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## ABSTRACT

This paper examines British trade and growth in general equilibrium. It rejects Peter Temin's contention that the Crafts-Harley 'new view' of sectorally concentrated productivity growth during the Industrial Revolution is inconsistent with actual industrial exports. A CGE trade model with diminishing returns in agriculture that also emphasizes demand conditions indicates that while technological change in cottons and iron were major spurs to exports, the demand for food imports generated by population growth and diminishing returns in agriculture also stimulated trade. The trade data are compatible with the 'new view' and any implied adjustment to TFP growth estimates is slight.

JEL Classifications: F14; N73; O52

Keywords: industrial revolution; Ricardian trade; productivity growth

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In traditional accounts of the British Industrial Revolution, as set out in famous books by T.S. Ashton and David Landes, technological change occurred widely through the economy and provided the engine that initiated modern economic growth.[1] Phyllis Deane and W.A. Cole's pioneering estimates of British national income provided support for this view.[2] Later reassessment of the quantitative evidence suggested that Deane and Cole had substantially overestimated British growth before 1840.[3] In putting forward this revised view, N.F.R. Crafts and C. Knick Harley indicated that the overall productivity impact of technological change in aggregate was much slower and more concentrated in a few industries than had been generally assumed. The famous modernizing sectors of the Industrial Revolution and a precocious British agriculture accounted for almost the entire aggregate productivity growth.[4] The Crafts-Harley view, although it has received wide support, has disturbed many commentators who find its implications hard to reconcile with the economic structure and the pattern of trade of the mid-nineteenth century British economy. Initial unease focussed on Crafts's conclusion that technological change in agriculture exceeded the rate of technological change in the rest of the economy, with the obvious exception of the textiles and metal industries at the heart of the Industrial Revolution. How, if agriculture was so productive, did Britain come to be an economy with a declining agricultural sector and

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[1] Ashton, *Industrial Revolution*; Landes, *Unbound Prometheus*.

[2] Feinstein, "Capital Accumulation", p. 141; Deane and Cole, *British Economic Growth*, p. 78, 283.

[3] Harley, "British Industrialization", Crafts, *British Economic Growth*, and Crafts and Harley, "Output Growth".

[4] Harley, "British Industrialization", Crafts, *British Economic Growth*, and Crafts and Harley, "Output Growth".

an increasingly large exporter of manufactured goods?[5] Recently, Peter Temin has extended the challenge using a theory of international trade that incorporates technological change. He argued that the continued export of manufactures from sectors beyond those famously transformed by the Industrial Revolution implied widespread technical change in British industries during the early nineteenth century.[6]

Trade data, because of their availability and reliability and because they reveal comparative advantage, have always been an important source of evidence about economic growth. In this paper, we explore the British economy during the Industrial Revolution using a general equilibrium model that incorporates international trade. Our model, although a radical simplification of historical reality, is considerably more complex than the parsimonious model that Peter Temin relied upon. We think, however, that Temin's model abstracted from key elements of the Industrial Revolution and consequently he arrived at erroneous conclusions.

We feel that any realistic modeling of the Industrial Revolution must include three features that Temin ignored: First, British population grew very rapidly but land resources were effectively constant. Second, the British industries of the Industrial Revolution, and particularly cotton textiles, became very large relative to world markets for their products and their output levels crucially affected world prices of these goods. Third, the conventionally defined industries produced a variety of goods that were at best imperfect substitutes for one another and goods within categories of

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[5] Harley, "British Industrialization", Crafts, *British Economic Growth*, and Crafts and Harley, "Output Growth".

[6] Harley, "British Industrialization", Crafts, *British Economic Growth*, and Crafts and Harley, "Output Growth".

the trade statistics were a heterogeneous bundle of imperfect substitutes. Examination of a computational general equilibrium model with these features comfortably reconciles our view of the broad outlines of technological change with the history of British trade. The model also reveals that the answer to our critics' concerns arises from aspects of the economy that we see as central in the history of the Industrial Revolution.

The model explains the general equilibrium evolution of Britain's mid-nineteenth century trade structure. First, increasing population in the face of limited land resources even with improving agricultural technology put upward pressure on British food prices. In the absence of trade, British food prices would have risen above the prices elsewhere. However, trade was possible so the demand for imports increased. Increased imports had to be paid for and, in general equilibrium, increased demand for imports leads to increased exports. Without the Industrial Revolution, British exports of various products probably would have expanded approximately in proportion to their levels around 1770. Of course, British cotton textiles experienced spectacular technological change at this time and quickly captured export markets, independently of the demand for food imports. But we must keep in mind that the export success of British cotton textiles rested on the dramatic fall in the price of cloth. As a result, increased exports of cottons had a more limited general equilibrium effect in meeting the need to pay for increased food imports than it would initially appear. Exports increased dramatically but prices fell dramatically as well. As a result revenue from cotton exports grew much less than cotton exports.[7] This limited growth of revenue, despite the spectacular increase in the volume of cotton exports, implied that the export

[7] In fact, if the elasticity of foreign demand had been sufficiently low, one or below, the revenue, and thus the food that could be purchased, from cotton exports would not have expanded at all.

of other commodities remained necessary to pay for food imports. Furthermore, some trade persisted within broad commodities independent of technological change because foreign and domestic goods within trade categories were not homogeneous. Exports of some specialized goods persisted even if relatively unfavorable technological change eliminated most exports in the category.

## TEMIN'S CRITIQUE AND THE USE OF THE RICARDIAN TRADE MODEL

Peter Temin has recently proposed a test to discriminate between the old and new views of technological change during the Industrial Revolution that uses data on exports and imports. Temin argued, on the basis of a Ricardian model of the effect of technological change on international trade, that the fact that export of other manufactures (from the "unmodernized" sectors) continued as the Industrial Revolution progressed implied that technical change was widespread among British industries in the early nineteenth century.[8] Other manufactures remained important exports through 1850, so he concluded that "the traditional, 'old-hat' view of the Industrial Revolution is more accurate than the new, restricted image...The spirit that motivated cotton manufactures extended also to activities as varied as hardware and haberdashery, arms, and apparel...The low rate of productivity change shown [by Crafts and by Harley] for other activities is too low. There must have been more technical progress outside the listed sectors..."[9] Temin's conclusions also receive some support from Richard Sullivan's research into patenting. Sullivan examined patents within a sectoral breakdown that corresponds to Temin's trade categories. Over the period 1781-1850, he found that only 20.7 per cent of patents occurred in cloth and iron while 32.1 per

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[8] Temin, "Two Views", pp. 72-3.

[9] Ibid., p. 79.

cent occurred in other exporting industries.[10] He argued that the patenting evidence "attests to the widespread nature of invention and innovation during the first half of nineteenth century England."[11]

We agree with Temin that it is important to enquire whether trends in external trade are consistent with interpretations of the Industrial Revolution. We do not, however, believe that Temin's conclusions are justified. His use of the simple Ricardian trade model embodies restrictive assumptions inappropriate to the historical circumstances. None the less, examination of the Ricardian model provides a useful starting point for examination of the relationship between technological change and trade in the Industrial Revolution. The model underlies Temin's conclusions. In addition, when suitably modified the same model provides insights into the results that we obtain with a more appropriate but more complex general equilibrium model.

Temin's choice of model is in line with much of the theoretical literature that investigates the effect of technological change on trade. A Ricardian model of trade with a continuum of goods produced with a single factor of production abstracts from complications that more complex specifications would introduce.[12] An implication of the model is that each good will only be produced in one country and exported to the other, with the possible exception of one marginal good that may be produced in both countries but exported by only one. The theorists usually also simplify the demand side of the model and assume that consumers spend a constant share of their income on each

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[10] Sullivan, "Out of the Bottle", Table 1.

[11] . Ibid; p.3.

[12] Grossman and Helpman, "Technology".

good. As Grossman and Helpman remark, "this simple continuum model gives sharp predictions" but, at the same time, there is a serious danger that the simplifications will be misleading in the analysis of historical data.[13]

[Insert Figure 1]

Temin's Figure 1, which is reproduced here, shows his use of the model. Since there is a single factor of production, labor, the production technology of each good on the continuum may be represented by a single parameter, $a_n$, where $a_n$ is the number of hours of labor needed to produce a single unit of good $n$ in Britain. Similarly, $a^*_n$ is the number of hours needed to produce a single unit of the good abroad. For any given ratio of British to foreign wages, British relative costs of goods (and prices if there were no trade) will be ranked, from low to high, according to the ratio of $a^*/a$ — Britain's relative technological advantage. We can conveniently order the continuum of goods produced along the horizontal axis according to Britain's relative technological advantage. At a high relative British wage $(w/w^*)$, Britain produces only those goods in which its technological superiority is greatest but as $w/w^*$ declines, Britain produces and exports more goods. Curve $A$ in Figure 1 traces the goods produced in Britain as a function of the relative British wage rate given the relative technologies in the two countries.

As the Britain produces more goods, its share in world income increases, and since all income from production accrues to wages in the producing country, its relative wages rise. If the home country produces all of the goods with an index less than $z$ and the

[13] Ibid., p. 1287.

share of world income devoted to its aggregate output is $B(z)$, then $B(z)(wL + w^*L^*) = wL$ or

$$\frac{w}{w^*} = \frac{L^* B(z)}{L(1-B(z))}$$

Thus we obtain the upward sloping curve $B$ in Figure 1 where the relative wage rate is a function of the proportion of production occurring in Britain. Equilibrium occurs at the intersection of the $A$ and $B$ curves determining British relative wage and production. Britain produces and exports all goods to the left of $x_0$ and imports all goods to the right.

Temin uses Figure 1 to analyze the effects of technological change. General relative improvement in British technology would shift curve $A$ to $A'$ while leaving curve $B$ unaffected. This would increase the range of goods exported by Britain to include all goods to the left of $x_1$.[14] Temin also considers the case of technical changes restricted to a narrow range of goods already exported. In this case demand shifts to these now cheaper goods and, he argues, the $B$ curve shifts to $B'$ because the income of the producers increases as sales increase. The new equilibrium is to the left of the original point at $x_2$ and the range of exports falls. He concludes "General technical change causes the list of exports to rise, while restricted technical change causes it to fall. This difference provides a test of [the two] views".[15] Moreover, the tendency for other manufactures to become imports would be intensified by TFP growth in agriculture that would cause these goods to move to the right in the array over time.

