On the measurement of growth over the long run[1]

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Received: 05/03/2024
Accepted: 04/12/2024

Abstract

Methodologies for the construction of nominal and real gross domestic product (GDP) time series often differ over time and between countries. This paper discusses the main issues raised by this methodological heterogeneity for long-run measures of economic growth and, informed by these issues, provides a set of internationally comparable GDP estimates from 1820 to 2020. The estimates are based on real product benchmarks relative to the United Kingdom as the reference economy. The GDP time series of the reference economy is a normalized composite of several indices. These estimates suggest that the Maddison Project data sets overestimate economic growth after 1950 relative to the period from 1820 to 1950.

Keywords

Economic growth, national accounts, gross domestic product, time-series analysis, statistical methodology

JEL classification

E01, O47, O57

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[1] The author is grateful to Carlos Ponce, Marcelo de Paiva Abreu and the participants in the sixth Brazilian Economic History Workshop in São Paulo for helpful feedback and discussion. This paper has had no specific source of financial support.

I. Introduction

Although gross domestic product (GDP) time series data are universally used by economists as an easy way to visualize economic growth and development, there is great heterogeneity in their quality and the methods used to produce them. GDP is an accounting convention that varies over time and between countries. In addition, owing to the complexity of national economies, GDP is constructed using data that are inevitably incomplete. As a result, the official real GDP time series produced by an economy's statistical agencies often changes substantially from one vintage of the series to another.[2]

The present paper does two things. First, it discusses how variations in methodologies and data incompleteness change the measured growth rate. Second, it provides alternatives to the data sets of Maddison (2010) and Bolt and Van Zanden (2020), estimating historical GDP time series in constant 1990 dollars after correction for methodological heterogeneity.

It is a well-known feature of the national accounts literature that benchmark estimates of GDP measured in purchasing power parity (PPP) for different economies are inconsistent with the growth rates implied by their national accounts. These discrepancies are natural and occur even if there are no measurement errors, since different economies have different relative prices, and relative prices change over time (Deaton, 2012). Methodologies for estimating GDP growth are heterogeneous, and different PPP benchmarks produced with different methodologies yield different relative levels of GDP (Deaton and Heston, 2010).[3]

This means that long-run estimates of economic performance should be constructed using a uniform methodology for the whole period under analysis. For example, Broadberry, Fukao and Zammit (2015) and Van Zanden and Van Leeuwen (2012) produced series for England and the Kingdom of the Netherlands covering very long periods (from the thirteenth to the mid-nineteenth century and from the fourteenth to the early nineteenth century, respectively). However, because these series were constructed with a very different methodology from the official GDP time series produced by modern nations, their quantitative values are not comparable to those of a contemporary GDP time series.

This paper makes two contributions. First, using a simple theoretical framework, it shows that different methods produce different estimates even when based on the same data. In addition, if statistical agencies have more complete information on the full scope of economic activity in the present than in the past, the measured growth rate of GDP might be distorted relative to a situation where the statistical agency had complete information.

Second, and taking these issues into consideration, this paper presents alternative estimates of real GDP time series over a long period (from 1820 to 2020) for a set of 57 economies that collectively comprised to of the world's population over this period. One implication of the series estimated by this paper is that the GDP time series data in the data sets presented by Maddison (2010) and Bolt and Van Zanden (2020) appear to overestimate the rate of economic growth since 1950 relative to the rate of growth before 1950.

The estimates presented here address these problems by normalizing the level and growth rates of GDP relative to the GDP of a reference economy. The reference economy's long-run GDP time series is necessarily a composite of different series, but this composite is corrected for the methodological variance across series. The time series for the other 56 economies are then normalized by means of several benchmark comparisons of real GDP using PPPs.

[2] See Semieniuk (2024) for an example of how different GDP vintages induce different measured growth rates and thus change the measured degree of decoupling between CO_2 emissions and economic growth.

[3] For example, the case of China was studied by Feenstra and others (2013).

In principle, a time series for GDP measured at local prices should be a more accurate measure of economic growth than a GDP series anchored in real product comparisons relative to a reference economy. However, that will only be the situation if the time series for GDP measured at local prices is constructed using a uniform methodology for the whole period under consideration, which is not the case for the GDP time series of any economy covering long periods up to the present. The normalization method used here yields more reasonable estimates of long-run GDP growth than simply using several GDP times series without any attempt at normalization.

The author's estimates are more strongly correlated with national accounts estimates in local prices than are the estimates from the Penn World Table version 10.0 (see table 4). This shows that, despite the numerous issues that can be raised on theoretical grounds, it is possible to construct estimates for the evolution of GDP across time and space over the past couple of centuries that are consistent with the local evidence for economic growth and with the cross-country evidence of relative income levels.

The paper is organized as follows. Section II studies a simple example of an economy with a representative consumer, which illustrates how changes in the methodology used for computing GDP alter the computed growth rate. Section III describes the methodology used to construct the real GDP time series data set. Section IV presents the resulting data set and compares it to Maddison (2010) and the 2020 release of the Maddison Project. Section V discusses the implications of these estimates for the historical applicability of the Balassa-Samuelson effect. Concluding remarks are offered in section VI. Robustness tests are performed in annex A1. First, the exercise is replicated, with the reference economy changed from the United Kingdom to the United States, showing that the results do not alter significantly. Second, it robustness tests are performed on the GDP time series of the United Kingdom to ascertain whether these series exhibit biased relative growth rates for different periods. There is also an online annex that discusses the measurement of productivity per hour worked and presents all the data sources used and the benchmarks of real product levels.

II. The measurement of economic growth

This section briefly describes the most commonly used methodologies for measuring real GDP changes across time and countries. It makes two points. First, it shows that even if a statistical agency had complete information about the economic activity of a country, measured GDP growth rates would vary significantly across different methodologies. Second, it shows that, in the realistic case of statistical information being incomplete, new distortions make measurement more problematic. In particular, the interaction between technological change and incomplete statistical information makes the disparities between methodologies even more pronounced.

1. Measuring growth in an economy with complete data

These points can be illustrated by a simple but useful discrete-time infinite horizon economy with two goods (the bare minimum needed to discuss aggregation issues): food (f) and manufactured goods (m).

On the demand side, a (representative) consumer has Stone-Geary preferences over non-negative bundles of food and manufactured goods. Specifically, the consumer's per-period utility function is given by

$$u\left(x_f^t, x_m^t\right) = \left(x_f^t - c_f\right)^{\alpha} \left(x_m^t\right)^{1-\alpha} \tag{1}$$

where $\left(x_f^t, x_m^t\right)$ is the bundle of food and manufactured goods consumed in period $t \in \{0, 1, 2, \ldots\}$, $\alpha \in (0, 1)$, and c_f represents the minimum ("subsistence") level of food consumption.

On the supply side, one unit of labour (inelastically supplied by the consumer) can be used to produce each good. Production technologies are linear in labour. In other words, the production function of good $k \in \{f, m\}$ at time t is

$$x_k^t = a_k^t l_k^t \tag{2}$$

where l_k^t is the amount of labour used to produce good k at time t and a_k^t is labour productivity in sector k at time t. We assume that $a_f^0 > c_f$, so that labour productivity in food production is high enough to meet the minimum required level of consumption.

Production is performed by competitive firms. The labour share of income is equal to 1, and because the firms are competitive, relative prices in terms of wages are determined by labour productivity. Therefore, $p_f^t / p_m^t = a_m^t / a_f^t$, where p_k^t is the price of good k at time t, and $p_k^t / w^t = 1 / a_k^t$, where w^t is the wage at time t.

Given product prices and wages, the consumer maximizes the present value of utility from consuming streams of food and manufactured goods:

$$\max_{\{x_f^t, x_m^t\}_t} \sum_{t=0}^{\infty} \beta^t u\left(x_f^t, x_m^t\right) \quad s.t.\ p_f^t x_f^t + p_m^t x_m^t = w^t \tag{3}$$

where $\beta \in (0, 1)$ is the discount factor. The solution to the problem above gives equilibrium output of food, y_f, and manufactures, y_m, over time according to the following equations:

$$y_f = c_f + \left(1 - c_f / a_f^t\right) a_f^t \alpha \tag{4}$$

$$y_m = c_m + \left(1 - c_m / a_m^t\right) a_m^t \left(1 - \alpha\right) \tag{5}$$

For the quantitative exercise, the parametrization shown in table 1 is used without any loss of generality.

Table 1
Parametrization in the quantitative exercise

Parameter	Value
c_f	0.75
α	0.25
a_k^t	1
$\dot{a}_f^t$	1%
$\dot{a}_f^t$	5%

Source: Prepared by the author.
Note: a_k^t is the growth rate of labour productivity in sector k at time 't.

2. Methodologies for constructing GDP time series

Five series for real GDP between periods 0 and 30 will now be constructed using distinct methodologies, beginning with the simplest.

Series 1. This methodology computes the output index (GDP) at time t using relative prices from one base period. In this particular case, period 0 is taken as the base period. Then, the output index at time $t > 0$, Y_t is computed according to the following formula:

$$Y_t = Y_0 \times \frac{p_f^0 y_f^t + p_m^0 y_m^t}{p_f^0 y_f^1 + p_m^0 y_m^1} \tag{6}$$

where y_f^t and y_m^t are, respectively, the quantities of food and manufactured goods produced (consumed) at time t, p_f^0 and p_m^0 are, respectively, the prices for food and manufactured goods in base period 0, and Y_0 is set at 100.

This method is not officially used by any country to compute GDP series for long periods of time. Since relative prices tend to change substantially over long time periods, it is more satisfactory to use prices that are chronologically closer to the years selected for incorporation into an index of real GDP.

Series 2. This methodology (like the previous one) uses prices from a selected base period. In this case, however, the output index incorporates multiple base periods. In this example, three different base periods are used —10, 20 and 30— and the output index is set at 100 for period 0.

This methodology is typically used by the statistical offices of most developing countries because it requires less information than the methods used in series 3, 4 and 5. For example, from the beginning of China's official national accounts up to 2018, nine base periods were used: 1952, 1957, 1970, 1980, 1990, 2000, 2005, 2010 and 2015.[4] Other countries that use this method include Argentina, India, Indonesia, Mexico, Nigeria, Viet Nam and Uruguay.

