rather than agrarian change as the main impetus to industrialization of the labour force is clearly misleading.

In terms of our earlier work, these various simulations also make for more coherence. There was a transfer of labour to industry from the British agricultural sector which itself achieved comparatively high levels of productivity because it adopted large-scale capitalist farming (Crafts, 1989). Rapid technological change in exportable manufactures and diminishing returns in agriculture in the face of substantial population pressure were industrializing forces of unusual strength (Harley and Crafts, 2000). "Both industrial technology and mobility out of agriculture were important" (Crafts and Harley, 1992, p. 705). But *a propos* of this last remark, the quantification that we have now achieved indicates that a distinctive agrarian structure mattered considerably more than we have previously recognized.

6. Conclusions

There are several important messages to take away from this analysis both methodological and substantive. With regard to the former, we believe that the paper has reinforced the point that CGE models can be valuable tools for economic historians. At the same time, it should also be clear that to understand structural change in the British industrial revolution requires an open economy framework and explicit recognition that, in the terminology of international economics, Britain was a big country.

In terms of the historiography of British industrialization, our simulations suggest that various familiar explanations for pronounced structural change do

indeed have some validity. These include the suggestion by Williamson that unbalanced sectoral productivity growth played a part and the argument of Landes that population growth was conducive to industrialization. But we have also demonstrated that it is crucial to distinguish between a release of labour associated with a switch from family to capitalist farming and agricultural productivity improvement in a fully capitalist economy.

Indeed, our most important substantive conclusion is that the key feature of the British economy was its (virtually) complete conversion to capitalist farming. Without taking this into account, it is not possible to explain British exceptionalism in its mid-nineteenth-century employment structure.

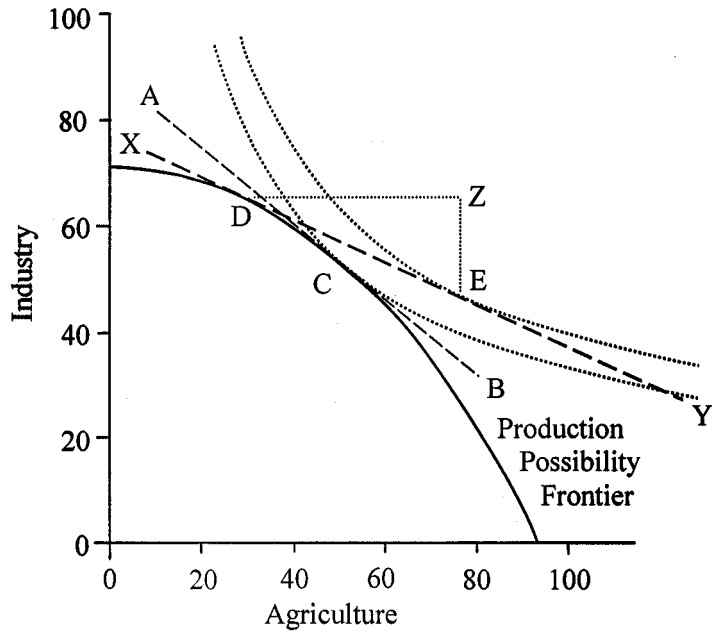Figure 1: Production Possibility and Autarchy and trade Equilibria
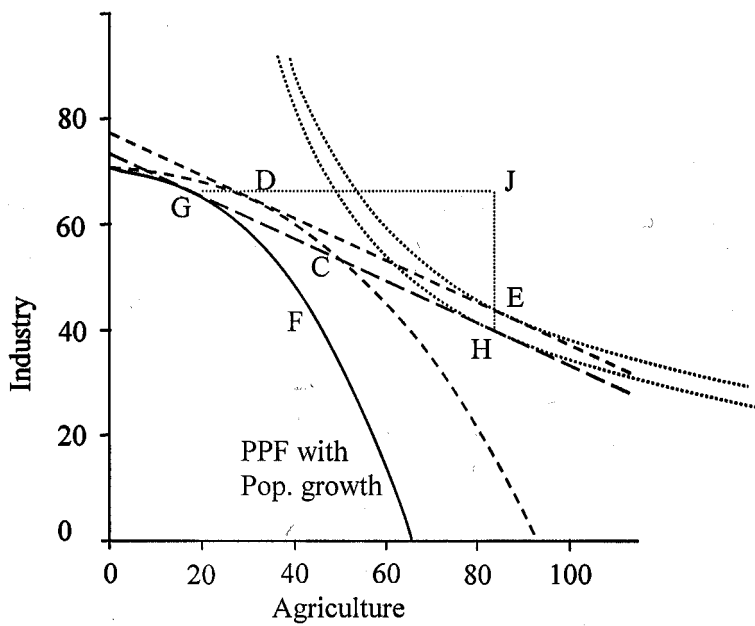