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[14] Temin, "Two Views", p. 70.

[15] Ibid., pp. 72-3.

Temin's outcome is, however, a special case for several reasons. It does not provide a sound basis upon which to discriminate between competing accounts of productivity growth during the Industrial Revolution. Even if we accept the basic model, Temin's inferences rely on implicit assumptions concerning demand elasticities that may not be valid. More seriously, the model fails to recognize the importance of a fixed factor, land, in the agricultural production function and of differentiated goods within the categories listed in the trade statistics. In fact, serious consideration of demand elasticity and population growth within the Ricardian model, issues we consider central and that provide the focus of our modeling below, reveals how misleading Temin's conclusions may be. Examination of the Ricardian model, perhaps somewhat surprisingly, also allow us to see why, contrary to Temin's assertion, Britain continued to export manufactured goods whose technology was not affected by the Industrial Revolution.

The results we find using a more realistic model of British trade arise from three sources. First, diminishing returns in agriculture led to food imports that in turn required a growth in revenue from manufactured exports. Second, Britain became such a dominant producer of Industrial Revolution goods that it faced downward sloping demand curves for these goods. Third, the trade categories in the British customs, which Temin uses for his test, were amalgamations of the goods in the conceptual Ricardian model and so, while technology may have driven some goods from exports to imports, others in the same industry remained exports. The broad trade categories failed to document the switch that occurred.

Let us start with the second of our concerns, the elasticity of demand for exports, because it fits directly into Temin's framework, and he seems to have failed to understand its significance. The elasticity of demand for the exports of the goods that experienced technological change matters. This is true both in Temin's restricted case and in the more general case we discuss below. Temin asserts that technological change in a single (or narrow range of) export industry will cause some goods that had been *exports* to become *imports* but this occurs within the model only under certain conditions of demand. If demand is inelastic, selective technological change in a single good will result in an increase in the quantity exported but price will fall more than in proportion and export earnings from that good will fall. Balance of payments equilibrium will require that some goods shift from *imports* to *exports* rather than the other way as Temin asserts. Under the assumption of constant expenditure shares (unitary elasticity of demand) usually used by theorists, the percentage increase in the quantity of exports will be matched exactly by the percentage fall in price. In this case the expenditure on the good (and command over other goods from its export) are the same. Consequently, after the technological change the *B* curve in Figure 1 will be unaffected. Since selective technological change shifts curve *A* upward only locally and not in the vicinity of $x_0$, equilibrium and the range of exports is unchanged. In this case, the benefits of technological change occur only in lower product prices and are shared equally by all consumers whether they are in the producing or importing country.[16] Only if demand is elastic, i.e., the proportion of income spent on the good increases as its price falls, will the range of exports shrink in line with Temin's predictions.

Differences in population (and labor force) growth affect the equilibrium distribution of production and trade. As is apparent from the formula for curve *B* presented above, a relative increase in domestic population will shift curve *B* downwards. Without technical change, even in the absence of diminishing returns, relative wages will fall in the country with the greater labor force increase. For that country, the *B* curve will

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[16] Harley, "Reassessing", pp. 201-3 makes this argument for cotton in the Industrial Revolution.

shift down and at the new equilibrium *there will be an expansion in its range of goods produced and exported.* If a country increases its proportion of the total world labor force, equilibrium requires that it also increase its share of production and this can only occur by moving along curve A in response to a fall in relative wage rates. If, in addition, the Ricardian model's assumptions are modified to allow diminishing returns in agriculture, as we feel must be the case, this effect will be augmented.

Consider a model with two types of goods: a set of Ricardian manufactured goods, each facing a unitary elastic demand, and an agricultural good produced with diminishing returns because of its dependence on land, a factor of production in fixed supply. Population increase, even if partially offset by technological change in agriculture, raises demand for agricultural goods, puts upward pressure on domestic agricultural prices and provokes increased agricultural imports. This will require an increase in export revenue. Within the model, an increase in export revenue can come only if some goods not previously exported are now exported.

As will become clear below, predictions of the impact of technological change on British trade are highly sensitive to the specification of the agricultural production function. Temin's agricultural goods are produced by labor alone and without diminishing returns. This is surely inappropriate for modeling trade in late eighteenth and early nineteenth century Britain where rapidly growing population pressed on land resources. Indeed, the standard view has been that land was to all intents and purposes a fixed factor and this was certainly a key feature of our own earlier discussions of productivity change in this period.[17] Moreover, this seems to be supported by trends in

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[17] Crafts, *British Economic Growth*, pp. 117-8 and "Some Difficulties of Interpretation", p. 253, and Harley, "Reassessing", pp. 205-6. For textbook assertions

agricultural rents that nearly tripled between the mid-eighteenth and the mid-nineteenth centuries.[18]

Finally consider the issue of industries producing differentiated goods. In principle, their existence would not rule out the use of a Ricardian model. Indeed, recent developments in the theory of trade in differentiated products rely heavily on the model. Each differentiated product can be considered separately and placed individually on the continuum. An industry will encompass a range of differentiated products and its goods, both domestically produced and imported, will be less than perfect substitutes for one another. Intra-industry trade is a likely outcome, particularly if there are economies of scale. Intra-industry trade of this kind is indeed a prominent feature of British trade during the Industrial Revolution, as Temin's Tables 3 and 5 confirm.[19] Problems' arise, however, when this type of Ricardian model is applied to data. A reduction in the number of export goods, when the goods are defined finely, may have occurred in the early nineteenth century as Temin's model suggests. But much of the shift of goods between exports and imports will take place within product categories and will be masked in the aggregations that the trade data impose.

Close examination of Temin's model shows that Temin's attempt to discriminate between the two views of the industrial revolution using the trade data would only be valid in a special case that did not obtain. Diminishing returns in agriculture, population growth and imperfect substitution between domestic and imported goods —

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see McCloskey, Industrial Revolution", p. 107 and Overton, *Agricultural Revolution*, p. 88.

[18] Turner et al., *Agricultural Rent*, ch. 8.

[19] Temin, "Two Views", pp. 75, 77-8.

issues that must be recognized when the trade data are confronted — destroy the simplicity of the test that Temin proposes. Theoretical predictions are unclear when complications are introduced but a possible way forward is to examine the more complicated cases with simulations from computable general equilibrium (CGE) models.

CGE simulations (discussed in detail below) yield three clear conclusions. First, diminishing returns in agriculture and British technical precocity were *both* significant causes of the growth of exports of textiles and metal goods. Second, with diminishing returns in agriculture and realistic demand elasticities for textiles and metal goods, exports of other manufactures grow even with an assumption of no TFP growth in that sector. If rapid TFP growth is assumed in these goods, exports of these goods appear to grow far too much. Third, without diminishing returns in agriculture, the model cannot replicate the extent to which the modernized sectors grew.

**HARLEY'S 1993 CGE MODEL**

Agriculture is among the sectors that experienced relatively rapid TFP growth in the Crafts-Harley view of growth during the Industrial Revolution. This struck some critics as inherently implausible and inconsistent with rapid industrialization in an open economy. Thus, Jeffrey Williamson asked "why didn't the alleged rapid technological advance in agriculture encourage a shift in comparative advantage which would have been revealed by a contraction in agricultural imports and manufacturing exports?"[20] Harley's 1993 CGE model was constructed to investigate this issue and he concluded

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[20] Williamson, "Debating", p. 275.

that it demonstrated that the sectoral productivity growth estimates could be consistent with these aspects of the trade data.[21]

The model, calibrated to embody Crafts's estimates of TFP growth, particularly highlighted three changes over the period 1770-1841. First, TFP advanced rapidly in a few key manufacturing industries but not in the rest of industry. Second, population grew rapidly and pressed on available land resources pushing up food prices and agricultural imports. Third, there was significant agricultural TFP growth. British trade was affected in two ways — prices of cotton textiles fell dramatically and exports soared while at the same time diminishing returns in agriculture were only partially offset by agricultural improvement so that food imports increased. Harley concluded that his model replicated the broad outline of changes in the output and trade of the British economy between 1770-1841.[22]

In outline the model was as follows. (A detailed specification is set out in the appendix). There are two trading countries — Britain and the rest of the world — each made up of four producing sectors: agriculture, 'modern' industry (an aggregate of textiles and metals), other industry, and services. International trade is allowed in the first two of these sectors only. The production technologies in most sectors are simple Cobb-Douglas production functions using only capital and labor. The agricultural production function differs in that it has a land input; unchanged land input introduces diminishing returns into agricultural output. The demand side of the model is also quite simple. Perfect substitution exists between foreign and domestic goods in agriculture and modern industry. A representative consumer in each country has a utility function

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[21] Harley, "Reassessing", p. 205.

[22] Ibid., p. 207.

in which there is a unitary elasticity of substitution between the modern and the other industrial good and a 0.5 elasticity of substitution between the composite industrial good, services and agricultural output.

Values of output in 1841 provided a benchmark to which the model was calibrated. Model solutions that incorporated changes in technology and factor supply allowed calculation of a comparative pre-Industrial Revolution equilibrium for 1770. Modeled British labor supply and capital stock increasing 2.3 times between 1770 and 1841 captured the effect of population pressure on fixed land resources. Industrial Revolution technological change was modeled as Hicks-neutral and taking place in modern industry, which used 2.8 times the resources per unit of output in 1770 as in 1841, and in agriculture, which, in 1770, used 1.75 times the resources per unit of output used in 1841. The rest of the world was modeled as partially sharing technological change in modern industry, using 1.5 times the 1841 resources per unit of output in 1770.

[Insert Table 1]

Table 1 summarizes some of the key outputs from the model in columns 2 and 3 and compares them with those in columns 4 and 5 from a modified version of the model in which there is no specific land factor in agriculture and thus no diminishing returns. The exercise shows the importance in the 1993 model of diminishing returns in agriculture as a driving force promoting changes in international trade. Without diminishing returns in agriculture, modern industrial output would have grown only 3.3 times rather than 6.9 times between 1770 and 1841 and the increase in agricultural imports would have been limited to only 1.4 times rather than 3.2 times. Industrial exports instead of growing 6.8 would have grown 2.3 times. This suggests that diminishing returns in agriculture led to a near tripling of industrial exports independent of technological change.