The method is, first, to compute the output index of period $t > 0$ using prices from time period 10, i.e.:

$$p_f^{10} y_f^t + p_m^{10} y_m^t \tag{7}$$

Second, compute the output index of period 0 using prices from period 10, i.e.:

$$p_f^{10} y_f^1 + p_m^{10} y_m^1 \tag{8}$$

Third, divide (7) by (8) and multiply the result by the output index of period 0:

$$Y_t = 100 \times \frac{p_f^{10} y_f^t + p_m^{10} y_m^t}{p_f^{10} y_f^1 + p_m^{10} y_m^1} \tag{9}$$

In general, the methodology works as follows. At any period $t \in \{b_{i-1}, ..., b_i\}$, where $b_i = 10 \times i$ para $i \geq t/10$ for is one of the three base periods and $b_0 = 0$, the index of output Y_t is given by

$$Y_t = Y_{b_{i-1}} \times \frac{p_f^{b_i} y_f^t + p_m^{b_i} y_m^t}{p_f^{b_i} y_f^{b_{i-1}} + p_m^{b_i} y_m^{b_{i-1}}} \tag{10}$$

where $p_f^{b_i}$ and $p_m^{b_i}$ are, respectively, the prices of food and manufactured goods in the base period b_i.

In other words, given a designated base period b_i, GDP at any time $t < b_i$ (i.e. previous to the base period) is measured in terms of the prices of the base period. Moreover, the base period changes at regular 10-period intervals. Using equation 10, the reader may find it useful to verify that the output index at any time $t \in \; 11, 12, ..., 20$ is given by

$$Y_t = Y_{10} \times \frac{p_f^{20} y_f^t + p_m^{20} y_m^t}{p_f^{20} y_f^{10} + p_m^{20} y_m^{10}} \tag{11}$$

Series 3. The output index is computed with what are generally known as "chained prices" or the "chained Fisher index". Under this methodology, the output index is measured using prices from every period of the series instead of prices from a set of fixed base periods. Brazil and Russia, among others, are countries that use this methodology.

[4] See National Bureau of Statistics of China [online] https://www.stats.gov.cn/english/ [date of reference: December 2018].

Let us assume that we have computed the output index at some time t. Then, the output index in the next period is determined as follows:

First, we compute the output index at $t + 1$ in terms of prices at t, Y^t_{t+1}. This is done by obtaining aggregate output at $t + 1$ using prices at t and then dividing the result by the aggregate output at t using prices at t as follows:

$$Y^t_{t+1} = Y_t \times \frac{p^t_f \times y^f_{t+1} + p^t_m \times y^m_{t+1}}{p^t_f \times y^f_t + p^t_m \times y^m_t} \tag{12}$$

Second, we compute the output index at $t + 1$ in terms of prices at $t + 1$, Y^{t+1}_{t+1}. This index is obtained by aggregating output at $t + 1$ using prices at $t + 1$ and then dividing the result by aggregate output at t in terms of prices at $t + 1$, i.e.:

$$Y^{t+1}_{t+1} = Y_t \times \frac{p^{t+1}_f \times y^f_{t+1} + p^{t+1}_m \times y^m_{t+1}}{p^{t+1}_f \times y^f_t + p^{t+1}_m \times y^m_t} \tag{13}$$

Lastly, the chained output index Y_{t+1} is computed by taking the geometric average of Y^t_{t+1} and Y^t_{t+1}:

$$Y_{t+1} = \left(Y^t_{t+1}\right)^{1/2} \times \left(Y^{t+1}_{t+1}\right)^{1/2} \tag{14}$$

Series 4. In this case, the index is estimated with chained weights like series 3, but with one important difference, which is that it incorporates hedonic methods. These methods are used to account for changes in the quality of goods over time. This methodology is currently used for the national accounts of the United States.

To incorporate hedonics, we assume that the quality of manufactured goods improves at a rate of 1% per period. The assumption means that the representative consumer is indifferent between an increase of 1% in the quantity of manufactured goods and the same quantity of manufactured goods in the consecutive period.[5]

Series 5. This method consists of estimating real output growth from periods 0 to 30 by comparing prices and quantities for only these two periods. For clarity, we can see how the output index of period 30 relative to period 0, Y^{30}_0 is computed by following a series of steps.

First, the period 0 index number, Y_0, is set at $Y_0 = 100$. Let Y^0_{30} denote the index of output at period 30 relative to period 0 measured in terms of period 0 prices. This index is computed by the formula:

$$Y^0_{30} = Y_0 \times \frac{p^0_f y^{30}_f + p^0_m y^{30}_m}{p^0_f y^0_f + p^0_m y^0_m} \tag{15}$$

Second, let Y^{30}_{30} be the index number that uses period 30 prices to measure the change in aggregate output from period 0 to period 30. The index is computed by the formula:

$$Y^{30}_{30} = Y_0 \times \frac{p^{30}_f y^{30}_f + p^{30}_m y^{30}_m}{p^{30}_f y^0_f + p^{30}_m y^0_m} \tag{16}$$

Lastly, the estimated output index at period 30, Y_{30}, is the geometric average of the indices calculated in the first two steps:

$$Y_{30} = \left(Y^0_{30}\right)^{1/2} \times \left(Y^{30}_{30}\right)^{1/2} \tag{17}$$

[5] Formally represented by a per-period utility function $u(.)$ such that $u(x) = u(x')$ for any pair of baskets of goods $x = (x_f, 1.01 \times x_{m,t})$ and $x' = (x_f, x_{m,t+1})$, with $x_{m,t+1} = x_{m,t}$.

If we suppose that the prices and quantities of periods 0 and 30 represent the prices and quantities of, say, two countries *A* and *B*, then this method is the one typically used to construct estimates of real GDP levels in terms of PPP across countries.[6]

Not surprisingly, even in a simple two-good representative agent economy, output indices vary substantially with different methodologies. Table 2 gives the estimated growth rates (from period 0 to period 30) measured according to the five indices discussed above.

Table 2
Measured GDP growth rate from period 0 to period 30, by method
(Percentages)

Method	Growth rate
Series 1	4.85
Series 2	3.86
Series 3	4.12
Series 4	4.49
Series 5	3.92

Source: Prepared by the author.

The differences in the estimated growth rates are not negligible. For instance, the growth rate of series 1 is much higher than that of series 2. To understand why this happens, we must recall the assumption that productivity in the manufactured goods sector increases at a higher rate than productivity in the food sector. This assumption implies that the relative price of manufactured goods falls relative to the price of food from one period to the next. Therefore, series 1, which only uses prices from period 0, when manufactured goods were relatively more expensive, gives greater weight to manufactured goods in the output index than the other series. As productivity grows faster in this category of goods, its measured total output also grows at a higher rate. Conversely, series 2 yields a much lower growth rate because it uses prices from future periods at which manufactured goods are cheaper than in period 0.

The chained index of series 3 uses prices from the "present" period (i.e. to measure the change in output from t to $t + 1$, series 3 uses prices from only these two times), and therefore the measured growth rate is at an intermediate value between the growth rates of series 1 and series 2. Series 4 builds on series 3, but the measured growth rate is higher because it incorporates time-quality improvements in manufactured goods.

Lastly, the growth rate of series 5 is much lower than that of series 1 and just slightly higher than that of series 2. The reason is that this methodology uses manufactured goods prices from period 30, which are lower than the period 0 prices used by series 5 in addition to period 30 prices. However, series 1 exclusively uses prices from period 0. Because productivity growth is higher in the manufactured goods sector, then, it follows that the relative weight of that sector in the output index is lower for series 5 than for series 1.

[6] The International Comparison Programme (ICP) of the World Bank employs what is known as the Gini-Éltetö-Köves-Szulc (GEKS) method to compute real GDP in PPP terms. This method uses Fisher indices across countries to construct PPP conversion factors. It can be briefly described as follows: (i) for a set of countries in the study, construct Fisher PPPs for each pair of economies, after which (ii) the PPP conversion factors are determined by taking the geometric average of all the indirect PPPs implied by the Fisher PPPs. For example, if there are three countries, *A, B, C,* in an ICP study and the Fisher PPP conversion factor between countries *A* and *B* is taken to be 2 units of *A*'s currency for 1 unit of *B*'s currency, the PPP between *A*'s currency and *C*'s currency is 2.5, and between *B*'s and *C*'s it is 1.4. Then the GEKS PPP between *A* and *B* is the geometric average of 2 and 2.5/1.4 (the indirect PPP conversion factor of the currency of country to that of through the Fisher PPPs of both to country *C*).

3. Measuring growth with incomplete data

For a given methodology, other factors can also negatively affect the possibility of obtaining "reasonable" measures of GDP growth. Clearly, for a given time period, the most significant one is incomplete coverage of economic activity by the statistical agency. For instance, it is very well known that black market activities are difficult to measure and value accurately. Moreover, the advent of new and more productive information systems for collecting data, though welcome, generates further intertemporal distortions in the measurement of economic growth.[7]

This can be illustrated by the following exercise. First, suppose that from period 0 to 15, only 50% of all manufactured goods transactions are observed by the statistical office. Thus, only this portion of final output is accounted for in the GDP figures. Second, assume that from period 15 onward, there is an improvement in the quality of the office's data collection. As a result, from period 15 to 30, 90% of manufactured goods transactions are observed by the statistical agency. These data are used to construct a new GDP series, series 3I, and its GDP growth rates are then compared with the growth rates of series 3.[8]

Note that because the manufacturing sector is underweighted in the index of real output, the growth rate from period 0 to period 30 of series 3I (3.48%) is substantially lower than the growth rate of series 3 (4.12%). Moreover, the discrepancies in the growth rate of series 3I relative to those of series 3 are heterogeneous over time. Relative to series 3, the growth rate of series 3I is nearly 30% lower over the first 15 periods but only 4% lower over periods 15 to 30. This simple example should suffice to show how the presence of incomplete data further distorts the measurement of GDP growth.

III. Methodology for the set of GDP estimates

This section presents estimates of real GDP in 1990 international dollars for 57 economies from 1820 to 2020. These time series are estimated as follows. First, a time series is estimated for a reference economy during the period. Then, the other 56 economies' real GDP time series are constructed on the basis of benchmark comparisons of real GDP relative to the reference economy. For each of these 56 economies, GDP estimates at local prices are normalized by the benchmark comparisons with the reference economy to construct time series. The details of the estimation procedure are presented in the following subsections, as are the resulting GDP time series using the United Kingdom as the reference economy. In section 1 of annex A1, the same exercise is performed using the United States as the reference economy instead of the United Kingdom.

The method of taking a reference economy and normalizing the GDP figures of other economies relative to it has been used before; for example, the versions of the Penn World Table released since 2015 have taken the United States.[9] The innovation of this paper is to also normalize the series of the reference economy by taking account of discrepancies from historical estimates for the more distant past. We use the United Kingdom as the main reference economy in this study for two reasons. First, there are more historical macroeconomic data for the United Kingdom than virtually any other country and, second, many historical real GDP benchmark comparisons include it.

7 Incompleteness in coverage of economic activity can arise, for example, from incomplete reporting of economic activity to the State's statistical agency due to tax evasion or imperfect State capacity.

8 Series 3I is of course constructed by the same methodology as series 3.

9 However, the author's estimates have a higher correlation with official national accounts than the estimates from the Penn World Table, as shown in table 5.

