Taking Over

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Abstract

This paper offers a direct industry-of-origin benchmark for the United States and the United Kingdom around 1910. The industry-of-origin approach allows for a disaggregation of international productivity differentials at the industry level, which enhances a deeper understanding of the comparative economic performance of these two countries. The benchmark sheds new light on the recent debate between Broadberry and Ward and Devereux regarding the Anglo-American income and productivity differentials in the nineteenth and early twentieth century. I find that, on the eve of the First World War, the gap between the US and the UK was greater than suggested by most previous studies in terms of GDP per worker and GDP per capita. This revision arises mainly from a considerably higher estimate of the comparative productivity in the American agricultural and mining sectors. On the basis of time-series evidence, I find that the UK ceded productivity and income leadership earlier than conventional estimates have shown. I date the US take-over in GDP per capita around the 1880s and not post-1900 as suggested by Broadberry and Maddison.

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1 Introduction

From the 1940s onwards such notable economists as Kuznets (1966) and Mitchell (2007) in the US and Clark (1951) in the UK have been active in the field of comparative economic performance of nations. At present the best known comparisons of long-run productivity performance come from the seminal work of Maddison (1982, 1991, 1995, 2001). Part of the appeal of his approach is the wide temporal and spatial coverage of his data, the transparent methodology and his sole reliance on national time-series published by statistical offices, which makes it exceptionally well suited for research on comparative economic growth.

The Maddison time-series, or any of the long-term studies on economic growth for that matter, suffer from at least one major drawback: time-series projections do not adequately account for shifts in sectoral output and changes in product prices. This becomes particularly apparent when time-series of different origins are projected from a certain benchmark-year into distant periods. In recent years, economic historians have stressed the need for new, more detailed, comparisons of welfare and productivity for earlier periods, particularly for the pre-World War I era (Prados de la Escosura 2000; van Zanden 2003; Fukao, Ma, and Yuan 2007).

As the debate between Broadberry (2003) versus Ward and Devereux (2003, 2004) in the *Journal of Economic History* has emphasized, direct benchmark comparisons between countries are a much wanted alternative for the long-span projections. In this discussion, Ward and Devereux challenge the conventional picture of relative income levels and the timing of the American take-over in particular. The consensus view of US/UK relative income is based almost exclusively on the work of Maddison (2001). Maddison's extrapolations shows that income levels in the United Kingdom exceeded that of the United States by approximately one-third in 1870. As illustrated in the second column of table 1, Maddison's time-series evidence reveals that, from 1870 onwards, the Anglo-American income gap declined until, sometime around the turn of the century, the US definitively took over the lead. These projections all hinge on an income benchmark for the year 1990, which Maddison extrapolates backwards to the late nineteenth century, relying on a collection of well over 100 years worth of national accounts to bridge the gap. Economists have cast severe doubts, however, whether these long-span projections are actually viable and produce credible results in the face of two World Wars, several major depressions, and the host of new products and services introduced over the course of the twentieth century.[1]

Ward and Devereux (2003, 840) provide an alternative measure of the US/UK income relatives based on direct Purchasing-Power-Parity (PPP) adjusted benchmarks of expenditure. For the period between 1872 to 1930, Ward and Devereux constructed seven Anglo-American expenditure benchmarks, which they supplemented with existing benchmarks from Gilbert and Kravis and the work done under the auspices of the International Comparison Project

1. See Prados de la Escosura (2000) for a discussion.

Table 1: Comparative GDP per capita, US and UK (UK=100, 1872–1990)

year	*Ward & Devereux*	*Maddison*	*year*	*Ward & Devereux*	*Maddison*
1872	118	78	1955	217	143
1874	118	79	1967	175	147
1878	127	84	1970	167	143
1884	130	87	1973	169	143
1891	122	90	1975	156	141
1905	122	105	1980	154	147
1930	133	118	1985	167	152
1950	208	143	1990	145	145

Sources: Ward and Devereux (2003, 840) and Maddison (2008, accessed on 11 March 2011).

(Gilbert and Kravis 1954; Gilbert 1958; Maddison 1995). In all they provide sixteen 'snapshots' which renders a complete overview of relative US/UK performance over the course of the long twentieth century (see table 1). From this Ward and Devereux (2003, 826) conclude that – contrary to the estimates by Maddison – the US, not the UK, led in terms of income per capita in the 1870s; "the UK kept pace with the US throughout the late Victorian era, while most of the British relative decline occurred between 1905 and 1950."

The findings by Ward and Devereux met with harsh criticism from Broadberry (2003, 852), who disputed their direct benchmarks on account of the implied revision of the relative US/UK price levels as well as their handling of the historical national accounts. Mostly though, Broadberry deplored the fact that no attempt was made toward a reconciliation of the long-span time-series projections and the direct benchmarks. He states that, "a satisfactory account of the evolution of relative per capita incomes over a long period should be able to encompass both sorts of evidence." As a check against the time-series extrapolations, Broadberry proposes a set of sectoral productivity benchmarks, for which he suggests basing the benchmark estimate of relative Gross Domestic Product (GDP) on output as opposed to the expenditure approach taken by Ward and Devereux.

To this aim, Broadberry and Irwin (2006) presented a comprehensive Anglo-American industry-of-origin benchmark for the year 1910. This industry-of-origin benchmark – based primarily on earlier work by Broadberry (1994a, 1997a, 1997b, 1998) – provides a full breakdown of the relative productivity and income differentials between the US and the UK at the sectoral level. Broadberry and Irwin conclude that their benchmark estimate of both GDP per capita and per worker move closely in line with the time-series projections. They trace the source of the initial British lead in GDP per capita to a slightly higher level of labor productivity in the UK coupled with a substantially higher share of the British population in the labor force. The latter greatly boosted overall British output per capita.

In their sectoral decomposition of labor productivity, Broadberry and Irwin (2006, 262) show that "the United States had roughly equal labor productivity in agriculture, much higher productivity in industry, and a rapid catch-up in service sector productivity." The UK, already by 1870, engaged a large share of its labor force in industry and services, while US labor was still primarily engaged in the low-productive agricultural sector. The initial British aggregate labor-productivity lead was thus the result of compositional effects rather than superior productivity at the sectoral level. On the basis of this evidence, Broadberry (1997a, 1998) claims that the US take-over, both in terms of overall productivity and per capita income, was the result of a structural shift away from agriculture together with rapid relative productivity increases in the American service sector. The close correspondence between the evidence presented by Broadberry and Irwin and the Maddison projections, led the former to suggest that the conventional view is indeed correct. Consequently, they reject the claim by Ward and Devereux, as well as Prados de la Escosura (2000), that index number problems introduce a considerable bias in the long-span Anglo-American projections.

Recent literature emphasizes, however, that comparative productivity in manufacturing was more dynamic than asserted by Broadberry and that technological developments in this sector played a substantial role in explaining the productivity gap between the US and UK for the inter-war era (Field 2006; de Jong and Woltjer 2011). In addition, it appears unlikely that the American agricultural sector was left entirely unaffected by the rapid developments in industry during the late nineteenth and early twentieth century. Given the strong increase in demand for agricultural goods (in particular from the textile and food and drink industries), rising wages accompanying the labor productivity gains in industry, as well as access to cheap fertilizers, energy, farm machinery, and the abundance of land, one would expect the American agricultural sector to develop in line with the industrial sector. As noted by Habakkuk (1962, 34–7), "scarcity of labor ensured that, within the limits set by geology and climate, American agriculture developed along land-intensive, labor saving lines, that is, assumed high labor-productivity forms." Studies of the American and British mining sectors also appear to suggest a greater US lead in productivity terms than suggested by Broadberry and Irwin. American miners were keen to take full advantage of the major improvements in labor-saving technologies – such as mechanized coal-cutting and electric lighting – whereas the British mine-owners generally displayed a conservative attitude toward these innovations (Taylor 1961, 59; Walters 1975, 296). Unfavorable geological conditions and a dwindling supply of natural resources in the UK explain this hesitant attitude and point at a much greater productivity potential in the US (McCloskey 1971, 293).

In this paper I revisit the Anglo-American benchmark around the year 1910. Similar to Broadberry and Irwin I opt for the industry-of-origin approach, as I agree with these authors that it is doubtful whether direct estimates of relative income and productivity between the US and UK should be based solely on expenditure benchmarks. The expenditure approach, as implemented by Ward and Devereux, establishes a direct link between comparative income levels and consumption possibilities, making those estimates particularly well suited for international comparisons of income and living standards. However, for the international comparisons of productivity and economic performance in general, a direct comparison of output at the industry level is preferable (van Ark 1993). Whereas expenditure PPPs are influenced by imports, trade margins and transport costs, industry-of-origin conversion factors are based on ex-factory prices, excluding these elements. Industry-of-origin PPPs thus produce a more refined comparison of labor productivity levels. More importantly, however, the expenditure approach does not allow for a breakdown of labor productivity at a sectoral level. The industry-of-origin approach provides a more in-depth view of the sources of growth and the effects of structural change. As I will illustrate in this paper, these relative sectoral productivity differences and structural effects are key to understanding the Anglo-American comparative economic performance in the late nineteenth and early twentieth century. I focus my efforts on agricultural, mining and manufacturing, the sectors in which the US had the greatest productivity potential, but provide a comparative productivity for the total economy as well.

I find that, on the eve of the First World War, the gap between the US and the UK was larger than suggested by most previous studies in terms of relative income per head of the population. Compositional effects in general and a high level of productivity in American agriculture and mining in particular are instrumental in explaining these revised income per capita estimates. The UK appears to have ceded productivity leadership earlier than conventional estimates have shown. I date the US take-over around the 1880s and not post-1900, as suggested by Broadberry and Maddison.

Section 2 provides an extensive discussion of the methods behind the benchmark comparison and presents an overview of the data sources used. My main results, the sectoral purchasing power parities and productivity levels, are presented in sections 3 and 4. I will discuss the implications for both the total-economy estimates as well as the time-series projections in section 5. In the last section I conclude.

2 Methodology and data

For the construction of my early twentieth century benchmark I opt for the industry-of-origin approach. My choice of industry-of-origin methodology does differ from the method applied by Broadberry and Irwin, however. The latter establish their sectoral productivity measures on the basis of a comparison of physical quantities of output, relying on a methodology first proposed by Rostas (1948). The benefit of the quantity approach is that it is generally less demanding in terms of data requirements, which has made it the method of choice for direct benchmarks for the period prior to the Second World War. Data availability for the post-war period has allowed a more sophisticated methodology though, based on the calculation of real value added at the industry level using relative producer prices. Instead of a direct comparison of physical quantities, this method measures the value of gross and net output by industry (in national currency) which is then translated into a common currency with a sector-specific purchasing power parity (PPP). This procedure was first applied by Paige and Bombach (1959) in an Anglo-American comparison for 1950. The methodology behind these industry-of-origin benchmarks was subsequently further refined and used in a host of international benchmark comparisons for the post-war period; most notably the International Comparison of Output and Productivity (ICOP) project by Maddison and van Ark (1988) and van Ark (1993). Recently however, the extended ICOP methodology has also been applied to international comparisons for the period preceding the Second World War (Dormois 2004; Fremdling, de Jong, and Timmer 2007a; de Jong and Woltjer 2011; Frankema, Woltjer, and Smits 2013). These historical industry-of-origin studies not only prove that it is feasible to apply modern techniques for earlier periods, but they also stress the advantages of these methods over the earlier quantity based benchmark comparisons.