Thus, Harley's 1993 model, designed to arbitrate in the debate between Crafts and Williamson on the compatibility of observed trade data with estimated patterns of productivity growth, emphasizes that population growth pressing hard against land resources provided an additional powerful force increasing industrial exports. The mechanism by which an increased demand for food generated increased manufactured imports is a central result from general equilibrium trade theory, but it is, perhaps, useful to spell it out here with reference to a simple Hume-type price-specie flow mechanism. If there were no increase in exports, increased British imports of food would result in an outflow of specie, a decline in the money supply and a fall in prices in Britain. The lower prices would stimulate increased exports. The process of specie outflow and price adjustment would continue until the value of exports (increased by falling British prices) equalled the increased food imports (moderated somewhat by the fall in British prices). In the 1993 model, by its construction, trade created by diminishing returns simply reinforced the trade in modern industrial goods. In a less restrictive specification, we might expect that the effect would be felt on other exports as well.

## A REVISED CGE MODEL TO RE-EXAMINE OUTPUT AND TRADE CHANGES

Temin observed quite rightly that Harley's 1993 model is unduly restrictive and ahistorical in its assumption that other manufactures were non-tradables. If these goods were modeled as tradable, Temin contended that they should have become imported during the Industrial Revolution, given the Crafts-Harley view that they experienced little or no TFP growth in contrast both with modern industry and agriculture.[23] In this section, we describe a CGE model that has been structured to capture the spirit of Temin's argument. Simulations of the model explore and reject his suggestion that the trade data refute the narrow view of technological change during the Industrial Revolution.

The new model may be regarded as an implementation of an extended Ricardian model specified to take account of the criticisms we have of Temin's formulation. The extensions include diminishing returns in agriculture (as was assumed in the 1993 model) and careful specification of the demand structure to allow for differentiated goods in industry (unlike the 1993 model) such that domestic and imported goods are imperfect substitutes. The calibration of the model retains most of the 1993 factor input and productivity growth assumptions, albeit with a more detailed specification. In the new model, agricultural productivity is assumed to grow in line with Robert Allen's recent estimates, that is a bit less rapidly with a unit of agricultural production using 1.5 rather than 1.75 times its 1841 inputs in 1770.[24] The original non-tradable industry sector has been split into two equal parts, one tradable but the other not.

In outline the new model is as follows. (A detailed specification can be found in the appendix). There are still two trading countries — Britain and the rest of the world —

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[23] Temin, "Two Views", p. 72.

[24] Allen, "Agriculture". In fact, results are not that different if the higher (Crafts) TFP growth in agriculture is retained. Certain results are, however, better with the Allen rather than the Crafts specification. In making this change we are also in line with Allen's recent review of the evidence in "Tracking the Agricultural Revolution". We accept the arguments that he puts forward there to reject the alternative estimates in Clark, "Too Much Revolution" on the grounds that they are flawed by virtue of the sample of land prices that is used in construction of the price dual measure of TFP.

and, as before, the model is benchmarked at 1841. There are now seven production sectors in Britain: agriculture, industry disaggregated into cotton textiles, other textiles, metal industries, other traded manufactures, other (non-traded) industry (primarily food processing and construction) and services. All except the last two are traded internationally. The rest of the world has eight sectors; in addition to the above seven, it also contains a tropical agricultural sector that produces both raw cotton and tropical foodstuffs that are imported by Britain.

The production technologies generally remain quite simple and similar in both economies. In services, other traded manufactures and non-traded industry, the production functions are Cobb-Douglas with a labor share of 0.6 and a capital share of 0.4. Cotton textiles, other textiles and metal industries are modeled as having a fixed proportion technological requirement for raw material inputs and Cobb-Douglas value added. Although production technology in industry involves capital as well as labor, the specification is close to the Ricardian model because the industries use the factors in similar proportions. Relative cost changes result almost entirely from differential rates of technological change as they do in Ricardian models. Temperate agricultural production functions in both Britain and the rest of the world were modeled with a CES production function with an elasticity of substitution of 0.5 between labor and capital and an elasticity of 0.3 between the capital and labor composite and land. In the 1841 benchmark the value of agricultural output is shared among labor, capital and land in proportions of 0.4, 0.2, and 0.4 respectively.

The demand side of the model is considerably more complex than in the 1993 model. The new model recognizes the heterogeneity of industrial output and distinguishes between domestic and imported goods, making them imperfect substitutes. That heterogeneity requires differentiation between domestic and imported goods within the same industry has long been recognized in CGE trade models. The so-called Armington specification models imported and domestic goods in the same industry as imperfect substitutes.[25] The Armington utility function models the import good and its domestic counterpart as imperfect substitutes that are aggregated with a relatively high elasticity of substitution into a composite good which then enters a higher level utility function that has lower substitutability between categories of goods.

We assume the Armington elasticity of substitution between the same category of domestic and imported good to be larger the more homogeneous the product in question. The elasticity of substitution between British and rest of the world cottons and metals is assumed to be 5 while those between other textiles and other traded manufactures are both assumed to be 2. The elasticity of substitution in the consumption function between aggregate textiles and other manufactures and among aggregate industry, temperate agricultural goods, tropical agricultural goods and services is taken to be 0.5.

We do not have direct empirical estimates of these elasticities but we have selected foreign-domestic elasticities of substitution in line with values commonly used in CGE modeling.[26] The substitution elasticities that we have chosen are also plausible in the context of the historiography of consumption and of the textiles industries in particular. Thus, Allen's recent review of elasticities of demand for agricultural goods implies a

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[25] See, for example, the discussion in Shoven and Whalley, *Applying General Equilibrium*, p. 81.

[26] Compare the values selected by the authors of the papers in Srinivasan and Whalley, *General Equilibrium Trade Policy Modeling* and by Harley, "The Antebellum American Tariff".

substitution elasticity with all other spending well below one.[27] Discussions of the cotton trade stress that while cottons were imperfect substitutes for linens, silks and woolens because of differences in durability, ease of washing and appearance, nevertheless there was fierce competition as cotton extended the range of its products to infiltrate its rivals markets.[28] In the eighteenth century fine British cotton cloths were usually regarded as inferior to their Indian counterparts by the fashion conscious, but they were in direct competition.[29] By the mid-nineteenth century American and Continental cotton producers could challenge British production in coarse textiles but not in fine.

[Insert Table 2]

Simulation of the Industrial Revolution involves solving the general equilibrium model with lower factor supplies and inferior technology and yields the 1770 solution that is reported in Table 2. The 1841 benchmark data are shown in column 1 for comparison. The results of the base case simulation are reported in column 3 of Table 2 together with the associated volume growth and changes in prices between 1770 and 1841 in column 4. The latter can be compared with estimates of actual historical volume growth reported in column 2 as a check on the plausibility of the model. In general, the model replicates the growth in volumes of output and trade between 1770 and 1841 reasonably well, although in cases where volumes were very small in 1770 the multiples are less exact. In particular, the model captures key features of structural change during the

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[27] Allen, "Tracking the Agricultural Revolution".

[28] Farnie, *English Cotton Industry*, pp. 129-30.

[29] Edwards, *British Cotton Trade*, p. 44.

industrial revolution, namely, the relative decline of domestic agriculture and the rapid expansion of cotton textiles output and exports.

Temin argued that the behavior of the trade of other traded manufactured goods was the key to discriminating between the traditional and new views of the Industrial Revolution. Notice, however, that the model generates significant growth in the exports of other traded manufactures even though the simulation allows zero TFP growth in the industry. The model's predicted export growth mirrors the historical result quite accurately. As might be expected for a sector lying near the margin of importation and exportation and whose goods were heterogeneous and imperfect substitutes, *both* exports and imports increased. This result is ruled out by Temin's pure Ricardian model. The simulation suggests that the observed behavior of exports is consistent with the Crafts-Harley account of productivity growth in the Industrial Revolution.

The simulation can also be judged in terms of its ability to replicate price changes in 1770 relative to 1841. Here too, the picture is generally encouraging, especially in terms of cottons, other traded manufactures, and agricultural output which are central to the external trade outcomes. At the same time, it should be remembered that some of the price comparisons are necessarily rather crude given the lack of adequate data from which to construct benchmarks as is apparent from the source notes to Table 2. The most obvious weakness is the model's overestimate of the change in the price of agricultural land, which rises too much over the period. A possible reason for this is that technological change in agriculture may have been biased towards land saving whereas we have specified it as neutral.[30]

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[30] This is suggested by a simulation of the model in which agricultural technological change was specified as relatively land saving such that 1770 factor inputs were 0.75

[Insert Table 3]

We further evaluated the model by performing a wide-ranging sensitivity analysis which altered key parameters. A few of these results are displayed in Table 3 which also reports the historical benchmark estimates in column 1 and the base simulation of the new model of Table 2 in column 2. We report in column 3 of Table 3 the 1770 solution for a modified version of the new model where the assumption of diminishing returns in agriculture is dropped. As was the case in Table 1, exports in every export category are much smaller without the stimulus of diminishing returns in agriculture. The simulated behavior of trade in other traded manufactures is closer to Temin's inference of the implications of the Crafts-Harley view. Exports of other traded manufactures, while not actually lower, grow much more slowly than they actually did and imports of these goods expand rapidly — at a considerably more rapid rate than the actual historical outcomes. Even here, however, it should be noted that exports by no means disappear because domestic and foreign goods are imperfect substitutes. The simulation confirms that population growth and diminishing returns in agriculture played an important role in expanding exports of other traded manufactures.

Without diminishing returns in agriculture, as with the 1993 model, key aspects of economic development during the British Industrial Revolution are not replicated. In particular, the simulation shows agricultural output expanding 4.8 times between 1770 and 1841 compared with an estimated actual doubling of output while output of cottons and metals in 1841 are only 38.3 times and 5.2 times 1770 respectively compared with

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land, 0.25 capital and 0.5 labor rather than 0.6, 0.3 and 0.6 respectively. This replicated the land price change over 1770 to 1841 exactly while leaving the other main outputs of the model little changed with the one exception that cotton's growth was significantly reduced.

actual multiples of 125 and 14.3. Similarly, simulated exports of cottons and imports of temperate agricultural products grow far more slowly than in fact they did. In addition, the prices of agricultural goods (and thus the cost of living) fall far too rapidly. In other words, without diminishing returns in agriculture, the key structural changes of the Industrial Revolution are seriously underestimated. The revised model, like Harley's simple 1993 model, shows that diminishing returns in agriculture as well as technological change in modern industry played an important role in promoting the growth of modern industrial exports.