1. Normalization procedure for the reference economy

The real GDP series of the United Kingdom over this long period (1820–2020) is a composite of several different real GDP series estimated by distinct methods. As shown in the previous section, different methods yield different growth rates. To correct for this inconsistency, the series are first normalized and then used to construct the composite GDP series.

To explain the normalization procedure, an example will be first presented and then formally described. Let us consider the economy described in section II and suppose that:

(i) The statistical office of this economy has computed series 2 as in the previous section (i.e. the GDP series has been computed with prices from fixed base periods). Suppose that the economy existed before period 0 and that the statistical office has also computed series 2 for this economy for 30 periods before period 0 and then up to period 15 (i.e. the GDP time series begins at period -30 and ends at period 15). Thus, series 2 covers periods -30, ...,15 using prices from base periods at 10-year intervals: -20, -10, 0, 10, 20.

(ii) The statistical office has also produced another GDP series for this economy, series 4 (chained prices adjusted by hedonic methods), which only covers periods 0 to 30.

A comparison of the economic growth rates of series 2 for the time up to period 15 with the growth rates of series 4 from periods 15 to 30 yields a substantial overestimation of growth performance in the later periods compared to the earlier periods. Note that series 4 does not cover periods before period 0, and series 2 does not cover periods 15 to 30. Therefore, no single time series covers the entire time interval from periods -30 to 30.

To properly compare growth before period 0 with growth from periods 15 to 30, consider a composite series of series 2 and series 4, where series 2 is used for periods -30 to 15 and a normalized version of series 4 is used for periods 16,17,...,30: the growth rate of series 4 is normalized by a constant proportion given by the ratio between the growth rates of series 4 and series 2 over the first 15 periods. This yields series 2N. The growth rate from period 15 to period 30 is 4.81% according to series 4 but only 4.13% according to series 2N. Series 2 has a growth rate of 4.18% from period 15 to period 30. Thus, this normalization means that series 2N closely approximates the growth rate of series 2.

The normalization procedure is formally implemented as follows. First, suppose there are two series: series $S^1 = \left\{S^1_{t_0}, S^1_{t_0+1}, ..., S^1_{t_2}\right\}$, which covers periods $\{t_0, t_0 + 1, ..., t_2\}$, and series S^2, which covers periods $\{t_1, t_1 + 1, ..., t_3\}$, where $t_0 < t_1 < t_2 < t_3$. Note that because $t_1 < t_2$, the two series overlap over periods $\{t_1, t_1 + 1, ..., t_2\}$. Let $\Delta_{S^j} = log\, S^j_{t_2} - log\, S^j_{t_1}$ be the log growth in GDP from t_1 to t_2 according to series S^j. Then, the composite series covering periods t_0 to t_3, $S^c = \left\{S^c_t\right\}^{t_3}_{t=t_0}$, is given by $S^c_t = S^1_t$ for each period $t \leq t_2$, while for each $t \in \{t_2 +1, ..., t_3\}$, it is given by

$$log\, S^c_t = log\, S^1_{t_2} + \left(log\, S^2_t - log\, S^2_{t_2}\right) \times \frac{\Delta_{S^1}}{\Delta_{S^2}} \quad (18)$$

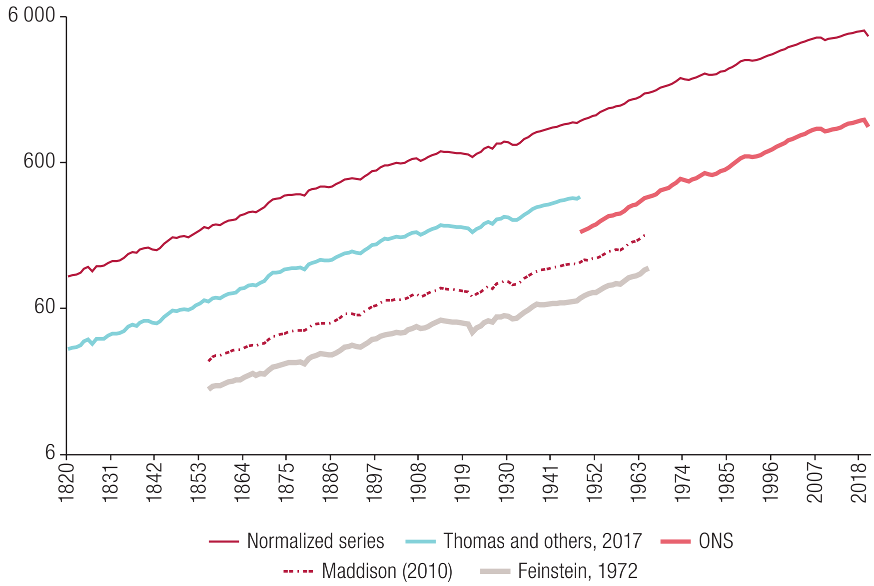
By normalizing all the series using a normalized series for the reference economy, this method yields more reasonable estimates of long-run growth than using different GDP time series without any attempt to control for methodological differences, as done hitherto in the literature.

2. GDP series for the reference economy

The GDP series for the United Kingdom from 1820 to 2020 is constructed by combining the Bank of England's estimated GDP series from 1820 to 1948 as published in Thomas and others (2017)[10] with the official national accounts from 1948 to 2020 as computed by the Office for National Statistics (ONS).

The normalization procedure consists in normalizing the GDP growth rates from both the Bank of England series for 1820–1948 and the ONS series for 1948–2020. The normalization coefficients (the ratio of growth rates Δ_{S1}/Δ_{S2} in equation 18) are derived from the overlap of these two series with the series from Maddison (2010) for 1855–1965. The series estimated by Maddison, in turn, was based on the real GDP time series estimated by Feinstein (1972). These four series and the resulting normalized series for 1820–2020 are shown in figure 1. Section 2 of annex A1 shows the results of robustness tests on this composite normalized series.

Figure 1
Normalized GDP series for the United Kingdom



Source: Prepared by the author, on the basis of A. Maddison, "World population GDP and per capita GDP 1–2009 ad", Groningen, University of Groningen, 2010; R. Thomas and others, "A millennium of macroeconomic data for the UK", *Technical Report*, London, Bank of England, 2017; C. Feinstein, *National Income, Expenditure and Output of the United Kingdom, 1855–1965*, Cambridge, Cambridge University Press, 1972; and Office for National Statistics (ONS).

3. Internationally comparable GDP time series: chained PPPs

This study includes GDP estimates for only 57 of the 200 or so sovereign countries that exist today, for two reasons: (i) these are the only economies for which very long-term national accounts estimates and historical estimates of PPPs are available, and (ii) the number of sovereign countries has increased dramatically since the mid-twentieth century, with most lacking any estimated time series for real GDP before independence.

The GDP time series for economies other than the United Kingdom are estimated as follows.

[10] This is a composite of many estimates, including Broadberry and others (2015) for Great Britain up to 1870, Feinstein (1972) for the United Kingdom from 1855 to 1948 and Andersson and Lennard (2016) for Ireland in the nineteenth century.

First, the United Kingdom's GDP series is stated in terms of 1990 dollars, using the 1990 benchmark of PPP relative to the United States. The use of 1990 dollars as a unit of account is also found in Maddison (1995, 2001 and 2010) and much of the literature on historical national accounts that followed. Normalized United States GDP for 1990 is computed here at US$ 5.803 trillion,[11] which in turn implies GDP of US$ 1.018 trillion in 1990 dollars for the United Kingdom in 1990. The GDP figures for all other times and also for the other economies are then normalized on this GDP figure of US$ 1.018 trillion in 1990 dollars for the United Kingdom.

Second, studies that estimate historical national accounts and PPPs for the United Kingdom and other economies are used to produce a set of benchmark estimates of real GDP levels for the other economies. For example, Ma, De Jong and Xu (2016) estimate the PPP level of Chinese per capita GDP relative to the United Kingdom in 1912; this estimate is used here to estimate Chinese GDP in 1990 dollars for that year. For China's GDP time series, real GDP benchmarks relative to the United Kingdom for 1840, 1912, 1986, 2005, 2011 and 2017 have been used in this study.

Third, a combination of these benchmark estimates of real GDP and the real GDP time series computed in local prices[12] are used to determine levels of GDP in 1990 dollars for other years. The basis of this method is that, for a pair of years, benchmark GDP estimates expressed in the same currency (such as 1990 dollars) for each year imply an average growth rate between them. Where estimates of GDP in local prices imply real GDP growth over a long period of time that greatly differs from the growth rates implied by the benchmark estimates, the growth rate of the estimated series is adjusted by the benchmark. In other words, the growth rate is multiplied by the ratio of the growth rate implied by the benchmark to the growth rate in local prices.

Formally, the interpolation procedure is as follows. Let $\{t_{b1}, t_{b2}\}$ be the dates of two real income level benchmarks with $t_{b2} > t_{b1}$, and let $Y_{t_{b1}}, Y_{t_{b2}}$ be two benchmark levels of observed GDP. Consider a time series index for GDP in local prices $\{i_t\}_{t=t_{b1}}^{t_{b2}}$ (for example the official national accounts for some economy); then, at some date $t \in \{t_{b1}, t_{b1}+1, t_{b1}+2, ..., t_{b2}\}$, the estimated GDP level at time t, Y_t, is given by

$$Y_t = exp\left[log\, Y_{t_{b1}} + \left(\frac{log\left(i_t/i_{t_{b1}}\right)}{log\left(i_{t_{b2}}/i_{t_{b1}}\right)}\right) log\left(\frac{Y_{t_{b2}}}{Y_{t_{b1}}}\right)\right] \tag{19}$$

For example, table 3 shows Japanese GDP levels in 1990 dollars relative to the United Kingdom for the three benchmarks used to construct Japan's GDP time series in this study. These benchmarks imply an annual growth rate of 5.2% from 1935 to 1990 and a growth rate of 0.8% from 1990 to 2014. For the same periods, the growth rates computed in local prices were 5.1% from 1935 to 1990[13] and 0.9% from 1990 to 2014.[14]

Table 3
Japan: real GDP benchmarks
(Millions of 1990 dollars)

Benchmark year	GDP
1935	145 492
1990	2 376 141
2014	2 853 794

Source: Prepared by the author, on the basis of official figures.

[11] Like Maddison (2010), we note that more recent revisions to the United States national accounts give a slightly higher figure for nominal United States GDP in 1990.

[12] These series may be official national accounts or historical national accounts estimates produced by economic historians.

[13] From Maddison's estimate, which combines official national accounts with estimates by economic historians for earlier years.

[14] From the official national accounts data reported by the World Bank.