Although the basic concepts behind the available industry-of-origin benchmark techniques are similar, there are some marked differences between the ICOP and the earlier quantity approach. In this section I will only discuss the basic methodology behind the ICOP approach, but appendix A provides an in-depth discussion of the methodological differences between both approaches. In this appendix I show that the quantity approach can be easily rewritten to approximate a basic version of the ICOP approach. I will also show, however, that in practice the outcomes of these methods can deviate substantially. Particularly the necessity, within the quantity approach, to assign labor to individual commodities instead of industries limits this method's ability to estimate productivity for industries producing a wide array of heterogeneous products. In addition, as I will illustrate below, the ICOP framework allows for differences in the relative prices of both outputs and inputs and takes differences between countries in their share of intermediate inputs in the value of gross output into account. I demonstrate the basic ICOP methodology on the basis of a simple single industry, two country, k product framework.

The ICOP approach

In the ICOP approach, the first step in the calculation of comparative labor productivity is the matching of products into unit values (p). The unit value, p_{ij}, which represents the local average price of commodity i in country j, can be obtained by dividing the output value (v_{ij}) by the respective quantity (q_{ij}) for this product; as shown in equation (1) below. In a bilateral comparison, broadly defined products with similar characteristics are matched – e.g. iron ore, refined sugar, cement or bicycles – and the ratio of the unit values in both countries is taken; see equation (2).[2] These unit value ratios (uvr) thus reflect the product specific relative

2. A complete list of the unit value ratios, on which the industry-specific PPPs presented in this paper are based, is provided in appendix B.

prices expressed in terms of country n's currency per unit of the base country o's currency.

$$p_{ij} = \frac{v_{ij}}{q_{ij}} \tag{1}$$

$$uvr_{io} = \frac{p_{in}}{p_{io}} \tag{2}$$

The $uvrs$ can then be aggregated to the industry level. For an industry which holds k matched products, the respective $uvrs$ are weighted according to their share in total matched output ($v_i / \sum v_i$). The resulting aggregated output $uvrs$ are generally referred to as purchasing power parities (PPP). In a bilateral comparisons the weights of either the base country (o) or the numerator country (n) can be used, which provide a Laspeyres and a Paasche type PPP respectively (Fremdling, de Jong, and Timmer 2007a, 14).[3] The Laspeyres gross output purchasing power parity, L^{go}, is then given by

$$L^{go} = \frac{\sum v_{io} \cdot \frac{p_{in}}{p_{io}}}{\sum v_{io}} = \frac{\sum v_{io} \cdot uvr_{io}}{\sum v_{io}} \tag{3}$$

whereas the Paasche gross output purchasing power parity, P^{go}, is given by

$$P^{go} = \frac{\sum v_{in}}{\sum v_{in} \cdot \frac{p_{io}}{p_{in}}} = \frac{\sum v_{in}}{\sum v_{in} / uvr_{io}} \tag{4}$$

Throughout this paper, I will use the geometric mean of the Laspeyres and Paasche price indices, the Fisher price index, as the currency conversion factor for my productivity comparisons; see equation (5). The Fisher PPPs, as well as the Paasche and Laspeyres PPPs, are still expressed in terms of country n's currency per unit of the base country o's currency, in line with the $uvrs$ on which they are based.

$$F^{go} = \sqrt{L^{go} \cdot P^{go}} \tag{5}$$

As illustrated by Paige and Bombach (1959, 82), suitable conversion factors can be obtained from output price data alone (single deflation) or from price data for both outputs as well as intermediate inputs (double deflation). Double deflation is generally considered to be the preferred approach for sector comparisons of output and productivity. A number of recent studies have shown that the adjustment for differences in the prices of intermediate inputs is particularly important for benchmark studies for the early twentieth century (Fremdling, de Jong, and Timmer 2007a; de Jong and Woltjer 2011).

3. Note that as v is equal to $p \cdot q$, the Laspeyres gross output PPP L^{go} can also be expressed as $\frac{\sum p_n \cdot q_o}{\sum p_o \cdot q_o}$, while the Paasche gross output PPP, P^{go}, is identical to $\frac{\sum p_n \cdot q_n}{\sum p_o \cdot q_n}$.

Unfortunately, direct quantity and price information for inputs is not widely available in the early twentieth century British production statistics. For the construction of the intermediate input PPPs, I thus relied on implicit input-output relations instead. By definition inputs for one industry are made up of the output of other sectors and industries. The input PPP for an industry can thus be derived as a weighted set of output PPPs from the industries furnishing its inputs. For example, around 1900 the British food and drink industry obtained well over 60 percent of its inputs from the agricultural sector, while most of the remaining inputs originated from within the food and drink industry itself.[4] A weighted average of the output PPPs for the food and drink industry and the agricultural sector will thus provide a good proxy of the intermediate input PPP for the food and drink industry.

I relied on the Anglo-American Laspeyres and Paasche output PPPs, previously introduced, as the basis for my intermediate input PPPs. These were subsequently weighted on the basis of information on the flow of goods between sectors and industries from input-output tables. Note that this procedure does not take differences in the cost of transport or trade margins into account, which I implicitly assume to be similar for both countries (relative to total costs). Even if the trade and transport margins for both countries differ, however, the differences in these costs are unlikely to be so large as to have a substantial effect on the resulting input PPPs.

The equation for the derivation of the PPPs for intermediate inputs is similar to the calculation of the output PPPs in equations (3)-(5). The Laspeyres input PPP is given by

$$L^{ii} = \frac{\sum w_{io} \cdot L_i^{go}}{\sum w_{io}} \tag{6}$$

and the Paasche input PPP by

$$P^{ii} = \frac{\sum w_{in}}{\sum w_{in} / P_i^{go}} \tag{7}$$

where $w_i / \sum w_i$ represents the share of intermediate inputs supplied by industry i in the total of inputs consumed by the industry for which the PPP is calculated.

The output and input PPPs in turn allow me to calculate the double deflated value added PPPs. go_j and ii_j denote respectively the value of gross output and intermediate input for a single industry in country j, at national prices. The Laspeyres value added PPP is given by

$$L^{va} = \frac{go_o \cdot L^{go} - ii_o \cdot L^{ii}}{go_o - ii_o} \tag{8}$$

4. In practice, a substantial proportion of the inputs consumed by an industry will originate from within the industry itself. This reflects the production of semi-manufactured, or partly finished goods, by separate establishments within an industry (e.g. flour mills) and the use of these intermediate products by establishments still part of this industry but further down the production chain (e.g. bakeries).

while the Paasche value added PPP is given by

$$P^{va} = \frac{go_n - ii_n}{go_n/P^{go} - ii_n/P^{ii}} \tag{9}$$

Again, the Fisher value added PPP is derived as the geometric mean of the Laspeyres and Paasche price indices

$$F^{va} = \sqrt{L^{va} \cdot P^{va}} \tag{10}$$

The double deflated value added PPPs can in turn be used to convert either countries' output per unit of labor to the other countries' currency; see equation (12). Throughout this paper I use value added (va) as the measure of output, as in (11). LP thus measures the industry-specific level of PPP-adjusted value added per worker in country n relative to the value added per worker in the base country o.

$$lp_j = \frac{va_j}{emp_j} \tag{11}$$

$$LP = \frac{lp_n/F^{va}}{lp_o} \tag{12}$$

Sources

The gross output PPPs presented in the next section are based on the official agricultural, mining and manufacturing production censuses of the United Kingdom and the United States. These surveys contain detailed information on quantities and values of produced items as well as average prices, enabling me to construct currency conversion factors bottom-up. For the US I based my PPPs on the agricultural, mining and manufacturing reports of the *Thirteenth Census of the United States*, all taken in the year 1909 (United States Department of Commerce 1913b, 1913e, 1913d), as well as the *Mineral Resources of the Unites States* published as part of the United States Geological Survey for the year 1910 (United States Department of the Interior 1911). For the UK I relied primarily on the *First Census of Production* of 1907 and the 1908 *Agricultural Output of Great Britain* (Board of Trade 1912; Board of Agriculture and Fisheries 1912). Supplementary information for UK agriculture came from the *Agricultural Statistics* (Board of Agriculture and Fisheries 1911), while Fabricant (1940) provided additional information for a number of American manufacturing industries.

Data on gross output, intermediate input, value added and employment was taken from a variety of sources. For the US, I primarily relied on output data for the year 1909 from the Historical Statistics (Carter et al. 2006), supplemented with data by King (1930), Fabricant (1940) and the 1909 censuses of mining and manufacturing (United States Department of Commerce 1913e, 1913d). 1909 employment data was taken from Kendrick (1961, 308) for

Table 2: GDP per capita and unemployment, US and UK (1905–1913)

variables	*1905*	*1906*	*1907*	*1908*	*1909*	*1910*	*1911*	*1912*	*1913*
US GDPpc (1913=100)	75	84	85	79	88	89	92	96	100
UK GDPpc (1913=100)	87	89	91	87	89	92	95	96	100
US unemployment (%)	3.9	2.5	3.1	7.5	5.6	5.9	7.0	5.9	5.7
UK unemployment (%)	7.4	6.0	5.5	8.7	9.1	6.6	5.2	4.8	4.1

Sources: US and UK Gross Domestic Product per capita, see Maddison (2008, accessed on 11 March 2011); US unemployment, see Weir (1992, 341–3); UK unemployment, see Boyer and Hatton (2002, 662).

all sectors except agriculture, which is based on figures by Lebergott (1964, 118). Total gross domestic product is also based on Kendrick (1961, 296–7). For the UK, 1907 gross domestic product, value added and employment are all based on figures by Feinstein (1972, 208; 1976, T10, T125–6, T131), which is supplemented by data on the use of intermediate inputs from the production censuses (Board of Agriculture and Fisheries 1912; Board of Trade 1912). Population data for both countries was taken from Maddison's Historical Statistics (Maddison 2008).

For the construction of the intermediate input PPPs, I relied on the 1899 American input-output table by Whitney (1968) and the input-output table for Edwardian Britain by Thomas (1984, 152). I adjusted the row and column totals for both the US and UK input-output tables to match the level of gross output and intermediate input for the years 1909 and 1907 respectively. The totals for output and input were then translated to the cells of the matrix to create a fit as close as possible to the original input-output table.

The choice of benchmark years was at least partly determined by the availability of the production censuses listed above. For this benchmark comparison I took care to select two stable years on the eve of the First World War. Whenever possible I selected data from 1907 for the UK and 1909 for the US respectively. Table 2 shows that the unemployment rate at that point in time was relatively low or stable and that the actual per capita income level for the census years chosen was close to those of 1910. I see this as an essential requirement as I strive to determine the level of *potential* productivity differentials between the countries under comparison. I thus aim to exclude the effects of business cycles and capacity under-utilization as much as possible, which, I am convinced, is the case for the selected census years.[5]

5. See de Jong and Woltjer (2011) for an elaborate discussion of the business cycle and capacity utilization effects and a sensitivity analysis for the interwar period.

Table 3: Gross output PPPs, US and UK (1909/07)

branch/sector	*matches*	*coverage (%)* US	*coverage (%)* UK	*gross output PPP (\$/£)*[a] *Laspeyres*	*Paasche*	*Fisher*	*rel. exch.*[b]
Agriculture	29	69	88	4.4	4.2	4.3	0.88
Mining	9	71	93	3.0	3.1	3.0	0.63
Manufacturing	111	33	46	5.5	4.6	5.1	1.04
Food, drink and tobacco	20	40	37	5.4	5.1	5.2	1.07
Textile and apparel	20	40	59	5.7	5.5	5.6	1.15
Lumber and wood products	3	7	1	4.0	3.9	3.9	0.81
Paper and printing	6	17	22	5.1	4.6	4.8	0.99
Chemicals and rubber	20	30	44	5.3	5.0	5.2	1.06
Petroleum and coal products	3	28	98	4.3	3.2	3.7	0.76
Leather and leather products	4	60	78	9.1	8.4	8.7	1.80
Stone, clay, and glass products	2	30	35	5.3	5.1	5.2	1.06
Metal industries	25	39	66	4.9	4.3	4.6	0.95
Machinery and transport eq.	5	20	19	4.8	4.0	4.4	0.90
Instruments and miscellaneous	3	9	4	8.2	7.4	7.8	1.60

[a] *Sources:* see text.
[b] Fisher gross output PPP relative to exchange rate (4.87). Source for exchange rate: Svennilson (1954, 318–9).