As was noted above, we have no way of obtaining precise estimates of the elasticities in the utility functions. Accordingly, we paid considerable attention to the sensitivity of the model's results to variations in these values. Columns 4 and 5 of Table 3 give a flavor of some of the results that we obtained and provide some insight into the role of demand elasticities in the growth of other manufactured exports. In column 4, rather against the general tenor of the literature, the elasticity of substitution in textiles was reduced from 2.0 to 1.0 thus making cotton a poorer substitute for other textiles, in the process diminishing the export demand elasticity for the premier Industrial Revolution good. This simulation replicates the historical benchmark less well than the base simulation. It also underlines the importance of demand conditions in cottons' extraordinary growth. With the lower demand elasticity the industry grows much more slowly. In column 5, the elasticity of substitution in consumption of manufactures was raised to 1, which seems rather high for such a heterogeneous collection of goods. Here too the results are fairly similar to the base model and, in this case, actually slightly better with regard to growth of cotton output[31]. Relative to the other simulations, the

[31] The simulations generate very small 1770 outputs, as of course did the history. As a result small changes in resource allocation make a considerable difference to growth

higher elasticity of substitution among the manufactured goods increased the exports of the goods whose prices had fallen most as a result of technological change. A consequence was somewhat slower growth of the exports of other manufactured goods.[32] Two important points to note about both simulations (and others not reported here) are the following. First, most key outputs of the model are not very highly sensitive to the assumed Armington elasticities. Second, in each case the simulated growth in exports of other traded manufactures is robust to the changes.

Temin's assertion that Britain could have exported other manufactured goods only if they had achieved substantial rates of productivity growth seems thoroughly discredited by these results from a model simulation in which there is no TFP growth in those industries. It remains interesting, however, to examine what the impact of technological change in the other exportable manufactured goods would be in the context of the CGE model. We have explored two cases incorporating TFP growth in other traded manufactures. In the first, reported in column 3 of Table 4, we assumed TFP growth at 0.2 per cent per year in other manufactures. In the second, in column 4, we assumed TFP growth at 0.5 per cent per year, i.e., about the low end of the rates for modernized sectors. In both cases we have used a demand function with the elasticity of substitution in manufacturing raised from 0.5 to 1 as in column 5 of Table 3.

[Insert Table 4]

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rates. The calculated 1770 value in the base case is 0.10 and in the case with the higher elasticity of substitution among manufactured goods the value was 0.08

[32] This result was further accentuated when the elasticity of the high level utility aggregation was increased from 0.5 to 1.0.

The main effect of TFP growth in the other traded manufactures shows up in the growth rates of output and exports. A 0.5 per cent TFP growth seems to result in an excessive growth of exports of other traded manufactures. The simulation with 0.2 per cent TFP growth in other traded manufactures, however, gives results that are a reasonable replication of the historical record. The only possible anomaly is the large increase in agricultural imports. The higher agricultural imports equilibrate the model as the means of spending the greater export revenue generated by more cheap manufactured goods capturing foreign markets. The simulations suggest that modest but not rapid TFP growth in other manufactured exports might be accommodated within the CGE framework. It should be noted, however, that this conclusion is not very robust. If the 0.5 substitution elasticity in manufacturing, which we prefer in the simulation above, is used in the exercise, even 0.2 per cent TFP growth produces excessive growth in exports of other traded manufactures. With 0.2 per cent TFP growth exports increase with a multiple of 2.9 while 0.5 per cent TFP growth pushes the multiple up to 4.2 — twice the actual historical growth.

Finally, in other simulations not reported here, we considered the nearest equivalent to Temin's own specification in the context of the CGE model. In this case, diminishing returns are removed from agriculture and TFP growth is introduced into the other traded manufactured goods sector. With these assumptions, as Temin supposed, it clearly would be necessary to have rapid TFP growth in other exports to replicate the historical export experience — indeed, the model suggests that this TFP growth would have to be well in excess of 0.5 per cent per year. But as with Table 3, this specification generates agricultural output growth that is far too rapid and growth of modern sector output and exports and of agricultural imports that are much too slow. These simulations appear to be much less satisfactory than the base case of Table 2.

Our CGE simulations indicate that Temin's attempt to discriminate between different views of technological change during the Industrial Revolution by observing that the list of exported goods does not change significantly through the early nineteenth century is based on an inadequate view of British trade. Our general equilibrium model illustrates the likely mechanisms that maintained exports even in industries where technological change was either modest or non-existent. Clearly, diminishing returns in agriculture, a clear feature of the early nineteenth century, played a key role. An effective demand for food imports required greatly expanded export earnings from industrial goods generally. The inelastic demand that faced the new industries of the Industrial Revolution resulted in the price of these goods falling in response to technological advance. This in turn limited the export earnings from these products. Some of the expanded export earning came from traditional exports whose production had not been transformed. To realistically approximate historical reality as recorded in census and customs categories, we needed models with less than perfect substitution between the imported and exported goods in the broad, somewhat heterogeneous, categories. This specification greatly increases the likelihood that exports of goods from sectors experiencing relative technological retardation will continue to be recorded in the trade data. While it is likely that, in a Ricardian way, some specific goods ceased to be exported, it would be hidden in the aggregation in the historical data. When we extend Temin's basic Ricardian model to improve its realism, we can see why industrial goods where there was no TFP growth continue to be exported despite the concentration of technological change in the modernized sectors.

It must be recognized, however, that we do not have enough information to use a CGE model of this type to go beyond general tendencies and make firm predictions about specific quantitative details. In particular, we lack estimates of the elasticities that are central to the specification of the demand side of the model and affect the pattern of trade. In particular, we do not feel we can rule out modest TFP growth in other manufactures. But, we have shown strongly that the continuation of exports of other manufactures certainly cannot be taken as convincing evidence that technology changed in these industries at a rate comparable to that in modern industry or even in agriculture.

The present model allows us to gain considerable insight into the way trade patterns were affected by the Industrial Revolution. There are, nonetheless, a number of ways in which it could be developed further. We have already noted that it may be appropriate to consider bias in agricultural technological change to explain the observed course of factor prices and factor input ratios. The model also seems deficient in its treatment of the metal industries where it inadequately replicates actual trade performance. Addressing this issue, and possibly others, effectively would require considerable extension of the model. In the case of the metal industries it would be necessary to disaggregate the heterogeneous output. Two obvious issues are the imports of iron bars in the eighteenth century which were inputs into later stages of metal production, and the intermediate demand for iron created by railroads in the nineteenth century. In addition, the model pays little attention to the complex pattern of protection, both tariffs and prohibitions that were common in the late eighteenth and early nineteenth centuries and affected British iron among other goods. Similar modifications might be useful elsewhere as well. In particular, if, as seems appropriate, the model allowed faster technological progress in other textiles in Britain than elsewhere, simulation would underestimate the industry's pre-Industrial Revolution exports and thus predict faster growth than actually occurred. The most likely solution in this case seems to lie in the changed trading relationship with America. Before the American Revolution the colonies were major markets; in the nineteenth century the industry faced protective tariffs there.

**TFP GROWTH IN THE INDUSTRIAL REVOLUTION REVISITED**

Temin examined trade patterns for inferences about aggregate TFP growth and its sectoral breakdown. While we have shown above that his inferences from trade data were unwarranted, it is still worthwhile to consider the view of sectoral and economy-wide TFP growth that Temin was explicitly challenging.[33] A decomposition of aggregate TFP, originally set out by Harley, is reported in Table 5. In sectors where information is available, the contribution of a sector consists of its own estimated rate of TFP growth weighted by its share in gross output. The overall rate of TFP growth was calculated from macroeconomic estimates and the balance remaining after the contribution of individual sector was assigned to 'all others'.[34] We can examine how the calculation would be modified if we concluded that inferences from the trade data indicated a larger contribution from 'other manufactures'.

[Insert Table 5]

If we continue to accept the estimate of overall TFP growth, which derives from subtracting an appropriately weighted average of estimated input growth from estimated GDP growth, an increased TFP in 'other manufactures' implies that the residual estimate for the rest of the economy would fall somewhat (variant 1). Alternatively, we might imagine that the estimate of overall TFP growth should be increased to

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[33] Temin, "Two Views", p. 79.

[34] Harley, "Reassessing", p. 200. Putting the calculations on a gross output basis and taking explicit account of intermediate input use follows the procedure originated by McCloskey, "Industrial Revolution", p. 114. The weights add up to more than 1 because the sum of gross output exceeds that of value added; see, Gollop and Jorgenson, "US Productivity Growth", for the algebra of this type of growth accounting.

incorporate the higher estimate of TFP in 'other manufactures' — although nothing in our trade evaluation has directly affected the overall estimate of TFP (variant 2). Our discussion in the last section suggested that a CGE interpretation of the evidence of the trade data might be consistent with TFP growth in 'other manufactures' at a rate of about 0.2 per cent per year but not with much faster TFP growth in that sector. Table 5 reports variant 1 and variant 2 of the productivity growth decomposition for this case. At most, these modifications (variant 2) would raise the contribution of all other sectors from about 4 per cent to about 10 percent of overall TFP growth. This change, contrary to Temin's claims, leaves the Crafts-Harley view essentially unaffected.

Indeed, a little mental arithmetic reveals that even an assumption of substantially faster TFP growth in other manufactures would not alter either the TFP growth decomposition or the estimate of overall TFP growth a great deal. This is hardly surprising when we recognize that any evidence of greater productivity growth in other internationally traded manufactures affects a sector that had a relatively modest share of total output.[35] In particular, a large part of the economy, amounting to over a third of GDP, comprised non-traded services and the evidence of the trade data is completely irrelevant to estimates of productivity growth in those activities.