The GDP series for Japan from 1935 to 2014 is based on the GDP series in local prices, with the growth rate from 1935 to 1990 normalized to match the GDP level of the 1990 benchmark and the rate from 1990 to 2014 normalized to match the GDP level of the 2014 benchmark. For years before 1935 and after 2014, GDP levels are based on national accounts estimated at local prices without adjustment for international comparisons with the United Kingdom. However, nearly 70% of the log variation of Japan's estimated per capita GDP from 1820 to 2020 occurred between 1935 and 2014, as that was the period of greatest economic growth. For countries like China, India and the United States and most of Western Europe, benchmarks in the more distant past are available (for China, our time series uses benchmarks of relative GDP levels at PPPs for 1840, 1986 and 2017). Hence, dependence on the use of local prices in the estimation of long-run growth is smaller.

Exclusively for the period after 1990 and the GDPs of Greece, Italy, Portugal, Romania and the countries of the former Soviet Union, a different chained PPP method is used here. The reason is that the method described by equation (19) would imply even greater volatility of aggregate GDP than is suggested by official national accounts. The method of linear weighting of PPP benchmarks used in these cases can be described as follows: for a year $t \in \{t_{b1}, t_{b1}+1, t_{b1}+2, ..., t_{b2}\}$, the estimated GDP level at t, Y_t, is given by

$$Y_t = \left(\frac{t - t_{b1}}{t_{b2} - t_{b1}}\right)\left(\frac{i_t}{i_{t_{b1}}}\right)Y_{t_{b1}} + \left(\frac{t_{b2} - t}{t_{b2} - t_{b1}}\right)\left(\frac{i_t}{i_{t_{b2}}}\right)Y_{t_{b2}} \qquad (20)$$

The use of several real GDP benchmarks close together in time could dramatically change GDP growth rates over short periods and yield real GDP time series that were inconsistent with the macroeconomic trajectory of these economies. Therefore, the estimates follow the rule that only one benchmark is taken when a pair of PPP benchmarks are close together in time. Only benchmarks that are relatively far apart in time (over 20 years) are used in the construction of these estimates. This method results in modest normalization of growth rates over long periods while keeping relative changes in output levels consistent with the GDP time series constructed in local prices.[15]

Another rule followed by the estimates here is that extrapolations and interpolations between two benchmark estimates are made using the same source for the entire time segment of the GDP time series, if such a source is available. This is done to minimize distortions to relative growth rates, as different series are often constructed using different methodologies.

4. Differences from the estimates in the 2018 release of the Maddison Project

The release of the Maddison Project in Bolt and others (2018) used the GDP time series estimates of Maddison (2010) and several PPP benchmarks to modify the GDP levels estimated. Subsequent editions of the Maddison Project have used the same method as Maddison (2010), which is just to aggregate the series of different countries without any adjustments.

The methodological differences between Bolt and others (2018) and the current study are as follows:

(i) They use the United States as the reference economy but do not normalize the various GDP time series used by Maddison and his followers to construct the United States GDP time series from 1820 to 2016. The present study has carefully normalized the time series for both the United Kingdom and the United States (in section 1 of annex A.1) so as to

[15] This method avoids results that are completely inconsistent with national accounts data. For example, Brazil's GDP growth rate from 1980 to 2017 according to Penn World Table version 9.1 (the variable *rgdpe*, or real expenditure-side GDP in chained PPPs, which aims to measure GDP in terms of living standards) was 4.1%, but the official national accounts show a dramatically slower growth rate of only 2.2%; the series for Brazil estimated in this study also has a GDP growth rate of 2.2%.

make the adjusted GDP time series consistent with the theoretical ideal of a GDP time series constructed using a uniform methodology over the whole period under study.

(ii) The present study recomputed all real GDP benchmarks before including them, and this yielded some important differences from the results of the 2018 release of the Maddison Project. For example, Germany and France were found to be much closer to the United States in terms of per capita GDP than suggested by the Maddison Project 2018 estimates. The recomputed GDP benchmarks are in section 5 of annex A.1.

In the present study, the real GDP time series are normalized using the GDP PPP benchmarks in accordance with the procedure described by equation 19, with some exceptions as per equation 20. In Bolt and others (2018), the specific normalization procedure follows Feenstra, Inklaar and Timmer (2015) and is described by equation 20.

IV. The time series

Table 4 presents the estimates arrived at for per capita GDP in 1990 international dollars for selected economies.[16]

Table 4
Selected countries: estimated per capita GDP, 1820–2020
(1990 international dollars)

Year	1820	1850	1870	1890	1913	1929	1938	1950	1970	1990	2010	2020
Europe												
Great Britain	2 371	3 006	4 133	4 729	5 820	6 183	6 942	8 127	12 329	17 897	22 493	22 184
France	1 565	2 201	2 586	3 461	5 151	6 516	6 258	7 066	12 914	17 914	22 070	22 044
Germany[a]	1 618	2 145	2 462	3 433	5 104	5 725	6 684	4 869	11 832	16 994	23 514	26 925
Italy	1 308	1 281	1 334	1 659	2 735	3 294	3 355	3 758	10 368	17 438	21 768	20 426
Netherlands (Kingdom of the)	1 777	2 234	2 613	3 141	4 175	5 840	5 386	6 115	12 377	17 824	26 896	28 354
Russian Empire (1820–1922), Union of Soviet Socialist Republics (USSR) (1922–1991) and former USSR (1991–2020)	778		1 067	1 014	1 655	1 655	2 630	3 281	6 025	7 195	8 758	10 537
Spain	1 232	1 416	1 560	2 148	2 726	3 612	2 440	2 905	7 330	12 884	19 196	18 724
Western offshoots												
Australia		2 913	4 092	5 144	5 945	6 000	6 639	8 136	12 646	16 991	24 326	26 273
Canada	1 405	2 065	2 632	3 357	5 323	5 910	5 305	8 149	12 933	19 064	23 782	24 179
United States	1 672	2 427	2 890	4 409	6 225	8 094	7 497	11 519	16 469	23 248	29 022	31 348
Latin America												
Argentina	1 288	1 615	1 895	3 173	4 902	5 638	5 256	5 702	7 708	7 148	12 180	10 221
Brazil	769	816	849	944	965	1 354	1 516	1 938	3 410	5 412	7 706	7 334
Chile	579	815	1 129	1 721	2 615	3 024	2 766	3 211	4 699	5 723	11 025	11 607
Colombia					1 261	1 535	1 880	2 196	3 236	4 917	6 393	7 014
Mexico	744	778	772	1 158	1 479	1 897	1 898	2 687	4 969	7 161	9 143	9 566
Peru					1 083	2 000	2 019	2 354	3 814	3 063	5 348	5 818
Venezuela (Bolivarian Republic of)	593	1 155	1 084	1 638	1 072	1 803	2 628	5 186	8 979	8 293	10 165	2 632
Asia												
China	679	655	711	716	704	713	711	571	820	1 763	5 460	8 359
India[b]	728	736	661	696	765	798	727	698	852	1 130	2 153	2 990
Indonesia	594	618	561	594	849	1 114	1 087	780	1 147	2 463	4 329	5 987
Japan	678	735	759	1 042	1 395	2 037	2 449	1 984	9 890	19 243	21 615	22 563

[16] To access the full GDP and population time series for all 57 economies, see R. Guthmann, "GDP, population, and employment estimates 1820–2020", 2024 [online] https://docs.google.com/spreadsheets/d/1UQtQ2HdLeLz7bsbsB8qES2jHwJZqzeTk/edit?gid=2070000566#gid=2070000566.

Año	1820	1850	1870	1890	1913	1929	1938	1950	1970	1990	2010	2020
Asia												
Thailand	780		832	1 072	1 150	1 085	1 130	1 118	2 332	4 802	7 716	8 749
Turkey	757		972		1 429	1 429	2 031	1 911	3 593	6 522	10 296	14 813
Africa												
Egypt	597		815		1 133			1 144	1 529	3 214	5 907	7 038
South Africa	592		1 225		2 287			3 619	5 578	5 017	6 503	6 188
World[c]	787		1 060		1 836	2 151	2 210	2 512	4 105	5 332	7 337	8 275

Source: Prepared by the author, on the basis of A. Maddison, "World population GDP and per capita GDP 1–2009 ad", Groningen, University of Groningen, 2010; World Bank, World Development Indicators [online database] https://databank.worldbank.org/source/world-development-indicators.

Note: To the extent possible, country and territory names reflect the designations used during the period of analysis.

[a] To maintain consistency, Germany includes the Federal Republic of Germany and the German Democratic Republic during the period 1950–1990.

[b] To maintain consistency, India includes Bangladesh and Pakistan during the period 1950–2020.

[c] World per capita GDP is estimated by adding the GDP of the rest of the world (besides the 57 economies) in accordance with its ratio to the GDP of the United Kingdom. For the period 1820–2000, this ratio is taken from Maddison's (2010) estimate; for 2001 onward, it is extrapolated using data from the World Bank World Development Indicators.

As shown in table 5, the GDP time series estimated here exhibits a substantially higher correlation with the official national accounts of the countries in the sample from 1960 to 2019 than the estimates from the Penn World Table. The latter systematically overestimates growth rates relative to official national accounts data, while the estimates here, on average, exhibit similar growth rates, while also having a high correlation with historical national accounts estimated at local prices and similar rates of growth.

Table 5

Correlation between GDP time series and official national accounts, 1960–2019

Time series	Correlation with official national accounts	Mean annual growth rate *(Percentages)*
This paper	0.960	3.23
Penn World Table version 10.0	0.920	3.82
Official national accounts	1.000	3.40

Source: Prepared by the author, on the basis of official figures.

Table 6

Selected countries: estimated mean annual GDP growth rates, 1960–2019

(Percentages)

País	This paper	Penn World Table 10.0	Official national accounts
Argentina	2.39	4.57	2.26
Brazil	3.69	4.88	3.84
China	5.60	5.80	7.63
France	2.25	2.96	2.74
Germany (1970–2019)[a]	2.27	2.82	2.11
India	4.36	4.85	5.05
Indonesia	4.86	5.88	5.07
Italy	2.41	3.15	2.33
Japan	3.42	3.75	3.49
Mexico	3.92	3.92	3.70
Russian Federation (1990–2019)	1.92	1.92	0.79
United States	2.55	3.03	2.97
Mean difference from official national accounts	0.49	0.80	

Source: Prepared by the author, on the basis of official figures.

Note: To the extent possible, country and territory names reflect the designations used during the period of analysis.

[a] To maintain consistency, Germany includes the Federal Republic of Germany and the German Democratic Republic until 1990.

Table 7
World: correlation with the historical national accounts data set and mean annual growth rates, 1820–1953

Time series	Correlation with the historical national accounts data set	Mean annual growth rate *(Percentages)*
This paper	0.994	2.25
Historical national accounts	1.000	2.27

Source: Prepared by the author, on the basis of official figures.