3 Purchasing power parities

Table 3 presents my gross output PPP estimates at the sectoral level. These relative prices were constructed on the basis of 149 ex-factory and ex-farm unit value ratios for both intermediate and final goods. The sample of products in this study ranges from wheat to pigs meat for the agricultural sector, iron ore to petroleum in mining and jute yarn to sulfuric acid in manufacturing; a complete list is presented in appendix B.

The number of matches for each sector and the value of these matched products in sectoral gross output (the coverage ratio) are shown in the first three columns of table 3. In agriculture and mining I was able to cover nearly 90 percent of total gross output in the UK and approximately 70 percent in the US. The coverage ratio for the manufacturing sector was substantially lower, however, which is explained by the greater heterogeneity of products in this sector, as well as the unique national character and qualitative differences of some of the commodities produced. Nonetheless, I was able to cover well over 30 percent of the American and 40 percent of British manufacturing output. This is comparable to coverage ratios found in previous prewar productivity studies (Fremdling, de Jong, and Timmer 2007b, 16; de Jong and Woltjer 2009).

Table 3 shows substantial relative price differences between the three main sectors at the start of the twentieth century. The last column of this table compares the Fisher output

PPPs to the 1909 US/UK exchange rate. From this column we can see that the American mining products, which primarily consisted of coal, iron ore and petroleum, were relatively inexpensive as compared to the UK. In addition, American agricultural products were also relatively cheap, especially when compared to the price level of manufactured goods. Note that these large cross-industry variations in the output PPPs confirms that a uniform currency converter, such as the official exchange rate, will not generate accurate productivity comparisons at the sectoral level (Paige and Bombach 1959).

For this bilateral comparison, the weights of either the base country (UK) or the numerator country (US) can be used, which provide a Laspeyres- and a Paasche-type PPP respectively. The gap between both these indices can be interpreted as a measure of the structural output diversity of both countries.[6] Only for the manufacturing sector do my estimates show a notable bias as the result of such structural differences (see table 3). The relatively low PPPs in mining and agricultural therefore do not appear to be the result of product specialization, but reflect the consistently lower American relative prices for the majority of sampled products in these sectors. Nonetheless, to overcome the potential structural bias, I rely on the geometric average of the Laspeyres and Paasche indices, the Fisher index, as the currency conversion factor for my productivity comparisons. As noted in section 2, this is considered common practice in this type of research (van Ark 1993).

A further decomposition of the manufacturing sector offers additional insights into the price structure of these two economies. Table 3 reveals that the relative price differences across the manufacturing industries were quite substantial. These price differences testify to a specific pattern of industrial specialization, as already hinted at above by the substantial Paasche-Laspeyres spread for manufacturing as a whole. Whereas the textiles industries engaged the greatest share of British workers, American manufacturing was more geared toward the production of heavy and durable goods (metals, machinery, etc.). This is reflected in the relative price structure between the two countries as well. The PPP for the textile, apparel and leather industries rise above the manufacturing average, while the gross output PPP for metals and particularly the machinery and transportation equipment industries are below-average. Even within these branches considerable structural differences existed, again illustrated by the gap between the respective Paasche and Laspeyres PPPs. In the transportation equipment industries for instance, British producers were engaged primarily in the production of ships while the US transportation sector had already shifted its focus toward the production of automobiles.

6. Generally, using a single countries' production shares as weights in the comparison will introduce a bias in the PPP as the products which constitute a large share of the total production are those for which the country sustains a comparative advantage and for which her prices will thus, by and large, be relatively low.

Double deflation

The substantial differences in the gross output PPPs between the major sectors, observed in table 3, hint at a potential gap between relative output and input prices. Particularly the intermediate input PPPs for manufacturing industries that are dependent on inputs from the agriculture or mining sectors (e.g. food and metal products) are likely to deviate substantially from the single deflated gross output PPPs. As noted by Fremdling, de Jong, and Timmer (2007b, 13), "when relative prices of output and input differ across countries, single deflated productivity measures might be misleading." They demonstrate that "single deflated measures can diverge substantially from double deflated measures when there are major differences in the technical input-output coefficients of an industry between two countries. This might be due to, for example, differences in production methods, the type of materials used, and the amount of imported material."

Table 4 lists the intermediate input PPPs, in addition to the gross output PPPs discussed above. As illustrated in section 2, the intermediate input PPPs are based on *uvrs* of intermediate products weighted by data on the flow of these goods from input-output tables.[7] The intermediate input PPPs show a large cross-industry variation, although not as large as those observed for the gross output PPPs. The input PPPs for agriculture and particularly mining are below average, whereas the industries that rely on (semi-) manufactured goods – apparel and machinery, for instance – exhibit above-average PPPs.

On the basis of these gross output and intermediate input PPPs, I can now calculate the double deflated value added PPPs; see equations (8)-(10). The results for these value added PPPs are also shown in table 4. Given the similarity between input and output PPPs in the agriculture and mining sectors, combined with a relatively low share of intermediate inputs in gross output, the value added PPPs for these sectors stay close to the original single deflated output PPPs. For the manufacturing sector I do observe a notable gap between input and output PPPs, however. Table 4 shows that the relative US/UK price level for outputs was substantially higher than it was for inputs, which reflects the American access to cheap intermediate inputs flowing from the agricultural and mining sectors. These inputs represented a sizable portion of manufacturing gross output. For both countries, well over 50 percent of gross output consisted of intermediate inputs. Overall, the PPP for value added is raised by 13 percent (compared to the original manufacturing gross output PPP) to 5.74 \$/£, well above the official exchange rate, which stood at 4.87 \$/£ in 1909 (Svennilson 1954, 318–9).

7. For two manufacturing industries, leather and leather products and instruments and miscellaneous manufactures, information on the flow of inputs was missing, rendering the calculating of specific value added PPPs impossible.

Table 4: PPPs and intermediate input ratios, US and UK (1909/07)

	gross output PPP ($/£)			*int. input PPP ($/£)*			*value added PPP ($/£)*			*II/GO (%)*	
branch/sector	*Las-peyres*	*Paasche*	*Fisher*	*Las-peyres*	*Paasche*	*Fisher*	*Las-peyres*	*Paasche*	*Fisher*	*US*	*UK*
Agriculture	4.4	4.2	4.3	4.6	4.3	4.4	4.2	4.2	4.2	27	34
Mining	3.0	3.1	3.0	3.2	3.9	3.5	3.0	2.9	3.0	21	14
Manufacturing	5.5	4.6	5.1	5.1	4.4	4.7	6.4	5.1	5.7	59	67
Food, drink and tobacco	5.4	5.1	5.2	4.7	4.5	4.6	7.2	7.3	7.2	71	73
Textile and apparel	5.7	5.5	5.6	5.7	5.0	5.3	5.8	6.3	6.0	57	69
Lumber and wood products	4.0	3.9	3.9	4.4	4.0	4.2	3.5	3.8	3.6	46	56
Paper and printing	5.1	4.6	4.8	5.0	4.5	4.8	5.1	4.6	4.9	38	45
Chemicals and rubber products	5.3	5.0	5.2	4.9	4.6	4.7	6.4	5.8	6.1	61	71
Petroleum and coal products	4.3	3.2	3.7	3.0	3.4	3.2	7.3	2.7	4.4	78	71
Leather and leather products	9.1	8.4	8.7							67	70
Stone, clay, and glass products	5.3	5.1	5.2	3.5	3.9	3.7	6.4	6.0	6.2	35	39
Metal industries	4.9	4.3	4.6	4.6	4.0	4.3	6.0	5.2	5.6	67	76
Machinery and transport eq.	4.8	4.0	4.4	4.9	4.1	4.5	4.7	3.9	4.3	46	53
Instruments and miscellaneous	8.2	7.4	7.8							46	52

Sources: see text.

Table 5: Comparative labor productivity, US and UK (1909/07)

	comparative labor productivity (UK=100)		
branch/sector	*single deflated gross output*[a]	*double deflated value added*[a]	*Broadberry & Irwin*[b]
Agriculture	159	181	109
Mining	278	263	161
Manufacturing	198	214	209

[a] *Sources:* see text.

[b] *Sources:* Broadberry (1994a, 524; 1997b, 26–30) and Broadberry and Irwin (2006, 261).

4 Comparative labor productivity

What new light do these PPP estimates shed on the international labor-productivity comparison debate? Table 5 presents the comparative labor-productivity estimates with the UK as base-country. The first column of this table present the relative levels of gross output per worker, converted on the basis of the single deflated Fisher PPPs listed in table 4. The second column presents the comparative levels of real value added per worker, converted using the double deflated Fisher PPPs of table 4. The latter represents my preferred estimate of Anglo-American productivity around 1910. The last column lists the figures by Broadberry and Irwin, the original benchmark of US/UK productivity for the early twentieth century. Broadberry and Irwin estimate productivity on the basis of a direct comparison of physical quantities of output per worker which, as discussed in appendix A, makes them conceptually comparable to the single deflated productivity estimates listed in the first column of table 5.

So far my findings are in line with a large body of literature discussing the comparative advantages of the American economy during the late nineteenth and early twentieth century. The double deflated productivity figures in table 5 confirm the existence of a large transatlantic productivity gap in manufacturing, a phenomenon which has been extensively documented (Rostas 1948; Broadberry 1997a; Field 2003; Gordon 2004). I find that the US manufacturing productivity level was about 214 percent of the UK. My new estimates underline the US dominance in mining productivity as well, even though I do find a substantially greater Anglo-American productivity gap for this sector than originally reported by Broadberry and Irwin. Contrary to the consensus view, however, the present study also highlights the comparatively strong performance of the American agricultural sector. Below I will show that these upward revisions of sectoral productivity levels, particularly those for agriculture, raise the benchmark estimate of American total-economy productivity relative to the UK. This brings my aggregate estimates much closer to the GDP per worker and GDP per capita figures reported by Ward and Devereux and directly challenge the conclusions made by Broadberry and Irwin. Prior to discussing the results at the total-economy level, I will first discuss the origin and rational behind the revisions for each of the major sectors individually.

Agriculture

The main source for the discrepancy in the agricultural labor productivity estimates is not the method of productivity comparison – as Broadberry and Irwin also applied the ICOP approach here – but is the underlying figure of US value added per worker for this sector. The double deflated figures of value added per worker, listed in table 5, appraise American agriculture at 181 percent of the UK level. Broadberry and Irwin cite an estimate of 109. Table 6 provides an overview of the sources and figures behind both Anglo-American comparisons of agricultural productivity. In an earlier study, on which Broadberry and Irwin base their estimate, Broadberry (1997b, 27) lists a US net output per employee value of 347$. I base my considerably higher estimate of 488$ per worker on the value added figures listed in the Historical Statistics (Carter et al. 2006, 4:193) and the agricultural employment reported by Lebergott (1964, 510). Although the estimation of employment and particularly value added in agriculture is considerably more difficult than it is for other sectors, none of the primary sources point in the direction of a figure as low as suggested by Broadberry.[8]

Although Broadberry (1994a, 524) does not list the value added and employment figures underlying his labor productivity figures in US agriculture directly, they can be implicitly derived on the basis of the sectoral employment shares listed in his paper. Table 6 shows that this employment figure broadly matches the estimate by Lebergott (1964, 510), on which I rely. Total value added in the agricultural sector, derived from the productivity figure listed by Broadberry and the implicit employment estimate, lies considerably below my own measure, however. Broadberry's figure of approximately 3,875 million dollars does not appear to be supported by any of the primary sources available, which cite figures of total value added in American agriculture ranging from 5,780 million to 6,077 million dollars in 1909 (Carter et al. 2006, 4:193; United States Department of Agriculture 2011). Broadberry's underestimation of American agricultural output by over 30 percent accounts for a large share of the difference between his comparative productivity figure and those presented in the present study.