The evidence of the trade data certainly fails to discredit our earlier estimates of overall TFP growth during the Industrial Revolution. We have previously acknowledged their inevitable crudeness given the quality of the available data. In this context, however, it is worth remembering that some of the biases such as measuring labour inputs by

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[35] Our 1841 benchmark gives these sectors 8.7 per cent of value-added (see Table 2) based on the sectoral weights in Harley, "British Industrialization", p. 269. Our assumption of a weight of 20 per cent in gross output in Table 5 errs on the high side but is convenient to bias the calculations against our view.

persons rather than hours worked may well lead to TFP growth being overestimated.[36] Certainly we welcome continued investigation of our estimates. Peter Temin's imaginative use of trade data has stimulated us to understand the Industrial Revolution better in a general equilibrium framework than we would otherwise have done. Examination of the trade statistics has deepened our view of the British Industrial Revolution but does not warrant major adjustments in our view of its essential character.

We accept that at some point our estimates may need to be seriously revised when better data are obtained. It would, however, be unwise to be dismissive of the growth accounting estimates. Critics should recognize that some of the difficulties that arise in estimating TFP growth in recent times are actually much less serious in the British Industrial Revolution than they are in modern economies. There are two major problems in measuring TFP growth. First, what are the appropriate relative weights to be given to capital stock and labor force growth? Secondly, how should growth accounting allow for quality changes/new goods in the growth of real output? Both these are probably relatively minor in the early nineteenth century. We pointed out on an earlier occasion that the weighting problem is rendered relatively small because the growth rates of the capital stock and the labor force differ by only about 0.1 percentage points during the key decades of the Industrial Revolution.[37] William Nordhaus recently investigated the issue of quality change and has assessed the degree to which it may matter. He found that 'run of the mill' sectors in which there was little to worry about

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[36] Crafts and Harley, "Output Growth", p. 719.

[37] Ibid., pp. 718-9.

comprised less than a third of expenditure in the 1990s but they made up as much as three quarters of expenditure in the early nineteenth century.[38]

We feel that the picture we have drawn of TFP growth and the Industrial Revolution is quite plausible in the light of modern economic analysis. Modern econometric research has done much to clarify where rapid TFP growth has come from in recent times. In general, such analyses suggest that only a relatively small part of measured TFP growth is attributable to technological change whereas relatively large proportions come from scale effects and improvements in the allocation of resources. For example, Nicola Rossi and Gianni Toniolo found that the component of Italian TFP growth attributable to technical change was about 0.1 out of 0.8 per cent per year in 1895-1939 and about 0.5 out of 3.0 per cent per year in 1950-1990.[39] Similarly, Susanto Basu and John Fernald found that, for the US business sector, only 0.2 out of 1.1 per cent per year TFP growth in 1950-1989 was due to technological change.[40]

Arnold Harberger has recently examined the sectoral pattern of TFP growth in the United States. He found that contributions to real cost reduction are typically concentrated in relatively few industries. For example, between 1980 and 1991 about 40 per cent of industry accounted for 100 per cent of TFP growth.[41] The post-war American economy can hardly be accused of a lack of inventiveness and its investment in research and development is many times larger relative to GDP than that of

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[38] Nordhaus, "Do Real Output and Real Wage Measures Capture Reality?"

[39] Rossi and Toniolo, "Catching Up", p. 550 and idem, "Italy", p. 435.

[40] Basu and Fernald, "Aggregate Productivity", Table 2a.

[41] Harberger, "Vision", p. 6.

nineteenth century Britain. It would not really be surprising if the inventiveness that Sullivan sees in the British patenting data failed, by itself, to produce rapid TFP growth. Moreover, we know that spectacular inventions reflected in substantial clusters of patents sometimes raise TFP very little, at least initially. For example, the social savings from the steam engine have been estimated as no more than 0.2 per cent of GDP in 1800.[42] By the same token, we have already made clear that our finding that there was little or no TFP growth in much of the Industrial Revolution economy should not be taken to indicate a complete absence of innovation outside the modernized sectors.[43] The slow rate of TFP growth surely reflects the weakness of scale effects long before the era of Fordism. Even in cotton textiles, the epitome of the factory system, the median size of cotton mills in Manchester in 1841 was 174 employees and minimum efficient size was probably as low as 150 workers.[44] Detailed analysis of the American economy shows that rapid TFP growth is a phenomenon of the twentieth rather than the nineteenth century.[45]

## CONCLUSIONS

The nature of the Industrial Revolution continues to be debated. The Crafts-Harley view that aggregate TFP growth in the British Industrial Revolution was moderate and concentrated in relatively few sectors of the economy has gained wide support but doubts persist. In particular, critics have been concerned by apparent inconsistency between this view of change and Britain's external trade experience. The question was

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[42] Von Tunzelmann, *Steam Power*, p. 157.

[43] Crafts and Harley, "Output Growth", p. 719.

[44] Lloyd-Jones and Le Roux, "Size of Firms", p. 75.

[45] Abramovitz, "Search for the Sources".

posed originally by Jeffrey Williamson and now, in a new guise, by Peter Temin. We have addressed the issue with a general equilibrium model that embodies what we see as essential characteristics of the British economy. Simulations with this model support our position and also provide valuable insights into the operation of the British economy in its international context during the Industrial Revolution.

The model indicates that the pattern of British trade in the mid-nineteenth century can fit easily into our view of technological change. To be sure, Britain's technological leadership in cottons and iron production was a major source of export growth. But the pattern of trade evolved under other important influences as well. The rapid growth of British population was the first of these. Higher population inevitably increased the demand for food and British agriculture, with limited land resources, experienced diminishing returns and rising costs and prices despite impressive technological change. Since imports provide a relatively elastic source of food, imports increased. The exports of the technological leaders paid for much of this increase in imports, but the revenue from these exports was limited by the relative inelasticity of foreign demand. The rapid increase in cotton and iron exports occurred in response to rapidly falling prices and foreign exchange revenue increased much more slowly than export volumes. Old exports continued, despite the absence of technological improvement, for two reasons. First, they had a role to play in financing greatly expanded food imports. Second, many of the exported goods were of products of special character. Similar foreign goods differed from the British exports and were only poor substitutes in the eyes of foreign buyers.

We continue to believe that the exceptional feature of the British Industrial Revolution was rapid structural change culminating in a very low share of agricultural employment in the mid-nineteenth century rather than fast growth. Britain's structural transformation occurred in an open economy context that needs to be understood. The general equilibrium model we have constructed here underlines that both substantial TFP growth in part of the manufacturing sector and diminishing returns in agriculture contribute importantly to precocious British industrialization. The best estimates we have continue to suggest that growth during the Industrial Revolution was slower than used to be thought and modest by later standards. This does not detract from the fact that the period saw unprecedented technological progress while the economy coped successfully with population pressure that would have undermined living standards in earlier times. Equally, however, the increased inventiveness that was displayed is no reason to suppose that there was rapid or pervasive TFP growth.

## APPENDIX 1: DETAILS OF HARLEY'S 1993 MODEL

The CGE modeling in this paper has all been carried out with the aid of Thomas Rutherford's MPS-GE modeling software. The modeling process starts with a social accounting matrix that is taken to represent an initial equilibrium for the economy. Appendix Table 1 presents the benchmark matrix for the 1993 model. Model sectors (production functions in the model) are arrayed along the left-hand side of the matrix. Goods, the outputs (+) and potentially, inputs (-) in the production functions are arrayed along the top of the matrix. Positive entries in the cells are outputs of the industry. Inputs would appear as negative entries, but this very simple model has no intermediate inputs. The last three columns on the right in the table list the factor incomes generated in each industry. The unit of measure is one per cent of British 1841 GNP.

[Insert Appendix Table 1]

The data for the table are derived primarily from the estimate of national income in current prices for 1841 given by Deane and Cole.[46] The industrial sector is divided on the basis of Harley's estimate of industrial shares in value-added.[47] The modern industrial sector consists of the textile and metal industries. Factor incomes were allocated to be consistent with the parameters assumed for the Cobb-Douglas production functions for each sector. Modern industry was modeled as relatively capital intensive with a capital share of 0.6 and a labour share of 0.4. Agriculture was modeled with both labor and land shares of 0.4 and a capital share of 0.2. All other sectors have a labor share of 0.6 and a capital share of 0.4.

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46 Deane and Cole, *British Economic Growth*, p. 166.

47 Harley, "Output Growth", p. 269.

The benchmark for the Rest of the World provides a large but not overwhelming international trading partner for Britain. The overall size of the Rest of the World is set in proportion to the ratio of European to British population. The size of the modern sector is calibrated relative to the British modern sector using the estimates of Bairoch.[48] Other manufacturing and services are assigned slightly smaller shares of national income than was the case in Britain and the balance of national income is assigned to agriculture. The production functions and factor shares in each sector in the Rest of the World are assumed to be identical to those in Britain.

Only two of the produced goods are internationally tradable - modern industrial goods and agricultural goods. Trade in modern industrial goods occurs without transport or transactions costs so that the price of the good is identical in both countries. Trade in agricultural goods, effectively British imports, is assumed to incur transport costs that increase as the quantity of imports rises, reflecting the fact that increased British food imports had to draw on more distant sources of supply. In the model increased transport costs take the form of assuming that one unit of British agricultural imports is produced by combining 0.5 units of foreign agricultural goods with 0.5 units of a foreign-produced transport service. The price of transport services falls (rises) as its output falls (increases) because it is produced with a Cobb-Douglas production function in which 40 per cent of its cost in the initial benchmark is accounted for by a fixed factor of production. The specification causes Britain's agricultural prices in the 1770 simulation to be a little over a quarter cheaper relative to European agricultural prices than in the 1841 benchmark.

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[48] Bairoch, "International Industrialization Levels".

The demand side of the general equilibrium model consists of a single representative consumer in each country. The consumer receives all the factor income and spends that income to maximize utility. The consumers have the same constant elasticity functions in each country. The function assumes that modern industrial goods and other industrial goods have a unitary elasticity of substitution. This creates an aggregate manufactured good that enters into a higher level utility function with agricultural goods and services where the elasticity of substitution is set at 0.5.

In order to highlight the role of diminishing returns in Harley's 1993 simulation, we created a slightly revised version of the model and re-ran the 1770 simulation. To eliminate diminishing returns, land was removed from the agricultural production function and the labour and capital shares were raised to 0.667 and 0.333 respectively. The 1770 results presented in Table 1 columns (4) and (5) are the result of solving the revised model with the same changes in technology and factor supplies as in the original 1993 model.