As shown in table 8, the estimates of this paper agree with other estimates in finding that the period from 1950 to 2020 was exceptionally prosperous on a global level compared to the 130 years before. However, they still imply that economic growth from 1950 onward was substantially lower relative to the growth from 1820 to 1950 than is indicated by the data sets of Maddison (2010) and Bolt and Van Zanden (2020). This result is expected, since our method normalizes the growth rates of our reference economy to estimates from historical time series, which tend to be lower than those of official national accounts. For example, the mean annual GDP growth rate of the United States from 1929 to 1957 was 3.61% according to the country's official national accounts,[17] but Kendrick (1961) estimated it to be 2.95%, which means that the official national accounts imply a per capita GDP growth rate nearly 40% higher than that estimated by the methods used to reconstruct historical national accounts. The normalized GDP estimate using the United Kingdom as the reference economy implies a growth rate of 2.90%, which is closer to the estimates produced by economic historians for the period. Maddison (2010) estimated the same growth rate of 2.90%.

Table 8
World: estimated mean annual GDP growth rates
(Percentages)

Period	This paper	Maddison (2010)	Maddison Project 2020
1820-1870	0.60	0.54	0.62
1870-1950	1.07	1.11	1.01
1950-2008	1.85	2.24	
1950-2019	1.80		2.22

Source: Prepared by the author, on the basis of A. Maddison, "World population GDP and per capita GDP 1–2009 ad", Groningen, University of Groningen, 2010.

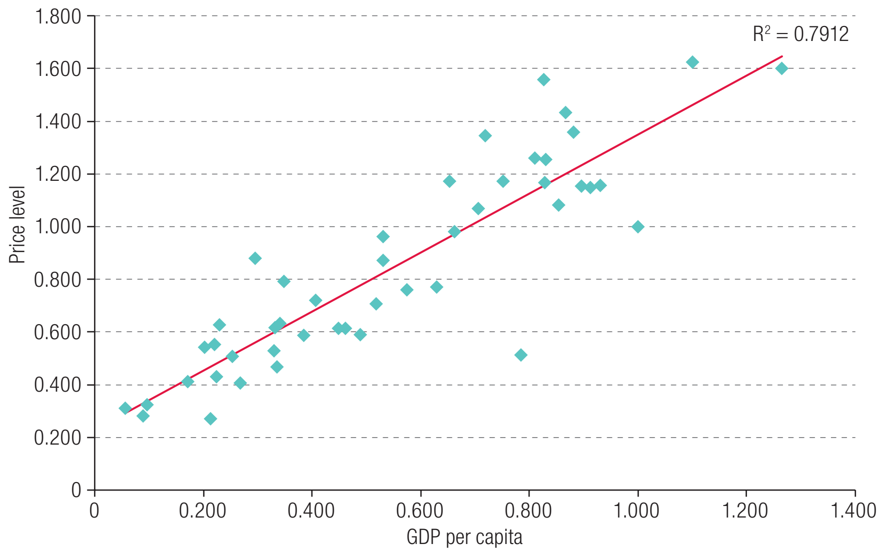
V. Changes in the implied Balassa-Samuelson effect

It is a stylized fact that there is a strong correlation between levels of per capita GDP and price levels (the "price level" of a country is the market exchange rate relative to the PPP conversion rate). This correlation is called the Balassa-Samuelson effect.[18] Figure 2 illustrates this effect across countries in 2011 (the year that a purchasing power conversion rate benchmark was computed by the World Bank International Comparison Program).

[17] According to the version available from the Bureau of Economic Analysis (BEA) [online] https://www.bea.gov/ [date of reference: September 2023].

[18] It was independently described by Balassa (1964) and Samuelson (1964).

Figure 2
Balassa-Samuelson effect in the 2011 World Bank International Comparison Programme benchmark
(Index: United States=1)



Source: Prepared by the author.

The estimates given here suggest that the Balassa-Samuelson effect was already present but weaker in the more distant past. On the basis of the same nominal per capita GDP estimates as were used to construct the real GDP time series, price levels have been estimated here for 35 economies in 1913 (before the First World War) and for 40 economies in 1936 (before the Second World War), yielding 75 data points. Regressing the price level on real GDP levels yields a lower correlation between the two variables, although it is still positive and statistically significant. To take an extreme example, the price level of China is estimated to have been about the same as Belgium's circa 1910 (Ma, de Jong and Xu, 2016), although Belgium's per capita GDP is estimated to have been nine times as high as China's from direct benchmark comparisons of real output at the time.

Although empirically a well-documented stylized fact, the Balassa-Samuelson effect depends on strong theoretical assumptions. A perfect Balassa-Samuelson effect would be a situation where there was a perfect correlation between relative price levels and per capita GDP. Given such a perfect correlation, nominal per capita GDP converted at market exchange rates would be a sufficient statistic to predict real per capita GDP. However, a perfect Balassa-Samuelson effect requires the following assumptions:

(i) The world economy is in perfectly competitive general equilibrium, and production technology is neoclassical with constant returns to scale.

(ii) The economy can be decomposed into two components: a tradable sector and a non-tradable sector, such that the costs of transportation are zero for the tradable sector's output and infinite for the non-tradable sector's output.

(iii) Currency exchange rates are set purely by the market, and trade barriers and tariffs for product markets across countries do not exist.

(iv) Cross-country productivity per worker (marginal product per worker) in the tradable sector varies in proportion to per capita GDP at PPP multiplied by a fixed ratio. In other words, there exists a $\Delta > 1$ such that for two countries *A* and *B* having $y_A > 0$, $y_B > 0$ as their pair of PP per capita GDP levels and y_A^T and y_B^T as their productivity levels in the tradable sector, $log\{y_A^T\} - log\{y_B^T\} = \Delta(log\{y_A\} - log\{y_B\})$.

Below are some conjectures as to why these assumptions might not have applied as strongly in the more distant past as they do today:

(i) A lower degree of economic integration, since the world economy was much less integrated in the more distant past than it is today. This lower degree of integration naturally implies that prices for tradable goods diverged across countries to a greater extent than in more recent years. This applies particularly to economies that were relatively closed to international trade, such as the former Union of Soviet Socialist Republics or China. Even among economies that were more integrated, however, the higher costs of information and transport meant that price levels for tradables could vary more across countries.

(ii) New World-specific and Old World-specific price levels, since by the early twentieth century, Argentina, Australia, Canada, New Zealand and the United States had much higher price levels than European countries at similar income levels, such as Belgium, Switzerland and the United Kingdom. This discrepancy in price levels is supported by both direct benchmark comparisons of prices for final goods (Williamson, 1995; Ward and Devereux, 2021) and income levels extrapolated from the 1990 benchmark. The current state of the evidence suggests that productivity in manufacturing and for other tradable goods was much higher in the New World. For example, productivity per worker in United States manufacturing is estimated to have been over twice as high as in the United Kingdom (Broadberry and Irwin, 2006) and 1.6 times as high as in Germany around 1910 (De Jong and Veenstra, 2016), a much larger difference than for per capita GDP. An additional factor that may help explain this discrepancy in price levels are capital flows from Europe to the rest of the world: capital flowed from European countries to their colonies, increasing their relative supply of gold[19] and resulting in a higher price level.

(iii) Changes in the relative variability of productivity for tradables and non-tradables, since the assumption that tradables prices are lower relative to non-tradables in richer countries is the central hypothesis used to explain the Balassa-Samuelson effect. This property holds for the present data, but it might not have always held in the past. For example, Ma, De Jong and Xu (2016) estimate PPP for the Chinese yuan relative to the British pound in 1912 at 7.85 yuan per pound in the services sector (which typically produces non-tradable goods) and 6.61 yuan for manufacturing (which typically produces tradable goods).

VI. Concluding remarks

This study has shown that different methodologies for computing GDP growth rates yield substantial differences in the measured growth of real GDP and that incomplete data and technological change amplify these problems. Therefore, the use of GDP figures to measure performance over the economic long run should be taken with a grain of salt and disciplined by the normalization of GDP time series across both time and space.

Taking these problems into consideration, this paper presents a set of estimates for the evolution of GDP over the last 200 years in 57 economies constituting 85% to 90% of the world's population during that two century period. The study has produced estimates that maintain the consistency of estimated GDP across different economies over time relative to national accounts estimates in local prices. The method consists of constructing a normalized real GDP time series for a reference economy and then normalizing the GDP figures for the other economies through real GDP comparisons with the reference economy. This set of normalized GDP time series largely agrees with historical and official national accounts estimates, is found to be robust in several tests performed in the annex and provides a global portrait of economic growth that is comparable over time and between countries.

[19] The world operated under a gold currency standard at the time.

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Annex A1

Robustness tests for the GDP time series

In this annex, we perform robustness tests on the estimated real GDP time series for the United Kingdom, the reference economy used to normalize the real GDP time series of all other economies. The first robustness test shows that the resulting GDP estimates do not change substantially when we use the United States as the reference economy.

1. The United States as the reference economy

Table A1.1 shows the estimates arrived at when we replicate the method of the paper to calculate per capita GDP in 1990 international dollars for selected economies using the United States as the reference economy instead of the United Kingdom. The overall estimates closely match the estimates made using the United Kingdom as the reference economy.

Table A1.1
Selected countries: per capita GDP estimated with the United States as the reference economy, 1820–2020
(1990 international dollars)

Year	1820	1850	1870	1890	1913	1929	1938	1950	1970	1990	2010	2020
Europe												
Great Britain	2 258	2 863	3 936	4 623	5 857	6 560	7 738	8 371	12 474	17 856	22 345	21 877
France	1 507	2 183	2 564	3 494	5 157	6 522	6 264	7 072	12 918	17 914	21 760	21 660
Germany[a]	1 558	2 065	2 371	3 363	5 105	5 750	6 705	4 893	11 858	16 994	23 229	26 456
Italy	1 259	1 233	1 285	1 625	2 747	3 306	3 367	3 770	10 379	17 438	21 439	20 070
Netherlands (Kingdom of the)	1 711	2 150	2 516	3 082	4 187	5 916	5 458	6 228	12 375	17 824	26 511	27 860
Russian Empire (1820–1922), Union of Soviet Socialist Republics (USSR) (1922–1991) and former USSR (1991-2020)	803		1 101	1 046	1 708	1 708	2 714	3 385	6 115	7 195	8 642	10 355
Spain	1 293	1 486	1 637	2 254	2 861	3 785	2 577	3 046	7 463	12 884	19 023	18 398
Western offshoots												
Australia		2 774	3 897	5 070	5 981	6 032	6 672	8 167	12 667	16 991	23 913	25 815
Canada	1 352	1 988	2 534	3 285	5 346	5 931	5 324	8 170	12 947	19 064	23 457	23 758
United States	1 593	2 359	2 809	4 383	6 269	8 235	7 869	11 864	16 768	23 248	28 523	30 802
Latin America												
Argentina	1 356	1 701	1 995	3 341	5 161	5 936	5 534	5 879	7 931	6 822	12 006	10 043
Brazil	810	859	893	994	1 016	1 425	1 595	2 031	3 542	5 559	7 610	7 206
Chile	595	838	1 161	1 769	2 688	3 109	2 844	3 301	4 831	5 840	10 916	11 405
Colombia					1 296	1 578	1 933	2 258	3 327	4 899	6 342	6 891
Mexico	722	756	750	1 125	1 436	1 842	1 843	2 609	4 688	7 072	8 956	9 399
Peru					1 113	2 057	2 075	2 420	3 921	3 162	5 318	5 716
Venezuela (Bolivarian Republic of)	585	1 139	1 070	1 616	1 058	1 779	2 593	5 116	9 467	8 470	9 591	2 912
Asia												
China	658	634	686	693	685	695	694	555	810	1 657	5 542	8 213
India[b]	708	715	642	681	754	792	723	688	858	1 136	2 124	2 938
Indonesia	580	604	548	584	844	1 117	1 093	781	1 165	2 498	4 294	5 882