In addition, net output per worker in the British agricultural sector appears to be overstated by Broadberry (1997b, 27); 78£ versus my estimate of 64£ (Feinstein 1972, 208; 1976, T60, T131; Board of Agriculture and Fisheries 1912, 17, 26; Board of Trade 1912, 20). The higher estimate by Broadberry is the result of his choice to exclude the agricultural production in Ireland from his productivity estimate. This, however, is inconsistent with the definition used by Feinstein as well as his own industrial benchmark. I reincorporated Irish

8. Cited estimates of US value added per worker in 1910 range from 426$ to 575$. For alternative sources on employment see: Kendrick (1961, 308), Carter et al. (2006, 4:77), and United States Department of Commerce (1913c, 40; 1914, 229; 1943, 104). For alternative sources on agricultural output see: United States Department of Agriculture (2011) and United States Department of Commerce (1913b, 474, 494, 505, 517, 519, 532).

Table 6: Value added, employment and PPPs in agriculture, US and UK (1909/07)

	United States (1909)			*United Kingdom (1907)*				*comp.*
	value added ($ mln.)	*employ-ment* (th.)	*labor prod.* ($ th.)	*value added* (£ mln.)	*employ-ment* (th.)	*labor prod.* (£ th.)	*PPP* *($/£)*	*labor prod.* *(UK=100)*
This study[a]	5,780	11,838	488	143	2,234	64	4.20	181
Broadberry & Irwin[b]	*3,875*	*11,167*	347	[...]	[...]	78	4.12	109

[a] *Sources:* US value added: Carter et al. (2006, 4:193); US employment: Lebergott (1964, 510); UK value added: Feinstein (1972, 208); Feinstein (1976, T10); UK employment: Feinstein (1976, T60, T131); PPP: double deflated value added Fisher PPP, table 4.

[b] *Sources:* Broadberry and Irwin (2006, 261) and Broadberry (1994a, 524); US employment (in italics) based on sectoral distribution of labor as listed in Broadberry and Irwin (2006, 262).

production and employment in the productivity figures and made a (minor) revision to the PPP – from 4.12 $/£ listed by Broadberry (1997b, 27) to 4.20 $/£.

These adjustments to the productivity estimates listed above are not only in line with those suggested in a recent paper by Ward and Devereux (2005, 267–8), they also substantiate Habakkuk's claim of relatively high levels of productivity in American agriculture. In his monograph, Habakkuk (1962, 11–4) argues that during the nineteenth century "America[n] improvements in agriculture took the form primarily of increasing output per head and the increase initially was probably more rapid than in industry; in England on the other hand, agricultural improvement was devoted primarily to increasing yields per acre." Reflecting his well-known thesis for industry, Habakkuk contends that the abundance of resources and scarcity of (skilled) labor in the US forced American farmers to pursue capital-intensive methods of production. Machinery and particularly land were substituted for labor, resulting in high levels of labor productivity. The importance of labor-saving innovations also features prominently in subsequent accounts of the American agricultural development, stressing the relative productivity of this sector in international perspective (Hayami and Ruttan 1985). Furthermore, Olmstead and Rhode (2008) demonstrate the importance of biological innovations in the form of improved crops and livestock. These biological innovations allowed the farm frontier to be pushed to the drier and harsher West and North, continuously expanding the available land for cultivation. This depressed the price of farmland in relation to labor even further. These developments allowed American agriculture to become regionally specialized, reaping all the benefits of returns-to-scale and raising productivity levels in the process.

The developments in American agriculture should not be viewed in isolation. As noted in section 1, it appears highly unlikely that the American agricultural sector was left entirely unaffected by the rapid developments in industry during the late nineteenth and early twentieth century. Demand for agricultural goods increased dramatically, both from the domestic as well as the international market, while the wage-level continued to rise, reflecting the sizable labor productivity gains in industry. Had productivity levels in agriculture remained stagnant, it would have become even more difficult to attract labor from the industrial areas of the US. This in itself would have provided further incentive for farmers to economize on labor and adopt even more land-intensive forms of agriculture, raising labor productivity in the process. Over and above, American industry provided farmers with cheap fertilizers, energy and farm machinery which had the effect of raising the output per acre as well as allowing farmers to work greater stretches of land unaided.

In the UK land was scarce and there were few opportunities to expand the arable acreage. Consequently, British farmers primarily adopted land-saving, as opposed to labor-saving improvements and were mostly interested in raising the output per acre (Habakkuk 1962, 101–2). In an attempt to overcome this barrier, from the 1840s to the 1870s – the period known as 'high farming' – a fair amount of new acreage was added, mostly through drainage (Turner

2004, 139). Still, this investment came at considerable expense and the supplemental farmland, approximately 4.5 million acres, was not enough to overcome the constraints posed by land-scarcity on the growth prospects of British agriculture. Doubt could thus be cast on the appropriateness of the designation 'high farming', as it is not evident that the addition of arable acreage made strict economic sense. From 1870 up to the First World War, other forms of land-saving technologies developed rapidly and began to spread across British agriculture; the primary applications were the use of chemical fertilizers and concentrated feeds (van Zanden 1991, 231–2). When compared to other Western-European countries though, the average consumption of fertilizers in the UK was still relatively low, while the level of consumption of imported animal feeds stagnated after 1880. In contrast to the US and parts of Europe, the improvements in labor-saving technology in late nineteenth and early twentieth century Britain were limited and the main agricultural activities remained largely dependent on draft animals and human labor (van Zanden 1991, 234).

As noted by Turner (2004, 133; 144), British agriculture appears to have been in more or less unremitting decline from 1860 down to the First World War. The UK became more and more dependent on imports of agricultural goods to satisfy the needs of the ever-growing urban population. Initially this flow of imports was composed largely of cash crops, such as wheat from North America. The influx of cheap grains caused a sharp realignment of the agricultural sector from crop production toward a livestock economy. In the 1860s and 1870s, Britain's isolated position and legislation still afforded the livestock producers some respite from foreign competition, and livestock's share in total agricultural output increased to well over 50 percent during the decades to follow. Yet, by the 1880s the free-trade policies and the development of chilled transportation opened the British meat market to foreign competition. Turner (2004, 134) shows that, "the benefits of bulk carriage and the attendant economies of scale meant that even after incurring substantial freight charges many overseas suppliers from the 1880s could compete more successfully in home markets than home producers."

The inability of British farmers to compete with foreign competitors and the substantial imports of American agricultural produce appear to support my finding of comparatively low levels of productivity in the British agricultural sector. This also aligns with the estimates by Ó Gráda (1994, 148–9) of TFP growth in the range of 0.4 percent per year between 1870 and 1910, which in comparison to the US and other European countries was fairly slow (van Zanden 1991, 229). Whereas American agriculture took full advantage of the major improvements in labor-saving technologies prior to 1910, British improvements focused primarily on the saving of land. By and large British farmers had trouble adapting to the rapidly changing economic and social conditions (van Zanden 1991, 237–8).

Table 7: Value added and employment shares in mining, US and UK (%, 1909/07)

	United States (1909)[a]		*United Kingdom (1907)*[b]	
branch/sector	*value added*	*employment*	*value added*	*employment*
Coal	49.3	68.8	91.0	87.9
Iron ore	8.8	4.8	1.5	1.2
Other metals	19.4	10.7	1.1	1.9
Fuel oils	13.9	4.4	1.3	1.0
Miscellaneous	8.5	11.3	5.1	8.1
Total mining	100.0	100.0	100.0	100.0

[a] *Source:* United States Department of Commerce (1913d, 24).
[b] *Source:* Board of Trade (1912, 39).

Mining

The estimate of labor productivity for mining by Broadberry and Irwin again appears to understate the relative lead of the US in comparison to the UK. The double deflated figures of value added per worker, listed in table 5, appraise American mining at 263 percent of the UK level. Broadberry and Irwin cite an estimate of 161. The main source for the discrepancy between both benchmark estimates is the method of productivity comparison. Broadberry and Irwin rely on Rostas' original quantity approach and estimate comparative productivity in mining solely on the basis of the physical production of coal and iron ore. Even though coal and iron ore comprise the bulk of output and employment in this sector, as shown in table 7, by focusing solely on these two items Broadberry and Irwin ignore the contribution of other upcoming mining products, most notably gas and fuel oils (e.g. petroleum).[9]

The average value added per wage earner in these uncovered mining branches – at least for the American mining sector – was substantially greater than that observed in coal and iron ore mining. Table 7 shows that the nonferrous metal ores, fuel oils and miscellaneous mining branches covered approximately 26 percent of employment and 42 percent of value added in US mining, raising the average labor productivity by about 27 percent when I include these to the coal and iron ore sample. For the UK, coal and iron ore already encompassed 89 percent of mining employment and about 93 percent of value added. Here, the addition of the other mining branches actually lowers the average value added per worker for the total British mining sector by 4 percent. The complete coverage of mining, which is made possible by the use of the ICOP methodology, thus raises the comparative productivity

9. Even though the share of oil and natural gas in the world's total energy consumption was still fairly low prior to the First World War (approximately 5.9 percent), their relative contribution to the total power supply increased rapidly in the decades to follow; by 1935 the share of these commodities in the world's power supply had risen to just over 20 percent. The American reliance on gas and oil was substantial greater than it was in the UK, however. According to the International Labour Office (1938, 33–6), in 1936 the American share of oil and gas in the total energy consumption was 37.4 percent, whereas the British share was only 8.7 percent.

Table 8: Comparative labor productivity in coal mining, US and UK (1909/07)

		output per worker		*PPP*	*comparative productivity*
	unit	*US*	*UK*	*($/£)*	*(UK=100)*
Quantity: Broadberry[a]	tons/worker	530	326		163
Quantity: McCloskey[b]	tons/worker	613	325		188
ICOP: *uvr* 'coal: total'[c]	*go*/worker	826	146	3.01	188
ICOP: Fisher PPP[d]	*go*/worker	826	146	2.78	203

[a] *Source:* Broadberry (1997b, 27).
[b] *Source:* McCloskey (1971, 291).
[c] *Sources:* Board of Trade (1912, 42, 44) and United States Department of Commerce (1913d, 186). The employment figures for the US were adjusted to exclude coke workers and take peak employment into account, while British employment was corrected for absenteeism and excludes iron miners working under the Coal Mines Regulation Act; see McCloskey (1971, 291). The price deflator is based on the unit value ratio for all coal combined, see table 9.
[d] *Sources:* see [c]. The price deflator is based on the Fisher PPP for coal, see table 9.

estimate by over 30 percent in favor of the US, accounting for a large part of the discrepancy between my new estimate and the original Broadberry and Irwin benchmark.

Apart from its limited coverage, the figure cited by Broadberry and Irwin also appears to understate productivity in coal mining directly. Given coal's large share in mining output, the estimate for this branch has serious implications for both Broadberry and Irwin's as well as my own estimation of overall mining productivity. Broadberry and Irwin's estimate is based on earlier work by Broadberry (1997b, 27), who cites the total tonnage of coal extracted and the number of wage earners in American and British coal mining. In his figures Broadberry erroneously includes the labor and output of the coke production at the American collieries. This lowers his estimate of output per worker for the US substantially. In an earlier study, McCloskey (1971, 291) uses identical methods and sources to compare Anglo-American productivity in the coal mining branch, but he adjusts the output and employment figures to exclude the production of coke. Table 8 lists both these estimates and the underlying country-specific output per worker figures, showing McCloskey's comparative US/UK productivity figure for coal mining to come out substantially higher at 188 compared to the Broadberry estimate of 163.[10]

On the basis of the same sources as McCloskey, but comparing the gross output value per

10. An international comparison of the coal-mining industry by the International Labour Office (1938) reports an even greater gap in productivity between the US and UK. Comparing the output of bituminous coal per man-shift in 1913 they observe an average production of 3,270 kg. per shift in the US and only 1,090 in Britain. Relative to other European countries, productivity in the UK was slightly above-average; productivity in the German Ruhr area was approximately 943 kg. per shift; for Belgium the International Labour Office (1938, 109) reports a figure of 528; 701 for France; 820 for the Netherlands; and 1,202 for the East Upper Silesia region in Poland.