## APPENDIX 2: DETAILS OF REVISED CGE MODEL

The model has been built using Thomas Rutherford's PPS-GE software. Models in this software begin with a consistent accounting matrix of product output, factor demand by product, factor incomes, and product demand. The accounting matrix is assumed to represent a full general equilibrium for the modeled economy. the quantities in the accounting matrix for the present model are presented in Appendix Table 2. The total factor incomes also represent the benchmark factor supplies. Benchmark prices are all taken to be 1.0, with the exception of the British price of tropical foodstuffs which is 1.5 to allow for a 50 per cent import tariff. The model redistributes the tariff revenue to British consumers. Alternative equilibria are simulated by using specifications of elasticities of substitution in both production and consumption to calculate a new equilibrium based on the original benchmark.

[Insert Appendix Table 2]

In the calculated equilibrium, factors in each country earn the same returns in all uses and all markets clear. Production and consumption functions are specified as constant elasticity relationships (and include the possibility of zero elasticity or no substitutability). Considerable flexibility is possible in the models because it is possible to constuct subaggregates with different aggregation elasticities that can be used as inputs into the final production and utility functions. For computational reasons, substitution elasticities above 10 are not accommodated but perfect substitution among goods is easily modeled by having two production processes make the same commodity.

[Insert Appendix Figure 1]

Utility Functions. There are only two consumers in the model, one in Britain and one in the rest of the world. Although the benchmark consumption patterns of the two differ, the elasticities of substitution used to calculate new equilibria are identical. The structure of the utility functions is summarized in Appendix Figure 1. At the top level, consumers choose manufactured goods, temperate agricultural goods, services, and tropical foodstuffs. The elasticity of substitution among these goods is 0.5.

Services and tropical foodstuffs are simple produced goods. All services in each country are domestically produced - there is no trade in services. Tropical foodstuffs are all produced in the rest of the world. Temperate agricultural goods are produced in both Britain and the rest of the world. The goods from each region are modeled as perfect substitutes in consumption.

Modeling of the Industrial Revolution required disaggregations of the manufactured good that enters into the final utility function. The first disaggregation separated textiles, metal goods, other traded manufactured goods, and non-traded goods. These goods aggregated into a composite manufactured good using an aggregation (or utility) function with the same 0.5 substitution that characterizes the top level utility aggregation. Because our understanding of the Industrial Revolution emphasizes the special nature of the changes in cotton textiles, textiles were further disaggregated into cotton and other textiles. It seemed appropriate to allow greater substitution between the textiles than was the case in higher levels of the utility function, so an elasticity of 2.0 was chosen.

Since the simulation focused on trade in the various commodities that entered into the consumers' utility functions, it was necessary to pay attention to the degree of substitutability between imports and domestic production. As indicated in the text, we decided that even at our level of disaggregation the various categories of goods were quite heterogeneous aggregates. In this case, it was generally inappropriate to consider imports and domestic production to be perfect substitutes. We adopted the procedure, generally used in empirical trade modeling, of an Armington specification. The greater the degree of heterogeneity in the goods in the model category, the lower the appropriate elasticity of substitution. Imported and domestically produced cotton goods and metal products were regarded as good substitutes and an elasticity of 5.0 was adopted in both cases. Other textiles and other traded goods are more heterogeneous and we adopted a lower (2.0) elasticity of substitution between imports and domestically produced goods.

Production Functions. Production functions in the two countries were specified with the same factor proportions and elasticities of substitution. Differences in the rate of technological change between countries were modeled in simulating the pre-Industrial Revolution equilibrium. Intermediate good inputs were specifically modeled in the textile industries and in metals. In terms of influencing the calculated equilibria, only the cotton textile intermediate demand for tropical raw materials (cotton) was vital. For most goods, production is specified as a simple Cobb-Douglas production function with capital and labor inputs. Other traded goods, non-traded manufactured goods, and services are all Cobb-Douglas functions and the income shares in the initial benchmark are 60 percent labor and 40 percent capital.

Agricultural production functions (for both temperate agriculture and tropical foodstufss and raw materials) are somewhat more complex. The production function for temperate agriculture in both Britain and the rest of the world combines a capital and labor aggregate (aggregated with an elasticity of substitution of 0.5) with land. An elasticity of 0.3 is allowed between land and the capital/labor aggregate. The lower elasticity between land and other inputs was chosen to allow the share of agricultural income going to land to increase as land scarcity increased. Tropical foodstuffs and tropical raw materials are modeled as perfect substitutes in production. They are produced only in the rest of the world. Production technology is a CES production function using labor, capital and land with an elasticity of substitution of 0.5. In the initial benchmark, the value of agricultural output in all cases is shared among labor, capital, and land at proportions of 0.4, 0.2, and 0.4 respectively.

Production in the manufacturing industries of the Industrial Revolution has been modeled in somewhat greater detail. In cotton textiles a fixed quantity of tropical raw materials (cotton) and non-traded manufactures are combined with a value added aggregation of capital and labor (in which 40 percent of the income goes to labor and

60 percent to capital) to produce a unit of output. Substitution between labor and capital occurs with an elasticity of 0.1. At the benchmark production, 21 percent of output goes to labor, 31 percent to capital, 27 percent to tropical raw materials, and 22 percent to non-traded manufactures. Other textiles and metal production have a similar production structure, with fixed intermediate inputs and a Cobb-Douglas value added from capital and labor. The distribution of the value of production in other textiles at the benchmark is 26 percent to labor, 40 percent to capital, 7 percent to tropical raw materials (silk), and 27 percent to temperate agricultural goods (wool and flax). The payments to inputs in metal production are 36 percent to labor, 54 percent to capital, and 9 percent to other traded manufactures (coal).

British commodity trade in 1841 was characterized by significantly larger import values than export values. The model accommodates this imbalance by modeling a British service export sector that paid for the excess commodity imports. The foreign consumer consumes these services directly in the top-level utility function. They are produced in Britain with a Cobb-Douglas production function with factor shares of 0.6 for labor and 0.4 for capital.

Simulations of 1770. The pre-Industrial Revolution equilibrium is calculated with lower factor supplies and inferior technology in various sectors. In addition, the tariff on tropical imports is removed and British service exports are eliminated so that commodity imports and exports are of equal value. British labor supply is reduced from 52.1 to 22.8. capital supply was reduced from its benchmark 39.1 to 14.4. Land was also reduced by 15 per cent from 8.8 to 7.5. Factor inputs in the rest of the world were reduced by about 30 per cent. labor fell from 279.9 to 200, capital from 170.9 to 120, and land from 127.6 to 87.

Various changes were introduced in technology. First, a unit of agricultural output was modeled as using 1.5 times its original inputs of land, capital, and labor (in the Allen technological change variants) or 1.75 times as much (in the Crafts variants). Technological change in British manufacturing was calculated to correspond approximately with the calculations made by McCloskey with the corrections in Harley.[49] In cotton, the assumption was that real cost was about 6 times its 1841 level in 1770 and that the improved technology had only resulted in savings of capital and labor and not in intermediate inputs. As a result, a point on the production function for a unit of output used 2.4 units of labor and 3.6 units of capital instead of the 0.21 and 0.31 units used in 1841. A similar procedure in other textiles, based on a real cost twice the 1841 level gave inputs of labor of 0.8 and capital of 1.2 in place of 0.26 and 0.40. The change in metal goods replaced a labor input of 0.36 with an input of 0.68 and a capital input of 0.54 with an input of 1.36. This corresponds to an increase of real cost of about 70 per cent. Technological change has been introduced in the Industrial Revolution goods in the rest of the world but at a slower pace. The coefficients on the various components of value added are presented in Appendix Table 3.

[Insert Appendix Table 3]

[49] McCloskey, "Industrial Revolution", p. 114; Harley, "Reassessing", p. 200.