Year	1820	1850	1870	1890	1913	1929	1938	1950	1970	1990	2010	2020
Asia												
Japan	700	757	784	1 075	1 439	2 102	2 411	2 045	9 985	19 243	20 573	21 584
Thailand	662		706	910	976	921	959	949	1 979	4 393	7 485	8 597
Turkey	749		961		1 414	1 414	2 009	1 891	3 555	6 454	10 121	14 555
Africa												
Egypt	573		783		1 088			1 098	1 468	3 094	5 781	6 915
South Africa	580		1 199		2 239			3 543	5 460	4 911	6 366	6 080

Source: Prepared by the author, on the basis of official figures.
Note: To the extent possible, country and territory names reflect the designations used during the period of analysis.
[a] To maintain consistency, Germany includes the Federal Republic of Germany and the German Democratic Republic during the period 1950–1990.
[b] To maintain consistency, India includes Bangladesh and Pakistan during the period 1950–2020.

The United States GDP series from 1820 to 1834 is taken from Williamson (2025), who in turn drew on estimates from 1800 to 1860 by Weiss (1992) and Berry (1988). The time series used from 1834 to 1909 is Gallman's, as reported in Rhode (2002). The time series used from 1909 to 1957 is Kendrick's, as reported in Smits, Woltjer and Ma (2009). The United States official national accounts as reported by the Bureau of Economic Analysis (BEA) and the World Bank are used from 1957 to 2020. Series values are linked at the years 1834, 1909 and 1957; the growth reported in the official national accounts from 1957 onward is normalized relative to the composite of Gallman's and Kendrick's series from 1834 to 1957 (since the two series exhibit exactly the same growth rate for the period when they overlap), following the same procedure as was described for the United Kingdom series in section III.1. In this case, the growth rate of United States GDP after 1957 is reduced by 17.9%, while the normalization procedure reduces the growth rate of the United Kingdom GDP series after 1948 by 19.4% compared to the official national accounts.

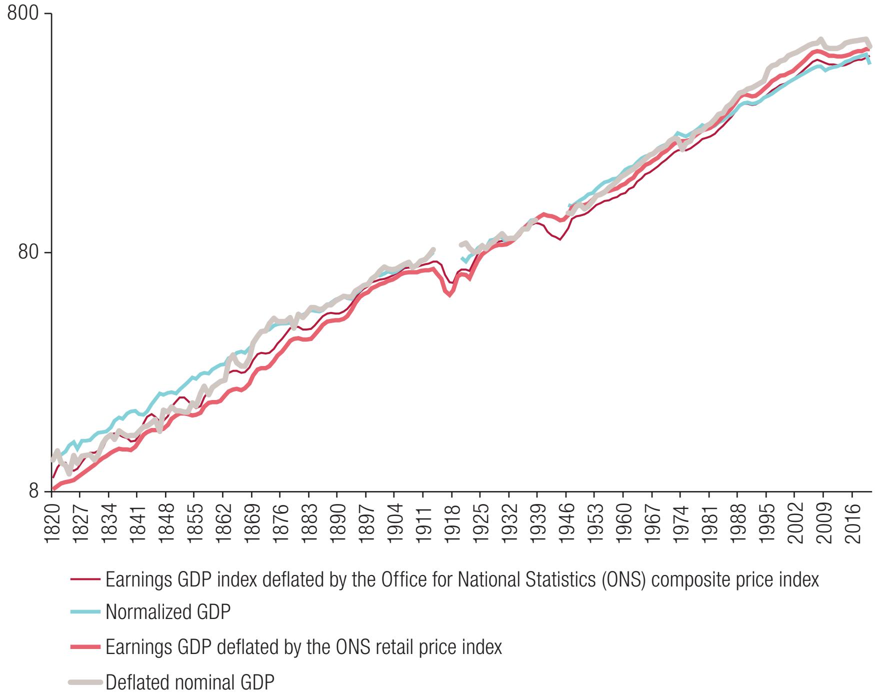
2. Nominal GDP series deflated by consumer price indices

First, let us consider the estimates of nominal GDP for the United Kingdom and deflate this GDP using a price index constructed with a relatively uniform methodology for the whole period under consideration (1820–2020).

The nominal GDP data used were those of Broadberry and others (2015) for Great Britain from 1820 to 1870, Feinstein's estimate for the whole United Kingdom from 1870 to 1965 and the official national accounts from 1965 to 2020. These series were then deflated by the Office for National Statistics (ONS) composite price index (CPI) and by the United Kingdom retail price index from Clark (2025). The series for Great Britain was then linked to the series for the United Kingdom in 1870, being adjusted by the ratio of Great Britain's GDP to the United Kingdom's total GDP as estimated by Thomas and others (2017).

As shown in figure A1.1 and in table A1.2, this method suggests that the GDP growth rate is slightly underestimated for the two century period. The robustness test suggests that the degree of underestimation appears to be slightly greater from 1948, the earliest date in the GDP series regularly updated by ONS. However, this test does not correct for the methodological heterogeneity in the estimation of the different nominal GDP series. The robustness check performed in the next subsection corrects for this heterogeneity, and the result is consistent with the relative growth rates implied by the estimates of the present study.

Figure A1.1
Normalized GDP series for the reference economy compared to alternative series, 1820–1920



Source: Prepared by the author.

Table A1.2
Great Britain/United Kingdom: annual per capita GDP growth rates, 1820–2019
(Percentages)

Great Britain 1820–1920/United Kingdom 1921–2019	Period			
	1820–1880	1880–1948	1948–2019	1820–2019
Normalized GDP	1.03	0.83	1.62	1.18
GDP deflated by composite price index (CPI)	1.13	0.74	1.89	1.27
Labour earnings series (CPI)	1.21	0.79	1.75	1.26
Labour earnings series (retail price index)	1.22	1.11	1.72	1.36

Source: Prepared by the author, on the basis of official figures.

3. Labour earnings-based GDP series

The heterogeneity of the methods and the quality of the data used in the estimation of historical national accounts imply that nominal GDP levels for the distant past are not directly comparable with more recent estimates. This study therefore includes an additional robustness check for the estimated GDP series that consists of a bottom-up estimate of GDP growth based on average labour earnings, labour force participation and an estimate for the share of GDP represented by labour earnings. This bottom-up estimate lacks the accuracy and resolution to describe GDP growth rates in the short run. However, because it is constructed using the same methodology for its entire duration, it can serve as an additional robustness check for the plausibility of the estimates of long-run economic growth. Given available estimates of the employed population, the labour share of national income, earnings as a share of labour compensation and real earnings, we constructed a series for Great Britain from 1820 to 2020 that can be used to check for biases in the reported measures of nominal product and is invariant to both methodological changes in national accounting methods and to routine updates to nominal GDP figures.

The earnings-based index of output is estimated by adopting a bottom-up approach to the evolution of domestic product that begins with the average earnings of individual workers taken from Clark (2011). Average total labour compensation is determined from earnings and the ratio of earnings to total labour compensation (which might include, for example, health insurance, social contributions and payroll taxes). Nominal net domestic product (NDP) per worker is then determined by dividing average total labour compensation by the labour share of NDP as computed by Piketty and Zucman (2014) from official national accounts and historical estimates. The capital depreciation rate, also estimated by Piketty and Zucman (2014), is used to estimate the gross to net domestic product ratio. This creates a time series for nominal GDP which, deflated by the CPI provided by ONS, creates a series for real GDP per worker. The aggregate output index series is determined from the GDP per worker and total employed population series.

Formally, let $\left\{Y_t^i\right\}_{t=1820}^{2018}$ be the estimated output index, L_t the employed population at time t, α_t the labour share of NDP, w_t average nominal labour earnings, ζ_t the share of earnings in labour compensation, δ_t the capital depreciation rate and P_t the price index. For each t, the output index Y_t^i satisfies

$$Y_t^i = L_t\left(\frac{w_t}{\alpha_t\left(1-\delta_t\right)\zeta_t P_t}\right) \tag{21}$$

Figure A1.1 compares four series (the normalized GDP series, the series for GDP deflated by the CPI and the two earnings-based output index series) from 1820 to 2020, and table A1.2 presents percentage growth rates for the modern statistical period (1948–2019) and the historical period. The two earnings-based series are more consistent with the estimates than those produced by simply deflating the time series of nominal GDP estimates, yielding growth rates similar to those of the normalized GDP series for both the pre-statistical and modern statistical periods. Measured in log terms, the standard deviation of the normalized GDP series from 1820 to 2019 relative to the earnings-based CPI output index is 0.077, compared to 0.138 for the estimate produced by the Bank of England over the same period.

4. Comparison with estimates from other studies for the United Kingdom

Our normalized series exhibits slower growth from 1950 onward than the time series produced by the Bank of England; however, it is consistent with output time series estimated by economic historians such as Broadberry, Fukao and Zammit (2015), as shown in table A1.3. Series such as those from the present study and from Broadberry, Fukao and Zammit (2015) aim to produce estimates of output across long periods with a consistent methodology.

Table A1.3
United Kingdom: output time series, 1820–2016
(Index: 1935=100)

Year	This study	Broadberry, Fukao and Zammit (2015)	Thomas and others (2017)
1820	13.0		13.3
1850	23.9		24.2
1870	39.2		39.6
1891	57.1	57.2	57.5
1911	80.1	79.8	80.3
1935	100.0	100.0	100.0
1950	135.3	128.8	136.7
1960	177.2	165.6	191.0

Year	This study	Broadberry, Fukao and Zammit (2015)	Thomas and others (2017)
1973	252.9	238.0	297.0
1990	337.7	325.5	425.4
2007	479.8	499.4	650.9
2016	516.3		708.8

Source: Prepared by the author, on the basis of S. Broadberry, K. Fukao and N. Zammit, "How did Japan catch-up on the west? A sectoral analysis of Anglo-Japanese productivity differences, 1885–2000", *The University of Warwick Working Paper Series*, No. 231, Coventry, University of Warwick, 2015; R. Thomas and others, "A millennium of macroeconomic data for the UK", *Technical Report*, London, Bank of England, 2017.