Figure 2: Population Increase

28

Figure 3: Technological Advance in Industry

Figure 3: Technological Advance in Industry

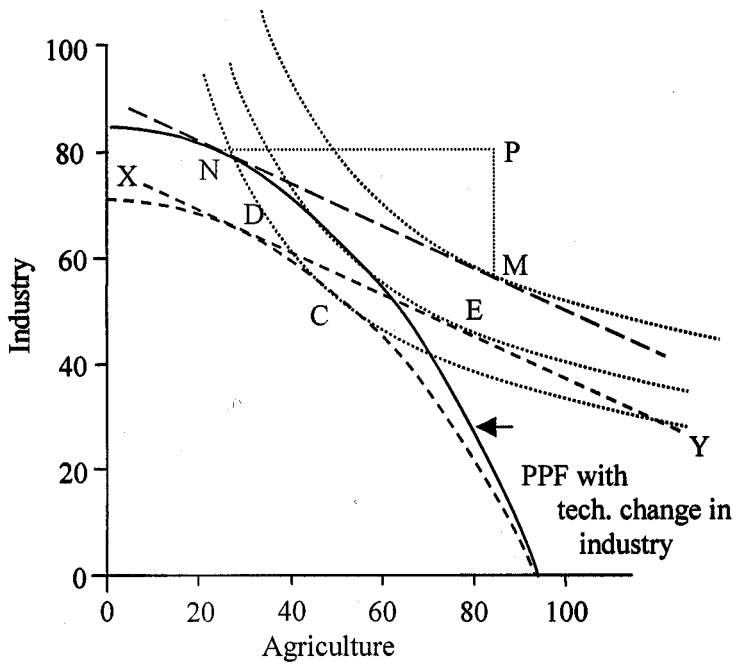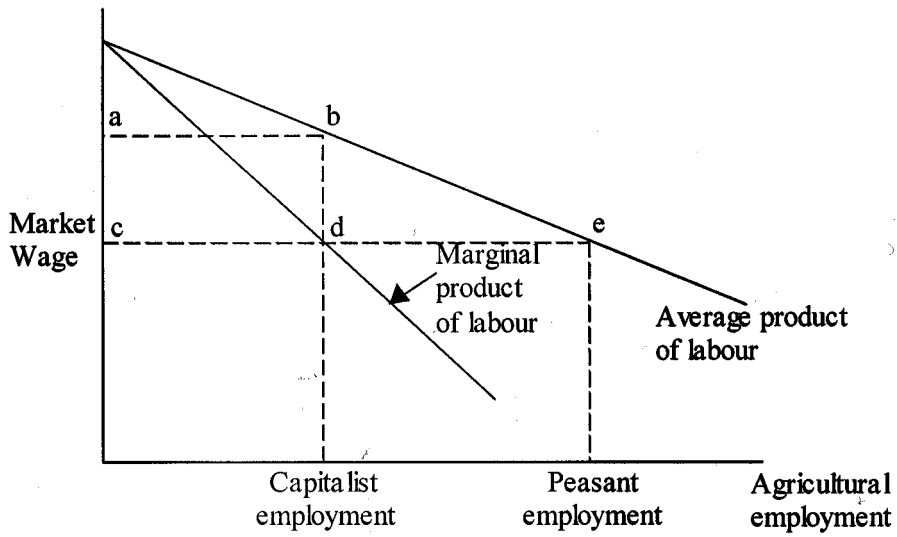## Figure 5: Peasant and Capitalist Agriculture

Figure 5: Peasant and Capitalist Agriculture

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