Table 9: Relative price of coal, US and UK (1909/07)

	United States (1909)[a]			*United Kingdom (1907)*[b]			
	quantity (ton, mln.)	*value ($, mln.)*	*unit value ($/ton)*	*quantity (ton, mln.)*	*value (£, mln.)*	*unit value (£/ton)*	*uvr ($/£)*
coal: anthracite	73.5	149.4	2.03	4.0	2.3	0.58	3.51
coal: bituminous	344.5	405.5	1.18	266.9	117.3	0.44	2.68
coal: total	418.0	554.9	1.33	270.8	119.6	0.44	**3.01**
	Laspeyres	*Paasche*	*Fisher*				
PPP	2.69	2.86	**2.78**				

[a] *Sources:* United States Department of the Interior (1911) and United States Department of Commerce (1911, 202–4).
[b] *Source:* Board of Trade (1912, 42).

wage earner instead, I arrive at an identical level of comparative productivity (see row 3 in table 8). For this estimate, I converted US gross output per wage earner to British Pounds Sterling on the basis of the ratio of the American and British unit values for all types of coal combined.[11] This is in line with the approach taken by Broadberry and McCloskey who also aggregated the total tonnage of coal excavated prior to comparing the quantity output per worker. The aggregation of the total tonnage and output value of coal implicitly ignores the variations in the quality and price for the different types of coal, however. Table 9 illustrates that in both countries the price for anthracite coal was markedly higher than the price for bituminous coal and that the share of the former in the output of the American coal mining branch was also substantially greater than the share of anthracite in British coal production. As an alternative measure, using equations (3)-(5), I estimated a new purchasing power parity for coal, taking both the price variations and the different value shares of anthracite and bituminous coal into account. This Fisher PPP was then used to re-estimate comparative productivity in table 8, resulting in a US/UK productivity level of 203.

The example of coal mining above highlights both the similarities between the quantity and the ICOP approach as well as the potential advantages of the latter. Based on the same sources, a direct comparison of the tonnage of coal per worker yields an identical productivity estimate as a comparison of the per worker value of coal production (based on the unadjusted average price of coal). The capacity of the ICOP approach to account for differences in prices between the various commodities produced within the same industry distinguishes it from the original quantity approach, however. Still, it should be noted that the quality adjustment illustrated above does not guarantee that the products being compared are fully equivalent between the two countries. The chemical composition of coal (e.g. carbon, mois-

11. The unit values and unit value ratios for coal are based on equations (1) and (2). The underlying quantity and value data and sources are given in table 9.

ture or volatile content) as well as the physical characteristics – which can differ markedly between geological regions – ultimately determine the suitability for specific consumption purposes.[12] In the early twentieth century, the world's coal markets recognized hundreds of individual classifications of coal, illustrating that the distinction between anthracite and bituminous coal is still quite rough.[13] Nonetheless, the expanded sample of products discussed previously, as well as the reliance on value added and sectoral employment figures and the application of double deflation in the present study, yields a markedly higher and, in my opinion, more representative estimate for the comparative Anglo-American productivity in the mining sector as a whole.

The superior performance of the American mining sector can, in part, be explained by the sheer quantity and quality of natural resources in this country. For the coal-mining sector, McCloskey (1971, 293) shows that the "American seams were generally thicker, closer to the surface, freer from faults, flatter and drier than British seams." The favorable geological conditions allowed American miners to introduce new mechanized methods of production and work considerably more efficiently than their British counterparts. Taylor (1961, 58-9) also emphasizes the British mine-owners conservative attitude toward the adoption of new innovations and technologies through, for instance, the late adoption of electricity as well as the hesitant introduction of the mechanized coal-cutter in the British mines.[14] As was the case for agriculture, American miners took full advantage of the major improvements in labor-saving technologies during the late nineteenth and early twentieth century, whereas British improvements focused primarily on overcoming the diminishing returns to land as the coal and ore deposits were slowly being exhausted (McCloskey 1971, 289–90). These developments drove a wedge between the labor productivity levels of both countries, resulting in a productivity ratio in the mining sector of 2.63 to 1 in favor of the US.

Manufacturing

As illustrated in table 5, the estimate of labor productivity in manufacturing by Broadberry and Irwin is actually very close to my own double deflated value added per worker figure for this sector. Broadberry and Irwin estimate a US/UK comparative productivity level of 209 versus my estimate of 214. Both these estimates confirm the existence of a large transatlantic productivity gap for manufacturing in the early twentieth century. Britain's falling behind during the nineteenth century and its inability to catch-up has been extensively documented and has traditionally been explained by differences in factor and resource endowments as well as demand patterns (Habakkuk 1962; Broadberry 1997a; Field 2003; Gordon 2004). The abundance of land and natural resources in the US gave rise to more capital- and resource-

12. The International Labour Office (1938, 17–24) report on the world coal-mining industry provides an extensive description of the characteristics of different ranks and grades of coal and their consumption purposes.

13. Neither the British nor the American census fully distinguish between bituminous, sub-bituminous and even lignite. See, United States Department of Commerce (1911, 203) and Board of Trade (1912, 42–3).

14. See also, Walters (1975, 296).

Table 10: Comparative labor productivity in manufacturing, US and UK (1909/07)

	comparative labor productivity (UK=100)		
industry/sector	*single deflated gross output*	*double deflated value added*	*Broadberry & Irwin*[a]
Food, drink and tobacco	200	155	146
Textile, apparel and leather	157	184	151
Chemicals, petroleum and rubber	169	176	143
Metal industries	203	224	288
Engineering and transport eq.	227	268	203
Miscellaneous	216	239	227
Manufacturing	198	214	209

[a] *Sources:* Broadberry and Irwin (2006, 261) and Broadberry (1994a, 524).

intensive production, a process which was further facilitated by a relatively homogenous demand for goods (Broadberry 1994b, 291). In contrast, in Britain natural resources were scarce while skilled labor was in ample supply, providing an incentive to economize on fixed capital in the form of machinery (Temin 1971, 162). The role played by resources in the Anglo-American manufacturing productivity gap is underscored by the relatively low input PPP for manufacturing, presented in table 4, which illustrates the American access to cheap intermediates flowing from the agricultural and mining sectors.

Table 10 shows that the new comparative labor productivity figures for the underlying industries deviate more substantially from the original estimates. Still, the overall picture sketched by Broadberry and Irwin remains intact. American producers excelled in the production of durable goods (e.g. metal, engineering and wood products), while the British manufactures were relatively productive in the non-durable industries (e.g. food, textile and chemicals). As noted by Broadberry (1994b, 523), the industry-specific productivity results are also broadly in line with the figures on revealed comparative advantage in British and American manufacturing trade by Crafts and Thomas (1986, 639).

A comparison of the real gross output and real value added figures in table 10 reveals that the application of the double deflation procedure can have a significant impact on the productivity estimates. As previously noted, the use of gross output in international benchmark comparisons introduces a potential bias as a result of differences in the share of inter-industry deliveries in the value of production. This is of importance particularly when the ratio of intermediate inputs to gross output varies between countries as well as industries. These variations can occur as a result of differences in production methods, the types of materials used, and the amount of imported materials, but can also be caused by differences in industry classifications between the countries under comparison (Fremdling, de Jong, and Timmer 2007a, 360). In addition, as discussed in section 3, double deflation takes both relative prices of output and inputs into account. The difference between the use of value added instead of gross output for the productivity comparison is most evident for the engineering and transportation equipment sector. Here the relative input and output prices vary only marginally, but the share of input in gross output is relatively high in the UK (see table 4). Consequently, British gross output is inflated by the large share of intermediates used in the production process and will considerably overestimate the added value of British machine builders in comparison to their American counterparts. In contrast, the share of intermediate inputs in the food, drink and tobacco industry is roughly identical for the UK and the US (73 and 71 percent respectively), but the use of relatively cheap agricultural inputs in the US leads to a considerable upward adjustment of the value added PPP. Taking the relative prices for outputs as well as inputs into account thus results in a substantial downward adjustment of the comparative productivity figure for this industry.

In appendix A, I demonstrate that the quantity approach – the method on which Broadberry and Irwin rely – is conceptually on the same footing as my measure of real gross output per worker. For the textile, apparel and leather as well as the engineering and transportation equipment industries, the gap between the new productivity figures and the original estimates by Broadberry and Irwin appear to be explained by the latter's implicit reliance on gross output instead of value added. The moderate upward revision for the productivity estimates in the chemical industries illustrates another one of the drawbacks of the quantity approach. Because of the complex structure of the chemical industries and the heterogeneous nature of its products, it is simply not possible to aggregate the quantities produced to a single measure or to assign labor to the various products. The assignment of labor used to produce a single good, as discussed in appendix A, is economically less sensible when the share of output for that good only comprises a small fraction of the total production value in that industry. As a result, the Broadberry and Irwin estimate for chemicals is primarily based on those chemical industries that produce a single or homogeneous set of products (e.g. seed crushing, coke, soap, fertilizers), disregarding the biggest industry in this sector: basic chemicals.

Hours of work

So far the productivity figures have been expressed solely in terms of output per worker. I implicitly assumed the average length of the working week as well as the number of vacation and holidays to be identical in both countries. This assumption is born out of necessity, unfortunately, as detailed figures on hours of work are generally unavailable for most sectors in the early twentieth century. For the manufacturing industries, however, statistics on the length of the working week are available. Table 11 provides an overview of the weekly and annual hours of work in both countries.

The UK figures in table 11 were taken from the *British Labour Statistics* (Great Britain

Table 11: Weekly and annual average hours worked in manufacturing, US and UK (1909/06)

	United States (1909)[a]		*United Kingdom (1906)*[b]	
branch/sector	*weekly hours*	*annual hours*	*weekly hours*	*annual hours*
Food, drink and tobacco	54.7	2,722	54.4	2,657
Textile, apparel and leather	54.2	2,697	53.9	2,631
Chemicals, petroleum and rubber	56.9	2,827	53.2	2,597
Metal industries	55.5	2,760	53.1	2,593
Engineering and transport eq.	54.2	2,692	53.2	2,596
Miscellaneous	54.3	2,699	53.6	2,617
Manufacturing	54.7	2,718	53.7	2,619

[a] *Sources:* United States Department of Commerce (1913e, 316–9), Jones (1963, 375), and Huberman and Minns (2007, 546).

[b] *Sources:* Great Britain Department of Employment and Productivity (1971, 95) and Matthews, Feinstein, and Odling-Smee (1982, 566).

Department of Employment and Productivity 1971, 95), which contains detailed statistics on the 1906 average hours of work per week for nearly all of the large industries within the British manufacturing sector.[15] The American industry-specific estimates were taken from the *Census of Manufactures* (United States Department of Commerce 1913e, 316–9) and the work of Jones (1963, 375). Data from Matthews, Feinstein, and Odling-Smee (1982, 566) on the number of vacations and holidays in Britain and Huberman and Minns (2007, 546) for the US allowed me to estimate the annual totals for hours worked. Overall, the length of the average working week was fairly similar between the US and the UK. American manufacturing wage-earners worked, on average, 1 additional hour per week compared to the British wage earners. The relative gap in the annual hours of work is slightly larger as a result of the greater number of vacation and holidays in the UK.