5. Benchmarks for GDP at PPP used in this study

Table A1.4
Selected countries: GDP benchmarks, 1840–1870

China/Great Britain 1840 benchmark						
Country	GDP *(Millions of local currency units)*	PPP converter	GDP *(Millions of pounds)*	GDP *(Billions of 1990 dollars)*		
Great Britain	517.7	1.00	517.7	52.32		
China	5 379.6	2.03	2 650	267.86		
United States/United Kingdom 1850 benchmark						
Country	GDP *(Millions of local currency units)*	PPP converter	GDP *(Millions of pounds)*	GDP *(Billions of 1990 dollars)*	Discrepancy from the estimate *(Percentages)*	
United States	2 537	5.63	450.4	57.24	7.9	
United Kingdom	610.5	1.00	610.5	71.91		
Java/Netherlands (Kingdom of the) 1860 benchmark						
Country	Nominal per capita GDP 1839–1841	Nominal per capita GDP 1878–1880	Price level (1858–1862)	Real per capita GDP index	Population *(Millions)*	GDP *(Billions of 1990 dollars)*
Netherlands (Kingdom of the)	208	271	100.0	100.0	3.33	7.27
Java	28	40	55.8	25.3	25.78[a]	14.23
India/United States 1870 benchmark						
Country	Real per capita GDP index	Population *(Millions)*	GDP *(Billions of 1990 dollars)*			
United States	100.0	42.24	116.32			
India	23.5[b]	253.00	171.85			

Source: Prepared by the author, on the basis of A. Maddison, "World population GDP and per capita GDP 1–2009 ad", Groningen, University of Groningen, 2010; S. Broadberry, H. Guan and D. Li, "China, Europe, and the great divergence: a study in historical national accounting, 980–1850", *Journal of Economic History*, vol. 78, No. 4, Cambridge, Cambridge University Press, 2018; R. Thomas and others, "A millennium of macroeconomic data for the UK", *Technical Report*, London, Bank of England, 2017; S. Carter and others, *Historical Statistics of the United States: Earliest Times to the Present*, Cambridge, Cambridge University Press, 2006; J. van Zanden, "Rich and poor before the industrial revolution: a comparison between Java and the Netherlands at the beginning of the 19th century", *Explorations in Economic History*, vol. 40, No. 1, Amsterdam, Elsevier, 2003; A. Heston and R. Summers, "Comparative Indian economic growth: 1870 to 1970", *American Economic Review*, vol. 70, No. 2, Nashville, American Economic Association (AEA), 1980.

Note: Great Britain nominal GDP is from Thomas and others (2017), and China nominal GDP and PPP for 1840 is from Broadberry, Guan and Li (2018). United States GDP is from Carter and others (2006) and population from Maddison (2010). Java and the Kingdom of the Netherlands are from Van Zanden (2003). To the extent possible, country and territory names reflect the designations used during the period of analysis.

[a] The total population includes other islands that compose the current territories of Indonesia.

[b] Heston and Summers (1980) estimate India's per capita GDP at 23.5% of the per capita GDP of the United States in 1870.

Table A1.5
Selected countries: GDP benchmarks, 1872

Country	GDP *(Millions of local currency units)*	Dollar exchange rate	Price level	GDP at PPP *(Millions of current dollars)*	Population *(Millions)*	Per capita GDP *(Current dollars)*
Australia	93.6	0.183	121	424	1.74	243
Belgium	5 586	4.609	103	1 176	5.14	229
Canada	447	0.892	82	612	3.87	158
Denmark	722	3.336	79	291	1.82	160
France	24 955	4.611	84	6 443	37.64	171
Germany	17 535	3.748	83	6 193	41.19	150
Italy	10 310	5.792	87	2 046	26.88	76
Netherlands (Kingdom of the)	1 121	2.232	85	577	3.68	157
New Zealand	17.1	0.183	121	77	0.32	242
Norway	636	3.319	95	202	1.75	115
Sweden	1 209	3.267	80	463	4.23	109
Switzerland	1 835	4.609	86	463	2.70	172
United Kingdom	1 312	0.183	96	7 468	31.87	234
United States	8 163	1.000	100	8 163	42.14	194

Source: Prepared by the author, on the basis of M. Ward and J. Devereux, "New income comparisons for the late nineteenth and early twentieth century", *The Review of Income and Wealth*, vol. 67, No. 1, Hoboken, Wiley, 2021; M. Curtis and P. Lindert, "Nominal GDP historical series", Davis, Global Price and Income History Group (GPIH), 2018 [online] http://gpih.ucdavis.edu/GDP.htm; P. Rhode, "Gallman's annual output series for the United States, 1834–1909", *NBER Working Paper*, No. 8860, Cambridge, National Bureau of Economic Research (NBER), 2002; M. Hiestand, M. Müller and U. Woitek, "A.1 statistische Grundlagen und Methoden", *Wirtschaftsgeschichte der Schweiz im 20. Jahrhundert*, P. Halbeisen, M. Müller and B. Veyrassat (eds.), Basel, Schwabe Verlag, 2012; L. Schön and O. Krantz, "New Swedish historical national accounts since the 16th century in constant and current prices", *Lund Papers in Economic History*, No. 140, Lund, Lund University, 2015.

Note: Price levels as estimated in Ward and Devereux (2021), using the United States as the benchmark economy. The estimate of the price level for France is taken from the working paper version of Ward and Devereux (2021), as the published version of the paper has a price level that is implausibly high and much higher than the working paper version. Nominal GDP is taken from Curtis and Lindert (2018), except for the United States, where it is from Rhode (2002) (foreign factor income is assumed to be irrelevant, with estimates putting it at less than 1% of GNP, so GDP and GNP are approximately equal); Switzerland, where it is from Curtis and Lindert (2018), adjusted for the average discrepancy from Hiestand, Müller and Woitek (2012) over the period 1890–1913; and Sweden, where it is from Schön and Krantz (2015). Germany's estimate is net national product (NNP) at market prices, while Denmark's is GDP at factor cost. NNP and GDP at factor cost were converted into GDP at market prices using, respectively, the ratio of NNP to GDP for the United States and the estimate by Thomas and others (2017) for the ratio between GDP at market prices and factor cost in the United Kingdom. To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.6
Selected countries: GDP benchmarks, 1910

Country	GDP *(Millions of local currency units)*	Dollar exchange rate	Price level	GDP at PPP *(Millions of current dollars)*	Population *(Millions)*	Per capita GDP *(Current dollars)*
Australia	312.7	0.206	98	1 549	4.43	350
Belgium	7 735	5.170	61	2 453	7.44	330
Canada	2 023	1.000	99	2 043	7.19	284
Denmark	1 922	3.739	73	760	2.74	277
France	40 218	5.170	75	10 372	39.68	261
Germany	47 300	4.200	71	17 764	64.57	275
Italy	19 676	5.324	75	5 126	34.38	149
Netherlands (Kingdom of the)	2 000	2.484	60	1 342	5.95	226
New Zealand	66.5	0.206	98	329	1.05	315
Norway	1 469	3.738	70	562	2.38	236
Sweden	3 298	3.740	73	1 208	5.50	220
Switzerland	4 817	5.170	72	1 294	3.74	346
United Kingdom	2 224	0.206	80	13 495	44.90	301
United States	31 304	1.000	100	31 304	92.77	337

Source: Prepared by the author, on the basis of M. Ward and J. Devereux, "New income comparisons for the late nineteenth and early twentieth century", *The Review of Income and Wealth*, vol. 67, No. 1, Hoboken, Wiley, 2021; M. Curtis and P. Lindert, "Nominal GDP historical series", Davis, Global Price and Income History Group (GPIH), 2018 [online] http://gpih.ucdavis.edu/GDP.htm; M. Hiestand, M. Müller and U. Woitek, "A.1 statistische Grundlagen und Methoden", *Wirtschaftsgeschichte der Schweiz im 20. Jahrhundert*, P. Halbeisen, M. Müller and B. Veyrassat (eds.), Basel, Schwabe Verlag, 2012; T. Piketty and G. Zucman, "Capital is back: wealth-income ratios in rich countries 1700–2010", *The Quarterly Journal of Economics*, vol. 129, No. 3, Oxford, Oxford University Press, 2014; L. Schön and O. Krantz, "New Swedish historical national accounts since the 16th century in constant and current prices", *Lund Papers in Economic History*, No. 140, Lund, Lund University, 2015; J. Smits, E. Horlings and J. van Zanden, "Dutch GNP and its components, 1800–1913", *Groningen Growth and Development Centre Monograph Series*, No. 5, Groningen, University of Groningen, 2000; C. Romer, "The prewar business cycle reconsidered: new estimates of gross national product, 1869–1908", *Journal of Political Economy*, vol. 97, No. 1, Chicago, The University of Chicago Press, 1989.

Note: Price levels as estimated in Ward and Devereux (2021). Nominal GDP is taken from Curtis and Lindert (2018), except for Switzerland, where it is from Hiestand, Müller and Woitek (2012); France, from Piketty and Zucman (2014) (income approach); Sweden, from Schön and Krantz (2015); and the Kingdom of the Netherlands, where the net national product (NNP) estimate from Smits, Horlings and van Zanden (2000) is used. Denmark's estimate is GDP at factor cost, and NNP is used instead of GDP for Germany. This benchmark of comparative real product levels uses Balke and Gordon's GNP estimate and subtracts foreign factor income to arrive at a GDP estimate. Estimates of United States product vary from Balke and Gordon's (1989) GNP estimate of US$ 31.240 billion and the Historical Statistics of the United States (Carter and others, 2006) GDP estimate of US$ 31.609 billion to substantially higher values for GNP of US$ 33.36 billion and US$ 33.187 billion in Smits, Woltjer and Ma (2009) and Romer (1989), respectively, with a divergence of only 6% from Balke and Gordon (1989). To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.7
Selected countries: GDP benchmarks, 1927

Country	GDP (Millions of local currency units)	GDP (Millions of 1990 dollars)		
		PPP	Benchmark	This study
Argentina (1938)	11 000	9.27	71 274	71 274
Australia (1927)	795.6	1.27	37 628	39 307
Belgium (1927)	70 110	117.6	35 809	47 479
Brazil (1937)	41 288	42.29	58 641	58 641
Canada (1927)	5 561	5.67	58 910	56 315
Denmark (1927)	5 318	16.86	21 203	20 335
France (1927)	321 281	89.1	224 112	242 041
Germany (1927)	80 466	18.08	302 021	354 610
Ireland (1927)	172.2	0.90	11 493	11 493
Italy (1927)	154 089	73.21	132.68	122.89
Norway (1926)	4 573	22.08	12 440	13 384
Netherlands (Kingdom of the) (1927)	6 032	8.99	40 301	42 865
Portugal (1927)	13 886	74.97	11 125	11 125
Spain (1927)	33 485	25.58	78 626	78 626
Sweden (1927)	9 497	20.45	27 894	32 043
United Kingdom (1927)	4 500	1.00	270 292	
United Kingdom (factor cost)	4 021			
United Kingdom (net national product)	3 983			
United States (1927)	96 802	7.57	768 081	923 504

Source: Prepared by the author, on the basis of M. Curtis and P. Lindert, "Nominal GDP historical series", Davis, Global Price and Income History Group (GPIH), 2018 [online] http://gpih.ucdavis.edu/GDP.htm; R. Thomas and others, "A millennium of macroeconomic data for the UK", *Technical Report*, London, Bank of England, 2017; T. Piketty and G. Zucman, "Capital is back: wealth-income ratios in rich countries 1700–2010", *The Quarterly Journal of Economics*, vol. 129, No. 3, Oxford, Oxford University Press, 2014; J. Williamson, "The evolution of global labor markets since 1830: background evidence and hypotheses", *Explorations in Economic History*, vol. 32, No. 2, Amsterdam, Elsevier, 1995.