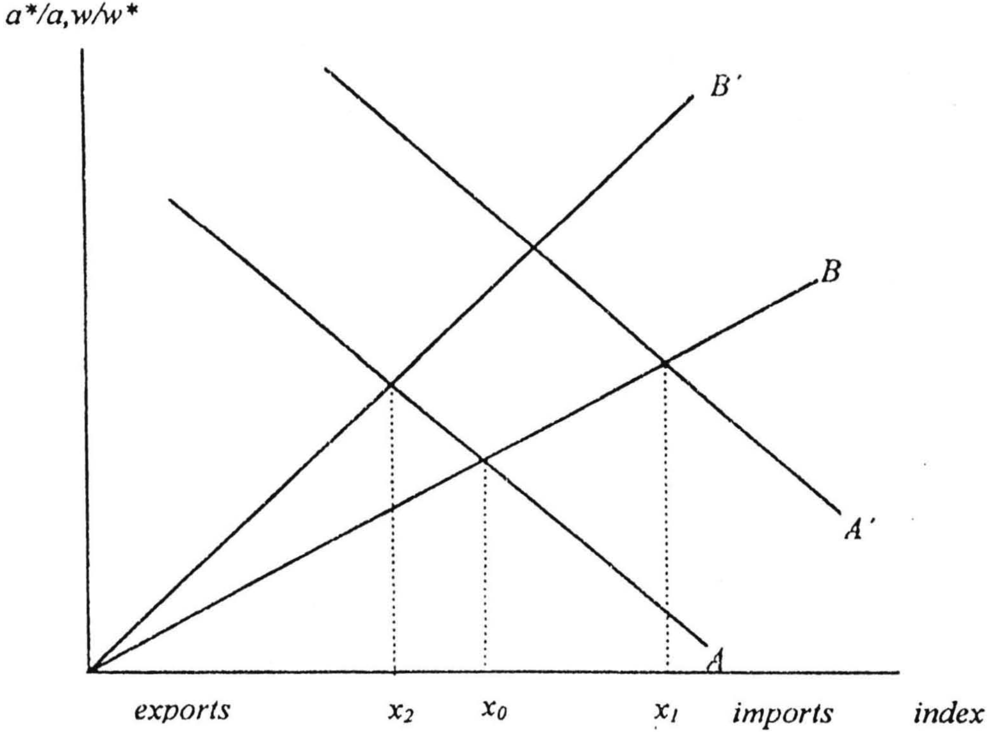


FIGURE 1

Appendix Figure 1: Structure of Consumer's Utility

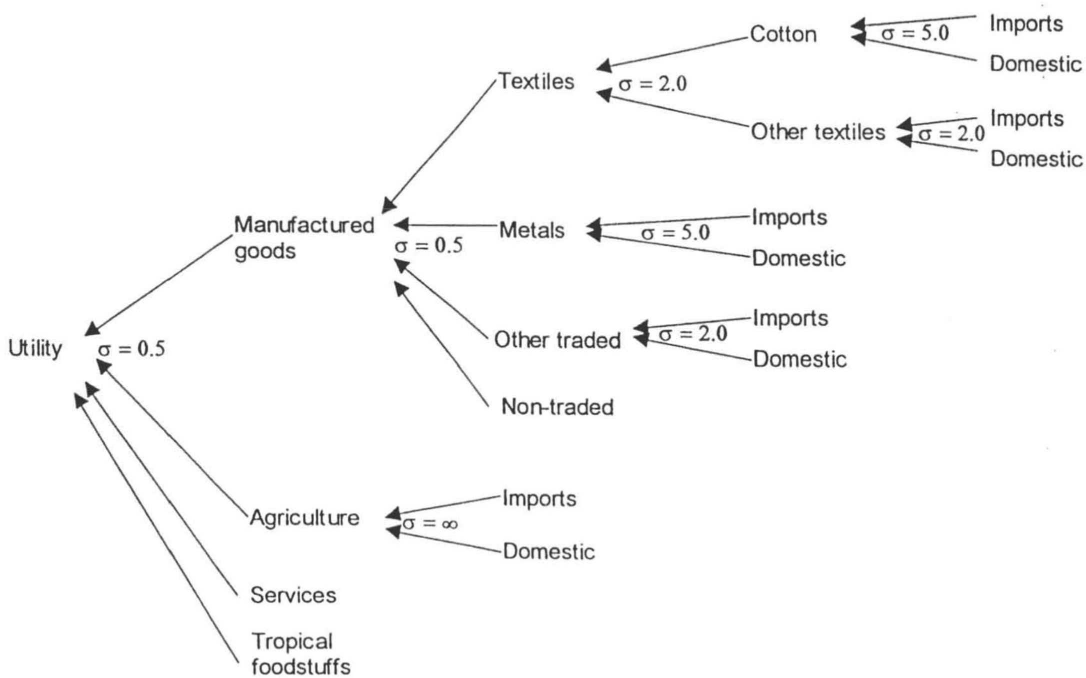

**Table 1. Diminishing Returns in Harley's 1993 Model.**

| | 1841 Benchmark | Diminishing Returns 1770 | Diminishing Returns 1841/1770 | No Diminishing Returns 1770 | No Diminishing Returns 1841/1770 |
|---|---|---|---|---|---|
| Modern Industry | 12.4 | 1.8 | 6.9 | 3.8 | 3.3 |
| Agriculture | 22.1 | 8.2 | 2.7 | 3.5 | 6.3 |
| Other Output | 65.5 | 27.5 | 2.4 | 26.1 | 2.5 |
| Agricultural Imports | 6.8 | 2.1 | 3.2 | 5.0 | 1.4 |
| Industrial Exports | 6.8 | 1.0 | 6.8 | 3.0 | 2.3 |

Note: Units are percentages of 1841 national income.
Source: Derived from Harley, "Reassessing", Table 3.8 and further experiments with the model on which it was based, see text

**Table 2. Simulations of the Revised CGE Model.**

| | Benchmarks | | Simulation | |
|---|---|---|---|---|
| | 1841 | 1841/1770 | 1770 | 1841/1770 |
| ***Outputs*** | | | | |
| Cottons | 10.3 | 125 | 0.1 | 98.4 |
| Other Textiles | 12.7 | 2.3 | 3.9 | 3.3 |
| Metal Industries | 4.2 | 14.3 | 0.4 | 11.2 |
| Other Traded Manufactures | 8.7 | 4 | 3.1 | 2.8 |
| Other Industry | 8.7 | 4 | 2.3 | 3.8 |
| Agriculture | 22.1 | 2 | 9.6 | 2.3 |
| Services | 41.8 | 2.5 | 14.7 | 2.8 |
| ***Exports*** | | | | |
| Cottons | 6.2 | 253 | 0.0 | 239 |
| Other Textiles | 2.8 | 1.6 | 0.9 | 3.0 |
| Metal Industries | 1.5 | 4.5 | 0.0 | 31.1 |
| Other Traded Manufactures | 2.9 | 2.1 | 1.2 | 2.3 |
| ***Imports*** | | | | |
| Temperate Agriculture | 7.1 | 6.8 | 0.5 | 15.3 |
| Tropical Raw Materials | 3.6 | 15.9 | 0.0 | 130 |
| Tropical Food | 3.0 | 3.2 | 1.5 | 2.0 |
| Modern Industry | 0.5 | ? | 1.0 | 0.5 |
| Other Traded Manufactures | 0.4 | ? | 0.2 | 1.8 |
| ***Goods Price Relatives*** | | | | |
| Cottons | | 7.5 | | 7.5 |
| Other Textiles | | 2.1 | | 2.7 |
| Metal Industries | | 1.8 | | 2.5 |
| Other Traded Manufactures | | 1.0 | | 1.1 |
| Other Industry | | 0.9 | | 1.1 |
| Agriculture | | 1.2 | | 1.2 |
| ***Factor Price Relatives*** | | | | |
| Labor | | 1.0 | | 1.0 |
| Capital | | 1.0 | | 1.3 |
| Land | | 0.6 | | 0.3 |
| Cost of Living | | 1.2 | | 1.4 |

*Notes*: Levels of outputs, exports and imports measured as percentages of 1841 national income. Price relatives are for 1770/1841 and measured relative to the price of labor in 1770/1841 (0.58 in the benchmark based on Feinstein, "New Estimates") as numeraire.

*Sources*: Model solutions are from the computable equilibrium model described in the appendix. The estimates of the benchmarks in column 2 were obtained as follows.
Outputs: based on Harley, "British Industrialization," p. 272 except for agriculture from Allen, "Agriculture,", p. 101 and services from Crafts, British Economic Growth, p. 37 extended using Deane and Cole, British Economic Growth, p. 166.
Exports: from Mitchell, British Historical Statistics, pp. 469, 471 extended to 1841 using Davis, The Industrial Revolution, pp. 98-100 except for Other Industry which was calculated directly for 1830/1770 using UK, Finance Accounts and Davis, "English Foreign Trade" and extended to 1841 based on Schlote, British Overseas Trade, p. 152.
Imports: from Davis, "English Foreign Trade" and Mitchell, British Historical Statistics, pp. 466-467 except for temperate agricultural imports for which 1841 estimates use the data in Davis, The Industrial Revolution adopting the correction for Ireland proposed by Thomas, "Food Supply", p. 145 with deflation using the agricultural price index in O'Brien, "Agriculture and the Home Market" extended to 1841 using the Rousseaux agricultural prices index.
Goods Price Relatives: cottons from Harley, "Cotton Textile Prices"; other textiles, metal industries, other traded manufactures (represented by leather), and other industry (represented by construction) from O'Brien, "Agriculture and the Home Market" extended respectively using woolens export prices from Imlah, Economic Elements; bar iron from Mitchell, British Historical Statistics, p. 762, leather from Gayer et al., Growth and Fluctuation, p. 143, 279, and building materials from Jones, Increasing Returns.
Factor Price Relatives: these are nominal prices where capital is based on consols yields from Mitchell, British Historical Statistics, p. 678 and capital goods prices from Feinstein, "Appendix", p. 441, and land is taken from Turner et al., Agricultural Rent, p. 150; cost of living index from Feinstein, "New Estimates".

**Table 3. Sensitivity Analysis of 1841/1770 Multiples.**

| | Benchmark | Base | Agriculture No DR | Elasticities = 1 Textile | Manfg |
|---|---|---|---|---|---|
| *Outputs* | | | | | |
| Cottons | 125 | 98.4 | 38.3 | 49.9 | 124 |
| Other Textiles | 2.3 | 3.3 | 2.8 | 3.7 | 4.1 |
| Metal Industries | 14.3 | 11.2 | 5.2 | 10.3 | 11.4 |
| Other Traded Manufactures | 4.0 | 2.8 | 2.0 | 2.7 | 2.1 |
| Other Industry | 4.0 | 3.8 | 3.8 | 3.8 | 2.8 |
| Agriculture | 2.0 | 2.3 | 4.8 | 2.2 | 2.3 |
| Services | 2.5 | 2.8 | 2.9 | 2.8 | 2.8 |
| *Exports* | | | | | |
| Cottons | 253 | 239 | 44.8 | 148 | 308 |
| Other Textiles | 1.6 | 3.0 | 1.6 | 3.2 | 3.8 |
| Metal Industries | 4.5 | 31.1 | 5.5 | 26.5 | 30.1 |
| Other Traded Manufactures | 2.1 | 2.3 | 1.2 | 2.1 | 2.0 |
| *Imports* | | | | | |
| Temperate Agriculture | 6.8 | 15.3 | 1.8 | ! | 16.0 |
| Tropical Raw Materials | 15.9 | 130 | 50.7 | 66 | 164 |
| Tropical Food | 3.2 | 2.0 | 2.4 | 2.1 | 2.1 |
| Modern Industry | ? | 0.5 | 1.8 | 0.4 | 0.6 |
| Other Traded Manufactures | ? | 1.8 | 4.0 | 2.0 | 1.3 |
| *Goods Price Relatives* | | | | | |
| Cottons | 7.5 | 7.5 | 8.1 | 7.4 | 7.3 |
| Other Textiles | 2.1 | 2.7 | 3.0 | 2.8 | 2.6 |
| Metal Industries | 1.8 | 2.5 | 2.7 | 2.5 | 2.4 |
| Other Traded Manufactures | 1.0 | 1.1 | 1.2 | 1.1 | 1.1 |
| Other Industry | 0.9 | 1.1 | 1.2 | 1.1 | 1.1 |
| Agriculture | 1.2 | 1.1 | 1.7 | 1.1 | 1.1 |
| *Factor Price Relatives* | | | | | |
| Labor | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Capital | 1.0 | 1.3 | 1.4 | 1.3 | 1.2 |
| Land | 0.6 | 0.3 | na | 0.3 | 0.3 |
| Cost of Living | 1.2 | 1.4 | 1.6 | 1.4 | 1.3 |

*Note*: the simulation shows Britain with no temperate agricultural imports but small exports in 1770.