Table 12 presents the labor productivity statistics on a person-hour basis. The industry-specific employment data have been multiplied by the data on annual hours of work taken from table 11. Given the comparable length of the average working week in the UK and the US, the hourly productivity estimates do not deviate much from the per worker figures. The hour-adjusted figures indicate that overall manufacturing productivity in the US stood at ca. 207 percent of the UK level, approximately 7 percentage points below the per worker estimate. At the detailed industry level, the drop in measured labor productivity ranged from 4 percentage points (food, drink and tobacco) to 14 percentage points (chemicals, petroleum and rubber). Overall, the per hour figures confirm the existence of a large transatlantic productivity gap in manufacturing, in the order of approximately 2:1, at the start of the twentieth century.

15. Note that I assume the average length of the working week to remain unchanged between 1906 and 1907.

Table 12: Real value added per worker and per hour in manufacturing, US and UK (1909/07)

branch/sector	*value added per worker (% US/UK)*	*value added per hour (% US/UK)*
Food, drink and tobacco	155	151
Textile, apparel and leather	184	180
Chemicals, petroleum and rubber	176	162
Metal industries	224	211
Engineering and transport eq.	268	258
Miscellaneous	239	232
Manufacturing	214	207

Sources: see tables 10 and 11.

5 Total economy

In order to assess the impact of the new sectoral benchmarks on the overall productivity levels of the two countries, table 13 presents the reconciliation of comparative GDP per worker and per capita for the US and the UK. As a first step in the output based estimate of comparative productivity, I calculated a PPP deflator at the total economy level. This PPP is a weighted average of the value added PPPs for the agricultural, mining and manufacturing sectors listed in table 4, supplemented with implicit price deflators for the construction and service sectors. The latter are based on the comparative productivity estimates for these two sectors by Broadberry and Irwin (2006, 261) which, when combined with the nominal value added per worker data listed in table 13, yield the comparative price levels at the sectoral level.

The PPP for total economy, at 6.14 $/£, comes out considerably higher than the official exchange rate at 4.87 $/£. In a study of the relative cost of living in Britain and the US, Williamson (1995, 184) obtains a fairly similar PPP of 6.48 $/£, however. This PPP, based on the relative prices of primarily food stuffs and rents, appears to corroborate the finding of a comparatively high American price level.

On the basis of the estimates of GDP at factor costs and total employment, the total economy PPP can be utilized to compare output per worker between the two countries. As shown in table 13, I find a US GDP per worker level of about 138 percent of the UK. This is nearly 10 percent above the original industry-of-origin estimate by Broadberry and Irwin (2006, 261) – who value the American output per worker at 125 percent of the British level. The new estimate puts the US comfortably in the lead in terms of total economy labor productivity at the start of the twentieth century.

As noted by Broadberry (1998, 386), “the aggregate comparative level of labor productivity at a point in time is the result not only of the levels of comparative labor productivity

Table 13: Comparative labor productivity and income, US and UK (1909/07)

	employment shares (%)		*PPP*[c]	*value added per worker/capita*		
branch/sector	*US*[a]	*UK*[b]	*($/£)*	*US ($)*[d]	*UK (£)*[e]	*US/UK*[f]
Agriculture	32.8	11.8	4.2	488	64	181
Industry	29.1	43.5	5.6	1,026	89	206
Mining	3.0	6.3	3.0	860	110	263
Manufacturing	21.3	32.1	5.7	1,063	86	214
Construction	4.8	5.1	*9.1*	970	80	*134*
Services	38.0	44.7	*7.2*	1,137	132	*119*
GDP per worker[g]	100.0	100.0	6.1	892	105	138
GDP per capita[h]			6.1	354	46	126

[a] *Sources:* Kendrick (1961, 296–7, 308) and Lebergott (1964, 118).
[b] *Source:* Feinstein (1976, 131).
[c] Fisher value added PPPs from table 4. PPPs in italics were derived implicitly from the value added per worker figures in the last three columns of this table.
[d] *Sources:* Carter et al. (2006), King (1930), and Fabricant (1940).
[e] *Source:* Feinstein (1972, 208).
[f] Double deflated value added per worker estimates from table 5. Productivity figures in italics were taken from Broadberry and Irwin (2006, 261).
[g] *Sources:* Feinstein (1976, T10, T125–6), Kendrick (1961, 296–7, 308), and Lebergott (1964, 118).
[h] Population figures from Maddison (2008).

Table 14: Different approaches to estimate comparative GDP per capita, US and UK (ca. 1910)

author	*approach*	*year*	*rel. GDP p. capita (UK=100)*
This study	ICOP	1909/07	126
Ward & Devereux	Expenditure	1905	122
Broadberry & Irwin	Quantity relatives	1909/11	113
Broadberry & Irwin	Expenditure	1909/11	105
Maddison	1990 GK$	1910	108
Maddison	1985 GK$	1910	125
Maddison	1970 GK$	1910	127

Sources: Ward and Devereux (2003, 2006), Broadberry and Irwin (2006), and Maddison (2001, 1991, 1982).

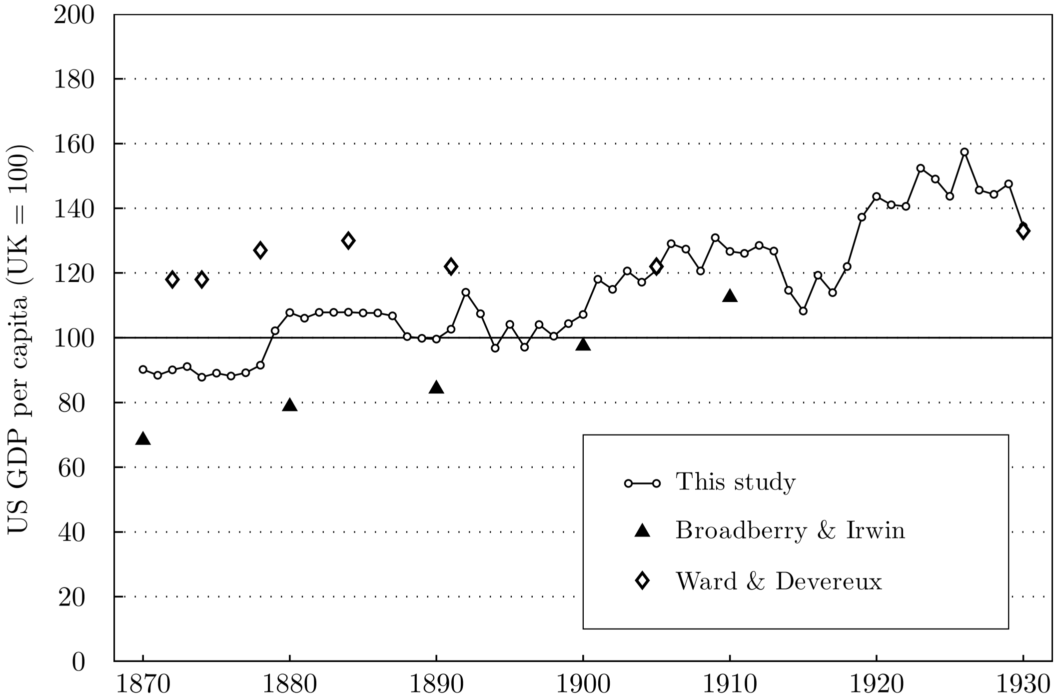
in each sector but also of differences in the structure of employment." Table 13 shows that a large share of the American labor force was engaged in agriculture, while in the UK the labor force was concentrated in the high value-added service sectors. These structural differences provided the UK with a notable advantage – as value added per worker was substantially lower in agriculture than in industry or services – helping to explain the relatively modest lead in GDP per worker despite the large US/UK productivity gap in agriculture and industry (Broadberry and Irwin 2006, 263). Had the structure of the labor force been identical between the US and the UK at the start of the twentieth century, then the level of US output per worker would have been between 150 and 157 percent of the British level, depending on whether the US or UK employment shares from table 13 are applied.

On the basis of Maddison's figures for the 1909 American and 1907 British population, an estimate of comparative GDP per capita can also be derived.[16] Table 14 compares this estimate with previous attempts to measure economy-wide income differences between the two countries. My industry-of-origin estimate is set against the expenditure-based productivity calculations by Ward and Devereux, the estimates by Broadberry and Irwin, and various versions of the Maddison data-set expressed in 1970, 1985 and 1990 international Geary-Khamis dollars respectively.

Overall, my Anglo-American GDP per capita estimate is higher than the figures suggested by Broadberry and Maddison. I appraise the American relative income per capita level to be 126 percent of the UK, which is actually very close to the figures provided by Ward and Devereux. It is interesting to note that my estimate also approximates the earlier estimates by Maddison, expressed in 1985 or 1970 dollars. This similarity seems to suggest that the earlier benchmarks of international dollars reflect the actual price differences around 1910 better than the later benchmarks, backing up earlier claims in this respect by Prados de la

16. Note that the GDP per capita figures are based on the estimates of GDP at factor costs and PPP deflator listed in table 13.

Figure 1: Comparative GDP per capita, US and UK (UK=100, 1870–1930)



Sources: Benchmark 1909/07 based on double deflated estimate listed in table 13. Time series output and population, see Maddison (2008). Broadberry and Irwin (2006, 270) and Ward and Devereux (2003, 840).

Escosura (2000).

A backward projection of my benchmark estimates on existing time-series again yield some interesting conclusions. Figure 1 summarizes the main findings of the changes in relative income levels. For the time series I rely on figures by Maddison (2008), allowing me to compare the extrapolated GDP per capita figures against the Anglo-American comparative per capita income figures by Broadberry and Irwin (2006, 261).

The estimates by Broadberry and Irwin (2006, 269) show a substantial British lead in per capita income terms between 1870 and 1890. According to their estimates, the US overtook the UK in GDP per capita not until 1910. My benchmark extrapolation dates the overtaking considerably earlier. I find that around 1870 the UK enjoyed a small lead in per capita income terms. By 1880 this lead had dissipated and between 1880 to 1900 the US level of GDP per capita remained roughly on par with the UK. During the first three decades of the twentieth century, however, the US charged ahead and the income gap widened to nearly 60 percent in the 1920s.

Even though my new estimate of relative GDP per capita is very similar to the early twentieth century benchmark by Ward and Devereux, the long-run trend illustrated in figure 1 does not correspond well to their nineteenth century expenditure benchmarks. As noted in section 1, Ward and Devereux show the US leading in terms of income per capita as early as 1872. In addition, they estimate a considerable gap in relative income levels between the US and the UK throughout the 1872–1905 period. On the basis of the new industry-of-origin benchmark and time-series evidence, I come to the conclusion that this appears to overstate the actual relative American income level in comparison to the UK. Still, the 1909/07 benchmark confirms the existence of a large gap in comparative productivity between the US and the UK in agriculture and industry and provides strong evidence for a sizable American advantage in terms of GDP per worker and GDP per capita at the start of the twentieth century.

6 Conclusion

This study offers a new benchmark for agriculture, mining and five manufacturing branches in the US and the UK around 1910. On the basis of the ICOP approach, I measure the value of net output by industry translated to a common currency on the basis of sector-specific double deflated PPPs. This procedure takes both the differences in the relative prices of outputs as well as inputs into account, which proved to be of particularly importance for the productivity estimate of the manufacturing sector. In this sector I observe a notable gap in the relative PPPs for inputs and outputs, reflecting the American access to cheap intermediate inputs flowing from the agricultural and mining sectors.

The new benchmark estimates confirm the existence of a large transatlantic productivity gap in manufacturing, supporting earlier claims to this effect by Rostas and Broadberry. Contrary to the consensus view, however, I demonstrate that the Atlantic productivity gap in the early twentieth century extended to mining and agricultural sectors as well. Industrial productivity in the US stood at ca. 206 percent of the UK level, while American agriculture maintained a lead of 181 percent against its British counterpart. I show that American farmers took full advantage of labor-saving technologies, greatly improving their productivity level in comparison to the British farmers who focused instead on the saving of land. In similar vein, productivity in British mining was hampered by the relative hesitant introduction of technological improvements and unfavorable geological conditions.

The substantial US lead in agriculture and industry provides firm evidence for a strong overall lead in total economy productivity. However, as argued by Broadberry, differences in the employment structure between both economies did play a role in the relative income and productivity differentials. The low share of British employees in the agricultural sector provided Britain with a structural advantage that substantially reduced the gap in the overall level of productivity between the US and the UK. Applying the new benchmark estimates for ca. 1910 to long term projections of value added and total population back into the nineteenth century reveals an interesting new perspective on the dynamics of comparative long-term economic development, suggesting an earlier American takeover in terms of GDP per capita.

Rather than offering any definitive answers to the questions of long run economic growth and dynamics, my new benchmark estimate serves as a starting point for further investigations based on an industry-of-origin approach. A lot of work remains to be done on improving the quality of time-series of gross output, value added and employment for the nineteenth century, and in many cases the early twentieth century as well. In addition, expanding and improving estimates of service sector productivity is crucial to arrive at a more complete picture of convergence and divergence of income and productivity levels since the industrial revolution.

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A Benchmark methods compared

Although the basic concepts behind the available industry-of-origin benchmark techniques are similar, there are some marked differences between the ICOP approach, used in this paper, and Rostas' quantity approach. In this section, I discuss both the basic methodology behind the quantity approach and provide an in-depth discussion of the methodological similarities and differences between both approaches. Below, I show that the quantity approach can be rewritten to approximate a basic version of the unit value approach. I will also show, however, that in practice the outcomes of these methods can deviate substantially. Particularly the necessity to assign labor to individual commodities instead of industries within the quantity approach, limits this methodology's ability to estimate productivity for industries producing a wide array of heterogeneous products. I demonstrate the basic methodology on the basis of a simple single industry, two country, k product framework.

Rostas' quantity approach

In the quantity approach, labor productivity (lp_{ij}) for product i of country j, is defined as the ratio between the physical quantity produced (q_{ij}) and the employment used to produce this particular commodity (emp_{ij}).

$$lp_{ij} = \frac{q_{ij}}{emp_{ij}} \tag{13}$$

Unfortunately, employment at the commodity level is rarely available in historical sources. Broadberry (1994a, 523) shows that when quantity data is not available for the whole output of the trade, the estimate of operatives in the trade (emp_j) can be reduced in proportion to the ratio of the value of covered items (v_{ij}) to the value of total gross output (go_j), as shown in equation (14) (Rostas 1948, 19–20).

$$emp_{ij} = emp_j \cdot \frac{v_{ij}}{go_j} \tag{14}$$

The comparative labor productivity ratio, LP_{io}, can then be obtained by dividing labor productivity of country n by the labor productivity of country o. In equation (15), the subscript n represents the numerator country, whereas the subscript o represents the base country.[17]

$$LP_{io} = \frac{lp_{in}}{lp_{io}} \tag{15}$$
$$= \frac{q_{in}}{emp_n \cdot \frac{p_{in} \cdot q_{in}}{go_n}} / \frac{q_{io}}{emp_o \cdot \frac{p_{io} \cdot q_{io}}{go_o}}$$
$$= \frac{go_n}{emp_n \cdot p_{in}} / \frac{go_o}{emp_o \cdot p_{io}}$$
$$= \frac{go_n/emp_n}{go_o/emp_o} / \frac{p_{in}}{p_{io}}$$

Substituting equation (14) into (13) – for both country n and o – in the comparative labor productivity ratio above, reveals that the outcome for the quantity approach is identical to the ratio of single deflated gross output per worker for both countries. In the case of a single commodity, the price deflator is given by the unit value ratio for this commodity. The *uvr* from equation (2) is used to transform either countries' gross output into the other countries' currency, making productivity in both countries directly comparable.

In the case when there are multiple clearly distinct products being produced in the same trade, the quantity output of these products can be weighted according to their relative prices. Broadberry (1994a, 525–6) provides an example of this procedure for the comparison of productivity in the American and British automobile, cycle and motorcycle industries. He shows that the heterogeneous output of this industry (i.e. automobiles, cycles and motorcycles) can be converted to automobile equivalents using the relative unit values for either the US or the UK. Equation (16) illustrates this step on the basis of country o's relative prices (Rostas 1948, 18–9).

$$Q_{j(o)} = \frac{\sum p_{io} \cdot q_{ij}}{p_{1o}} \tag{16}$$

The outcome of equation (16) above, represents the sum of the output of k products for country j, expressed in quantities of the base product 1 (e.g. automobiles, as in Broadberry's example).[18] This aggregate quantity, $Q_{j(o)}$, can in turn be used to estimate comparative labor productivity for the entire industry; see equation (17). Note that the estimate of operatives in the industry (emp_j) is now reduced in proportion to the ratio of the total value of all covered

17. Note that the total production value of commodity i (v_{ij}) is, by definition, equal to the physical quantity produced (q_{ij}) times the unit value (p_{ij}) of this product.

18. Note that, for the calculation of the labor productivity ratios in (17) and (19), the choice of base product is irrelevant as it cancels out in the equation.

items ($\sum p_{ij} \cdot q_{ij}$) to the value of gross output (go_j).

$$LP_{o(o)} = \frac{\frac{\sum p_{io} \cdot q_{in}}{p_{1o}}}{emp_n \cdot \frac{\sum p_{in} \cdot q_{in}}{go_n}} / \frac{\frac{\sum p_{io} \cdot q_{io}}{p_{1o}}}{emp_o \cdot \frac{\sum p_{io} \cdot q_{io}}{go_o}} \tag{17}$$
$$= \frac{go_n/emp_n}{go_o/emp_o} \cdot \frac{\sum p_{io} \cdot q_{in}}{\sum p_{in} \cdot q_{in}}$$
$$= \frac{go_n/emp_n}{go_o/emp_o} / P^{go}$$

Rearranging the terms in equation (17) shows that the resulting productivity estimate will still be identical to the single deflated gross output per worker, only now using the Paasche gross output PPP (P^{go}) from section 2 as deflator. If I rely on the relative prices of country n instead, I obtain the aggregate quantity, $Q_{j(n)}$, which in turn translates into the comparative productivity ratio given in equation (19). This productivity estimate is still equivalent to single deflated gross output per worker, now using the Laspeyres gross output PPP (L^{go}) from equation (3) as the price deflator.

$$Q_{j(n)} = \frac{\sum p_{in} \cdot q_{ij}}{p_{1n}} \tag{18}$$

$$LP_{o(n)} = \frac{\frac{\sum p_{in} \cdot q_{in}}{p_{1n}}}{emp_n \cdot \frac{\sum p_{in} \cdot q_{in}}{go_n}} / \frac{\frac{\sum p_{in} \cdot q_{io}}{p_{1n}}}{emp_o \cdot \frac{\sum p_{io} \cdot q_{io}}{go_o}} \tag{19}$$
$$= \frac{go_n/emp_n}{go_o/emp_o} \cdot \frac{\sum p_{io} \cdot q_{io}}{\sum p_{in} \cdot q_{io}}$$
$$= \frac{go_n/emp_n}{go_o/emp_o} / L^{go}$$

Broadberry (1994a, 525) shows that, in line with the ICOP approach, the geometric average of these two estimates is taken as the overall productivity estimate in the quantity approach – thus reflecting both the relative prices of the numerator country n as well as the base country o. Equation (20) illustrates that this is equivalent to the Fisher deflated ratio of gross output per worker.

$$LP_o = \sqrt{LP_{o(o)} \cdot LP_{o(n)}} \tag{20}$$
$$= \frac{go_n/emp_n}{go_o/emp_o} / \sqrt{L^{go} \cdot P^{go}}$$
$$= \frac{go_n/emp_n}{go_o/emp_o} / F^{go}$$

The ICOP versus the quantity approach

As illustrated above, the comparative labor productivity estimates at the industry level based on the quantity approach will be identical to those based on single deflated gross output, provided that employment at the commodity level is estimated according to equation (14). For his 1907/09 benchmark of Anglo-American manufacturing productivity – the study against which I contrast my own findings – Broadberry (1994a, 538–45; 1997b, 27) applies this method throughout, making his estimates directly comparable to the single deflated productivity ratios reported in table 10.

In section 4, I show that Broadberry's quantity based estimates do in fact differ from my own single deflated figures, however. These differences stem primarily from the increased coverage of this study, both with respect to the products matched as well as the number of industries incorporated into the productivity comparison. For the manufacturing sector, Broadberry (1994a, 538–45) directly compared 35 different products between both countries. In contrast, I matched a total of 111 products, considerably broadening the range of products covered and taking important variations in the quality of goods into account.[19] As noted in section 4, this underscores one of the drawbacks of the quantity approach. The assignment of labor used to produce a single good is economically less sensible when the share of output for that good only comprises a small fraction of the total production value in that industry. Consequently, this limits the quantity approach's ability to estimate productivity for industries producing a wide array of heterogeneous products (Rostas 1948, 12–4).

In addition, I base my productivity results on the total gross output (or net output) and employment for the entire manufacturing sector. I implicitly assume that the relative price ratios are representative conversion factors for both the industries for which products were covered as well as those for which no matches could be made. Broadberry does not make this assumption, and his productivity estimates are based on 29 industries covering 42 percent of British and 37 percent of American employment. Although, both approaches have their merits, the complete inclusion of all manufacturing industries does impact the productivity estimates.

Furthermore, the ICOP framework allows for several extensions which serve to improve the quality of the international benchmark estimates. The primary extension is the use of value added and the application of the double deflation technique. As illustrated above, the quantity approach relies on gross output as a measure of output in labor productivity, whereas modern international comparisons generally opt for value added (Paige and Bombach 1959; Maddison and van Ark 1988; van Ark 1993). This is of importance particularly when the ratio of intermediate inputs to gross output varies between countries as well as industries. As noted in the main text, these variations can occur as a result of differences in production methods, the types of materials used, and the amount of imported materials,

19. See table 3 and appendix B for further details.

but can also be caused by differences in industry classifications between the countries under comparison (Fremdling, de Jong, and Timmer 2007a, 360). In addition, I apply the double deflation technique, which does not only take relative prices for gross output into account, but also compensates for relative price differentials for intermediate inputs (Paige and Bombach 1959, 82). Double deflation is generally considered to be the preferred approach for sector comparisons of output and productivity, and recent studies have shown that this adjustment could be of particular importance for benchmark studies that examine the turbulent interwar years. As governments put in place increasingly restrictive foreign trade regimes and tight currency controls during this period, the internal price level and ratios between input and output prices tended to deviate substantially (Fremdling, de Jong, and Timmer 2007a, 352).

Another extension to the ICOP framework is the stratified sampling approach, which introduces an alternative weighting scheme. The stratified sampling theory proposes that the process of aggregation of the relative price ratios can be made more precise if a heterogeneous population (the products matched) is divided into more homogeneous sub-populations, referred to as strata. These strata usually take the form of industries, the output of which can be used as alternative weights to aggregate the price ratios. For an elaborate description of the stratified sampling theory see the work of Timmer (1996; 2000, 21).