*Source*: see text.

**Table 4. Technological Progress in Other Traded Manufactures: Sensitivity Analysis of 1841/1770 Multiples.**

| | Benchmark | Base | Manufactures σ = 1 OTM TFP = 0.2 | OTM TFP = 0.5 |
|---|---|---|---|---|
| ***Outputs*** | | | | |
| Cottons | 125 | 98.4 | 120.3 | 115.2 |
| Other Textiles | 2.3 | 3.3 | 4.1 | 4.0 |
| Metal Industries | 14.3 | 11.2 | 11.2 | 11.2 |
| Other Traded Manufactures | 4.0 | 2.8 | 2.5 | 3.3 |
| Other Industry | 4.0 | 3.8 | 2.8 | 2.8 |
| Agriculture | 2.0 | 2.3 | 2.3 | 2.3 |
| Services | 2.5 | 2.8 | 2.8 | 2.8 |
| ***Exports*** | | | | |
| Cottons | 253 | 239 | 295 | 277 |
| Other Textiles | 1.6 | 3.0 | 3.8 | 3.7 |
| Metal Industries | 4.5 | 31.1 | 29.6 | 29.3 |
| Other Traded Manufactures | 2.1 | 2.3 | 2.3 | 3.4 |
| ***Imports*** | | | | |
| Temperate Agriculture | 6.8 | 15.3 | 23.8 | 78.3 |
| Tropical Raw Materials | 15.9 | 130 | 159 | 152 |
| Tropical Food | 3.2 | 2.0 | 2.1 | 2.1 |
| Modern Industry | ? | 0.5 | 0.6 | 0.6 |
| Other Traded Manufactures | ? | 1.8 | 1.2 | 1.0 |
| ***Goods Price Relatives*** | | | | |
| Cottons | 7.5 | 7.5 | 7.3 | 7.3 |
| Other Textiles | 2.1 | 2.7 | 2.6 | 2.6 |
| Metal Industries | 1.8 | 2.5 | 2.4 | 2.5 |
| Other Traded Manufactures | 1.0 | 1.1 | 1.2 | 1.5 |
| Other Industry | 0.9 | 1.1 | 1.1 | 1.1 |
| Agriculture | 1.2 | 1.1 | 1.1 | 1.1 |
| ***Factor Price Relatives*** | | | | |
| Labor | 1.0 | 1.0 | 1.0 | 1.0 |
| Capital | 1.0 | 1.3 | 1.2 | 1.2 |
| Land | 0.6 | 0.3 | 0.3 | 0.3 |
| Cost of Living | 1.2 | 1.4 | 1.3 | 1.3 |

*Source*: see text.

**Table 5. Contributions to National Productivity Growth, 1780-1860 (% per year).**

| | | | | Variant 1 | | Variant 2 | |
|---|---|---|---|---|---|---|---|
| | Share | TFP | Amount | TFP | Amount | TFP | Amount |
| Cotton | 0.07 | 1.9 | 0.13 | | | | |
| Worsteds | 0.035 | 1.3 | 0.05 | | | | |
| Woolens | 0.035 | 0.6 | 0.02 | | | | |
| Iron | 0.02 | 0.9 | 0.02 | | | | |
| Canals & Railways | 0.07 | 1.3 | 0.09 | | | | |
| Shipping | 0.06 | 0.5 | 0.03 | | | | |
| Sum of Modernized | 0.29 | 1.2 | 0.34 | | | | |
| Agriculture | 0.27 | 0.7 | 0.19 | | | | |
| Other Traded Manfs | 0.20 | | | 0.2 | 0.04 | 0.2 | 0.04 |
| Rest | 0.65 | | | -0.02 | -0.02 | 0.02 | 0.02 |
| All Others | 0.85 | 0.02 | 0.02 | | 0.02 | | 0.06 |
| Total | 1.41 | | 0.55 | | 0.55 | | 0.59 |

*Sources*: Harley, "Reassessing", p. 200 and for variants, see text.

**Appendix Table 1: Accounting Matrix for Harley's 1993 Model**

| **BRITAIN** | Good: (+production - purchase) | | | | | Factor Incomes: | | |
|---|---|---|---|---|---|---|---|---|
| Sector: | Modern industry | Other industry | Agri-culture | Services | Transport | Labour | Capital | Rent |
| Modern industry | 12.4 | | | | | 5.0 | 7.4 | |
| Other industry | | 22.0 | | | | 13.2 | 8.8 | |
| Agriculture | | | 22.1 | | | 8.8 | 4.4 | 8.8 |
| Services | | | | 43.5 | | 26.1 | 17.4 | |
| Import | | | 6.8 | | | | | |
| | | | | | | | | |
| Total available: | 12.4 | 22.0 | 28.9 | 43.5 | | 53.1 | 38.1 | 8.8 |
| Consumption | 5.6 | 22.0 | 28.9 | 43.5 | | | | |
| Exports | 6.8 | | | | | | | |
| | | | | | | | | |
| REST OF WORLD | | | | | | | | |
| | | | | | | | | |
| Sector: | | | | | | | | |
| Modern industry | 11.1 | | | | | 4.4 | 6.6 | |
| Other industry | | 126.5 | | | | 75.9 | 50.6 | |
| Agriculture | | | 297.0 | | | 118.8 | 59.4 | 118.8 |
| Services | | | | 219.2 | | 131.5 | 87.7 | |
| Transport | | | | | 3.4 | 1.4 | 0.7 | |
| Import | 6.8 | | | | | | | |
| | | | | | | | | |
| Total available: | 17.9 | 126.5 | 297.0 | 219.2 | 3.4 | 331.9 | 205.0 | 118.8 |
| Consumption | 17.9 | 126.5 | 293.6 | 219.2 | 0.0 | | | |
| Exports | | | 3.4 | | 3.4 | | | |

**Appendix Table 2: Accounting Matrix for Complex CGE Model**

| BRITAIN | Good (+ production, - purchase): | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sector: | Cotton textiles | Other textiles | Metals | Other traded | Non-traded | Agricu-lture | Services | Int'l services | Tropical Raw mat. | Tropical food | Labour | Capital | Rent |
| Cotton | 10.3 | | | | -2.3 | | | | -2.7 | | -2.1 | -3.2 | |
| Other textiles | | 12.7 | | | | -3.4 | | | -0.9 | | -3.4 | -5.0 | |
| Metal | | | 4.2 | -0.4 | | | | | | | -1.5 | -2.3 | |
| Other traded | | | | 8.7 | | | | | | | -5.2 | -3.5 | |
| Non-traded | | | | | 8.7 | | | | | | -5.2 | -3.5 | |
| Agriculture | | | | | | 22.1 | | | | | -8.8 | -4.4 | -8.8 |
| Service | | | | | | | 41.8 | | | | -25.1 | -16.7 | |
| Int'l Services | | | | | | | | 1.2 | | | -0.7 | -0.5 | |
| Imports | 0.1 | 0.2 | 0.2 | 0.4 | | 7.1 | | | 3.6 | 4.5 | | | |
| Total final | 10.4 | 12.9 | 4.4 | 8.7 | 6.4 | 25.8 | 41.8 | 1.2 | 0.0 | 3.0 | -52.1 | -39.1 | -8.8 |
| Consumption | 4.2 | 10.1 | 2.9 | 5.8 | 6.4 | 25.8 | 41.8 | 0.0 | 0.0 | 3.0 | -52.1 | -39.1 | -8.8 |
| Exports | 6.2 | 2.8 | 1.5 | 2.9 | | | | 1.2 | | | | | |
| REST OF WORLD | | | | | | | | | | | | | |
| Sector: | | | | | | | | | | | | | |
| Cotton | 3.4 | | | | -0.8 | | | | -0.9 | | -0.7 | -1.0 | |
| Other textiles | | 17.4 | | | | -4.7 | | | -1.2 | | -4.6 | -6.9 | |
| Metal | | | 3.7 | -0.4 | | | | | | | -1.3 | -2.0 | |
| Other traded | | | | 12.9 | | | | | | | -7.7 | -5.1 | |
| Non-traded | | | | | 15.8 | | | | | | -9.5 | -6.3 | |
| Agriculture | | | | | | 297.0 | | | | | -118.8 | -59.4 | -118.8 |
| Service | | | | | | | 214.2 | | | | -128.5 | -85.7 | |
| Tropical Ag. | | | | | | | | | 22.0 | | -8.8 | -4.4 | -8.8 |
| Iimports | 6.2 | 2.8 | 1.5 | 2.9 | | | | 1.2 | | | | | |
| Total final | 9.6 | 20.2 | 5.2 | 15.4 | 15.0 | 292.3 | 214.2 | 1.2 | 19.9 | | -279.9 | -170.9 | -127.6 |
| Consumption | 9.5 | 20.0 | 5.0 | 15.0 | 15.0 | 285.2 | 214.2 | 1.2 | 13.3 | | -279.9 | -170.9 | -127.6 |
| Exports | 0.1 | 0.2 | 0.2 | 0.4 | | 7.1 | | | 3.6 | 3.0 | | | |

| Appendix Table 3: Model Factor Inputs 1840 and 1770 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Britain | | | | | | Rest of World | | | | | |
| | 1840 | | | 1770 | | | 1840 | | | 1770 | | |
| | Lab | Cap | Land | Lab | Cap | Land | Lab | Cap | Land | Lab | Cap | Land |
| Agriculture (Crafts) | 0.4 | 0.2 | 0.4 | 0.7 | 0.35 | 0.7 | 0.4 | 0.2 | 0.4 | 0.4 | 0.2 | 0.4 |
| Agriculture (Allen) | 0.4 | 0.2 | 0.4 | 0.6 | 0.3 | 0.6 | 0.4 | 0.2 | 0.4 | 0.4 | 0.2 | 0.4 |
| Cotton Textiles | 0.21 | 0.31 | | 2.40 | 3.60 | | 0.21 | 0.31 | | 0.96 | 1.44 | |
| Other Textiles | 0.26 | 0.40 | | 0.80 | 1.20 | | 0.26 | 0.40 | | 0.80 | 1.20 | |
| Metal Products | 0.36 | 0.54 | | 0.68 | 1.36 | | 0.36 | 0.54 | | 0.56 | 0.84 | |

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