B Output unit value ratios

Table 15: Output UVRs, US and UK (1909/07)

description	*quantity unit*	*United States* *quantity* (x,000)	*United States* *value* ($,000)	*United Kingdom* *quantity* (x,000)	*United Kingdom* *value* (£,000)	*uvr* ($/£)
Wheat	Cubic meters	24,081	657,657	1,911	10,370	5.0
Barley	Cubic meters	6,108	92,459	1,990	9,177	3.3
Oats	Cubic meters	35,491	414,697	4,496	13,264	4.0
Rye	Cubic meters	1,040	20,422	72	220	6.4
Beans	Cubic meters	396	21,771	338	1,735	10.7
Peas	Cubic meters	251	10,964	223	1,130	8.6
Buckwheat	Cubic meters	523	9,331	4	22	3.1
Hay	Tons (metric)	62,444	685,042	9,876	31,818	3.4
Potatoes	Tons (metric)	9,709	166,424	3,981	9,892	6.9
Hops	Tons (metric)	18	7,845	24	1,059	9.6
Straw	Tons (metric)	507	3,280	7,112	12,660	3.6
Strawberries	Tons (metric)	145	17,914	42	1,036	5.0
Raspberries	Tons (metric)	35	5,132	10	309	5.0
Currants	Tons (metric)	6	790	6	153	5.5
Gooseberries	Tons (metric)	3	417	18	208	11.8
Other small fruit	Tons (metric)	53	5,721	13	252	5.4
Apples	Tons (metric)	3,181	83,231	228	1,490	4.0
Pears	Tons (metric)	196	7,911	9	90	4.2
Cherries	Tons (metric)	75	7,231	9	194	4.5
Plums	Tons (metric)	393	10,299	36	357	2.7
Milk: farm	Liters (x000)	22,007	757,562	5,492	35,274	5.4
Butter: farm	Tons (metric)	451	222,861	25	2,940	4.2
Cheese: farm	Tons (metric)	4	1,142	25	1,400	4.9
Eggs: farm	Dozens	1,591,311	306,689	92,374	3,772	4.7
Horses	Number	1,768	210,264	53	1,590	4.0
Meat: cattle and calves	Tons (metric)	3,635	710,015	482	27,264	3.5
Meat: sheep	Tons (metric)	287	67,073	265	18,169	3.4
Meat: pigs	Tons (metric)	3,898	717,674	321	14,362	4.1
Wool: unprocessed	Tons (metric)	131	65,472	40	2,600	7.7
Coal: anthracite	Tons (metric)	73,536	149,416	3,972	2,297	3.5
Coal: bituminous	Tons (metric)	344,498	405,487	266,864	117,256	2.7
Iron pyrite	Tons (metric)	251	1,028	11	5	9.2
Petroleum	Liters (x000)	28,957	128,249	179	357	2.2
Iron ore	Tons (metric)	51,332	106,540	15,226	4,315	7.3
Gypsum	Tons (metric)	2,044	5,907	205	98	6.0
Arsenic oxides	Tons (metric)	1	53	4	41	4.8
Salt: unrefined	Tons (metric)	3,825	8,344	1,264	576	4.8
Sand	Tons (metric)	53,035	17,174	1,977	165	3.9
Barytes	Tons (metric)	53	199	35	43	3.0
Coke	Tons (metric)	35,666	89,965	11,526	9,516	3.1
Coke breeze	Tons (metric)	1,489	5,723	7,706	4,434	6.7
Tar	Tons (metric)	604	3,284	787	767	5.6
Cotton: yarn	Tons (metric)	230	132,249	675	78,304	4.9
Cotton: piece goods	Sq. meters	5,280,169	443,163	5,869,387	81,313	6.1
Cotton: waste	Tons (metric)	141	10,874	195	3,749	4.0
Wool: tops	Tons (metric)	5	8,027	26	4,751	8.6
Wool: noils	Tons (metric)	12	8,939	8	866	6.5
Wool: waste	Tons (metric)	11	3,525	13	746	5.4
Wool: shoddy and mungo	Tons (metric)	22	5,699	58	1,859	8.1
Wool: yarns worsted	Tons (metric)	42	83,918	72	17,524	8.2
Wool: yarns woollen	Tons (metric)	18	9,649	18	2,150	4.5
Wool: flannels	Sq. meters	17,219	4,390	40,530	1,774	5.8
Wool: carpets	Sq. meters	47,807	48,476	21,490	3,251	6.7

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Table 15 - continued from previous page

desc	*unit*	*us_q*	*us_v*	*uk_q*	*uk_v*	*uvr*
Wool: rugs	Sq. meters	20,102	18,490	3,182	638	4.6
Wool: woollen tissues	Sq. meters	412,078	271,013	196,733	24,403	5.3
Jute: yarns	Tons (metric)	28	4,362	138	4,022	5.3
Jute: piece goods	Sq. meters	59,798	4,057	218,450	3,579	4.1
Hemp: yarns	Tons (metric)	2	983	7	375	7.4
Hosiery: hose, half-hose	Pairs	748,688	65,121	172,668	4,402	3.4
Cordage, cables, ropes and twine	Tons (metric)	419	76,295	106	4,701	4.1
Skins: fellmongery	Number	97,681	75,648	9,831	996	7.6
Skins: tanned	Number	67,572	53,119	186,344	14,688	10.0
Gloves: leather	Dozen Pairs	40,424	22,526	7,020	839	4.7
Boots and shoes: leather	Pairs	247,643	442,631	97,984	20,066	8.7
Hats: felt	Number	40,267	46,146	18,888	2,491	8.7
Shawls	Number	2,627	916	1,219	238	1.8
Pig iron	Tons (metric)	26,063	387,830	10,276	33,304	4.6
Steel: ingots	Tons (metric)	129	3,594	6,627	29,740	6.2
Iron and steel: bars, rods and structural shapes	Tons (metric)	5,533	192,642	3,283	24,246	4.7
Iron and steel: rails	Tons (metric)	2,690	77,811	970	5,638	5.0
Iron and steel: plates and sheets	Tons (metric)	3,023	133,272	1,639	11,977	6.0
Iron and steel: armor plates	Tons (metric)	24	10,649	18	1,771	4.5
Iron and steel: hoops and strips	Tons (metric)	309	10,430	396	3,045	4.4
Iron and steel: pipes and fittings, cast	Tons (metric)	1,891	64,515	347	2,013	5.9
Iron and steel: tires and axles	Tons (metric)	93	3,831	139	1,910	3.0
Iron and steel: scrap metal	Tons (metric)	1,124	18,164	710	2,231	5.1
Iron and steel: blooms, billets and slabs	Tons (metric)	4,511	110,762	609	3,376	4.4
Steel: sheets and tinplate bars	Tons (metric)	1,499	37,745	1,007	5,308	4.8
Tinplate: tinplate and terneplate	Tons (metric)	597	45,815	537	7,402	5.6
Tinplate: black plates and sheets	Tons (metric)	573	30,956	145	1,343	5.8
Iron and steel: pipes and fittings, wrought	Tons (metric)	1,578	90,622	309	6,090	2.9
Iron and steel: wire rods	Tons (metric)	2,082	61,948	119	882	4.0
Iron and steel: wire	Tons (metric)	1,043	52,727	189	2,801	3.4
Iron and steel: nails	Tons (metric)	46	2,218	16	176	4.3
Iron and steel: wire nails and staples	Tons (metric)	657	28,900	5	55	3.7
Iron and steel: galvanized sheets	Tons (metric)	392	25,912	505	7,157	4.7
Bicycles	Number	168	2,388	624	3,441	2.6
Motor cycles	Number	19	3,016	4	139	4.4
Motor cars	Number	127	164,308	10	3,323	3.8
Vessels: wood and steel	Tonnage (gross)	467	37,680	1,614	24,178	5.4
Copper: ingots	Tons (metric)	496	142,084	42	3,422	3.5
Copper: plates, sheets, rods	Tons (metric)	138	40,916	51	4,881	3.1
Copper: wire	Tons (metric)	140	47,184	13	1,350	3.2
Brass: wire	Tons (metric)	16	5,580	3	218	4.2
Lead: pig	Tons (metric)	321	30,460	29	518	5.4
Tin: pig	Tons (metric)	0	16	13	2,177	4.0
Flour: wheat	Tons (metric)	10,497	557,815	4,037	43,139	5.0
Offals: wheat	Tons (metric)	3,788	91,407	1,959	8,694	5.4

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Table 15 - continued from previous page

desc	*unit*	*us_q*	*us_v*	*uk_q*	*uk_v*	*uvr*
Flour: barley, corn, buckwheat	Tons (metric)	2,972	117,213	1,459	11,100	5.2
Animal feed	Tons (metric)	5,444	164,735	150	1,006	4.5
Rice: cleaned	Tons (metric)	298	21,048	92	895	7.3
Pork: bacon	Tons (metric)	336	97,856	87	5,326	4.7
Pork: hams	Tons (metric)	358	101,089	23	1,663	3.9
Pork: salted	Tons (metric)	432	95,959	1	35	6.1
Lard	Tons (metric)	564	134,397	31	1,479	5.0
Butter: factory	Tons (metric)	186	115,098	56	5,840	5.9
Cheese: factory	Tons (metric)	139	42,435	4	193	6.0
Cream: factory	Tons (metric)	37	9,829	5	398	3.4
Margarine: factory	Tons (metric)	19	5,964	45	2,094	6.5
Ice	Tons (metric)	12,909	44,139	619	389	5.4
Sugar: refined	Tons (metric)	747	71,741	574	8,995	6.1
Molasses	Tons (metric)	249	3,975	56	303	3.0
Fish: cured	Tons (metric)	0	10	133	3,712	4.7
Cigars	Tons (metric)	64	193,807	2	1,146	4.5
Cigarettes	Tons (metric)	14	35,373	14	4,532	7.7
Manufactured tobacco	Tons (metric)	159	131,660	34	4,478	6.3
Acid: acetic	Tons (metric)	26	1,337	6	91	3.5
Acid: nitric	Tons (metric)	12	1,357	6	91	7.3
Acid: sulphuric	Tons (metric)	1,340	10,085	550	955	4.3
Sulphates: alum	Tons (metric)	33	654	73	213	6.7
Sulphates: ammonia	Tons (metric)	56	3,227	306	3,271	5.4
Bleaching materials	Tons (metric)	14	226	111	444	3.9
Borax	Tons (metric)	38	1,202	14	205	2.2
Essential oils	Tons (metric)	0	1,129	0	112	7.6
Soda compounds	Tons (metric)	842	17,270	693	3,317	4.3
Sulphur	Tons (metric)	260	4,605	31	148	3.8
Tallow and animal fat	Tons (metric)	117	20,372	56	1,459	6.7
Fertilizer: superphosphate	Tons (metric)	1,375	16,957	615	1,321	5.7
Fertilizer: other	Tons (metric)	3,379	75,413	520	2,353	4.9
Glue and gelatine	Tons (metric)	13	1,944	43	653	10.2
Soap: hard	Tons (metric)	802	89,830	302	7,266	4.7
Soap: soft	Tons (metric)	27	1,269	83	1,499	2.6
Glycerin	Tons (metric)	53	16,591	16	604	8.4
Paraffin wax	Tons (metric)	161	9,389	4	99	2.1
Seedcrushing	Tons (metric)	1,652	91,100	1,393	12,940	5.9
Hard wood: oak	Cubic meters	10,417	90,512	102	237	3.7
Hard wood: ash	Cubic meters	687	7,116	17	37	4.7
Hard wood: elm	Cubic meters	820	6,088	17	21	5.8
Paper: fine	Tons (metric)	172	29,079	120	3,059	6.7
Paper: printing	Tons (metric)	1,589	89,702	462	5,894	4.4
Paper: packing and wrapping	Tons (metric)	692	42,221	191	2,032	5.7
Paper: printed and coated	Tons (metric)	102	11,397	39	975	4.5
Paper: boards	Tons (metric)	801	29,498	54	626	3.2
Paper: other	Tons (metric)	15	1,736	14	440	3.9
Bricks	Thousands	12,473	94,993	4,760	6,329	5.7
Cement	Tons (metric)	13,407	68,752	2,923	3,439	4.4
Organs, reed	Number	64	2,595	4	30	5.8
Pianos	Number	331	46,188	58	972	8.3
Pianolas	Number	45	10,750	1	23	5.1