Note: GDP in local currency units is taken from Curtis and Lindert (2018), except for the United States, where it is taken from the Historical Statistics of the United States series. Thomas and others (2017) is used for the nominal GDP of the United Kingdom and Piketty and Zucman (2014) (income approach) for that of France and the United States. Denmark's estimate is GDP at factor cost, and NNP is used instead of GDP for Germany. The benchmark is constructed using PPP converters from Williamson (1995), these being Fisher PPPs for private consumption that take the United Kingdom as the star country, so that they should be regarded as less accurate in representing economy-wide relative price levels than the real product benchmarks for 1872 and 1910. These benchmarks were not used for countries where those more accurate earlier benchmarks were available. To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.8
Selected countries: GDP benchmarks, 1935

China/United States benchmark			
Country	Per capita GDP		
	Benchmark *(1935 dollars)*	This study *(1990 dollars)*	Difference *(Percentages)*
United States	574.7	6 794	
China	63.6	693	4.9
Japan/United States benchmark			
Country	Per capita GDP in PPP *(1935 dollars)*	Population *(Millions)*	GDP index
United States	574.7	127.86	100.00
Japan	180.8	69.24	17.04
Japan/United Kingdom benchmark			
Country	GDP *(Millions of local currency units)*	PPP	GDP index
United Kingdom	4 619	1.00	100.00
Japan	18 104	8.12	48.27
Japan/Korea/Taiwan benchmark			
Country	GDP *(Millions of local currency units)*	PPP	GDP index
Japan	18 104	1.00	100.00
Korea	2 233	0.87	14.17
Taiwan	796	0.86	5.11

Source: Prepared by the author, on the basis of K. Fukao, D. Ma and T. Yuan, "Real GDP in pre-war east Asia: a 1934–36 benchmark purchasing power parity comparison with the U.S.", *The Review of Income and Wealth*, vol. 53, No. 3, Hoboken, Wiley, 2007; "International comparison in historical perspective: reconstructing the 1934–1936 benchmark purchasing power parity for Japan, Korea, and Taiwan", *Explorations in Economic History*, vol. 43, No. 2, Amsterdam, Elsevier, 2006; S. Broadberry, K. Fukao and N. Zammit, "How did Japan catch-up on the west? A sectoral analysis of Anglo-Japanese productivity differences, 1885–2000", *The University of Warwick Working Paper Series*, No. 231, Coventry, University of Warwick, 2015.

Note: For the benchmark relative to the United States, nominal GDP and price level estimates are from Fukao, Ma and Yuan (2007). For the benchmark relative to the United Kingdom, PPP is from Broadberry, Fukao and Zammit (2015). Korea and Taiwan price level estimates relative to Japan are from Fukao, Ma and Yuan (2006). To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.9
Industry-of-origin benchmarks for GDP in PPP, 1935–1937

Germany/United Kingdom benchmark					
Country	Employed population *(Millions)*	Index of GDP per worker	GDP *(Billions of 1990 dollars)*		
			Benchmark	Estimate	Difference *(Percentages)*
Germany (1935)	29 382	75.7	351.40	367.85	4.7
United Kingdom (1935)	19 079	100.0	301.41		
United States/United Kingdom benchmark					
Country	Employed population *(Millions)*	Index of GDP per worker	GDP *(Billions of 1990 dollars)*		
			Benchmark	Estimate	Difference *(Percentages)*
United States (1937)	45 683	132.6	993.69	1 032.76	3.9
United Kingdom (1937)	19 942	100.0	327.13	327.13	

Source: Prepared by the author, on the basis of S. Broadberry, "Anglo-German productivity differences 1870–1990: a sectoral analysis", *European Review of Economic History*, vol. 1, No. 2, Oxford, Oxford University Press, 1997; "Forging ahead, falling behind and catching-up: a sectoral analysis of Anglo-American productivity differences, 1870–1990", *Research in Economic History*, vol. 17, Bradford, Emerald Insight, 1997; J. Williamson, "The evolution of global labor markets since 1830: background evidence and hypotheses", *Explorations in Economic History*, vol. 32, No. 2, Amsterdam, Elsevier, 1995.

Note: Industry-of-origin benchmark estimated from Broadberry (1997a) for the relative productivity of Germany and the United Kingdom in 1935 and Broadberry (1997b) for the relative productivity of Germany and the United Kingdom in 1937. Note that they are much closer to the estimates produced in this study than the benchmark constructed using Williamson's (1995) PPPs for private consumption in 1927. The 1937 benchmark was not used for the data set because the deviation of the interpolated United States time series from the benchmark was too small. The deviation between the benchmark and the interpolated United Kingdom time series in the United States benchmark economy data set was substantially greater, so the benchmark was used to correct the estimate of the United Kingdom's inter-war product level in that data set. To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.10
United States and United Kingdom: GDP benchmark, 1950

Country	Employed population *(Millions)*	Index of GDP per worker	GDP *(Billions of 1990 dollars)*
United Kingdom (1950)	23 232	100.0	407.90
United States (1950)	61 477	162.5	1 753.98

Source: Prepared by the author, on the basis of A. Maddison, *The World Economy: A Millennial Perspective*, Paris, Organisation for Economic Co-operation and Development (OECD), 2001.

Table A1.11
Cuba and United States: GDP benchmark, 1953

Country	Index of per capita GDP	Population *(Millions)*	Aggregate GDP ratio	GDP *(Billions of 1990 dollars)*
Cuba (1953)	27	6.13	0.0103	20.82
United States (1953)	100	160.18	1.000	2 014.91

Source: Prepared by the author, on the basis of M. Ward and J. Devereux, "The road not taken: pre-revolutionary Cuban living standards in comparative perspective", *The Journal of Economic History*, vol. 72, No. 1, Cambridge, Cambridge University Press, 2012; A. Maddison, *The World Economy: A Millennial Perspective*, Paris, Organisation for Economic Co-operation and Development (OECD), 2001.

Note: Cuba's relative per capita GDP is taken from Ward and Devereux (2012).

Table A1.12
Selected countries: World Bank International Comparison Programme GDP benchmarks, 1975

Country	GDP *(Millions of local currency units)*	Gini-Éltetö-Köves-Szulc (GEKS) PPP	GDP *(Billions of 1990 dollars)*
Iran	3 485 052	39.70	243.81
Mexico	1 007 036	7.53	370.40
Syria	20 617	1.243	47.30
Thailand	303 312	7.86	109.97
United Kingdom	115 176	0.406	738.21

Source: Prepared by the author, on the basis of A. Maddison, *The World Economy: A Millennial Perspective*, Paris, Organisation for Economic Co-operation and Development (OECD), 2001.

Note: Maddison (2001) adjusted the official national accounts estimates for Mexico downward by 12.2%, arguing that they overestimated the size of the informal sector, so we do the same in this benchmark. To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.13
Selected countries: World Bank International Comparison Programme GDP benchmarks, 1980

Country	GDP *(Millions of local currency units)*	Geary-Khamis PPP	GDP *(Billions of 1990 dollars)*
Argentina	3 840 000	26.04	237.51
Brazil	12 805 000	29.55	697.82
Chile*	1 132 432	26.67	59.34
Colombia	1 579 084	21.99	115.66
Hungary	720 956	14.78	78.43
India*	1 451 011	3.88	586.54
Indonesia	48 913 811	294	267.78
Ireland*	10 596	0.461	34.74
Mexico*	4 142 579	13.18	475.08
Norway*	318 279	6.16	78.56
Peru	5 920 159	137.0	74.19
Poland	2 482 452	17.42	232.47
Romania			126.82
United Kingdom*	259 962	0.487	806.79
United States	2 686 154	1.000	4 439.7
United States*	2 857 307	1.000	4 439.7
Uruguay	89 654	6.491	22.25
Venezuela (Bolivarian Republic of)	297 800	3.14	152.75
Yugoslavia	1 800 000	19.35	149.55

Source: Prepared by the author, on the basis of A. Maddison, *Monitoring the World Economy, 1820–1992*, Paris, Organisation for Economic Co-operation and Development (OECD), 1995.

Note: Data from Maddison (1995) with adjusted GDP estimates are used for the informal sector in Argentina, Brazil and Mexico. The estimate for Mexico relative to the United States is not used, as the 1975 benchmark is preferred (the two benchmarks diverge by only 4%). GDP levels for countries using old figures (not marked with *) are estimated relative first to the old national accounts figures for the United States and then to the figures for the United Kingdom using the United States to United Kingdom GDP ratio implied by the latest national accounts figures. To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.14
Selected countries: World Bank International Comparison Programme GDP benchmarks, 1985

Country	GDP *(Millions of local currency units)*	Geary-Khamis PPP	GDP *(Billions of 1990 dollars)*
Egypt	33 130	0.2828	156.22
Republic of Korea*	87 239 600	459.5	230.77
Pakistan*	472 157	3.761	152.60
Sri Lanka	157 763	5.288	39.78
United Kingdom*	414 329	0.568	886.66
United States	3 962 217	1.000	5 073.2
United States*	4 346 734	1.000	5 073.2

Source: Prepared by the author, on the basis of A. Maddison, *Chinese Economic Performance in the Long Run, 960–2030 AD, Second Edition, Revised and Updated*, Paris, Organisation for Economic Co-operation and Development (OECD), 2007; *Chinese Economic Performance in the Long Run*, Paris, Organisation for Economic Co-operation and Development (OECD), 1998.

Note: GDP levels for countries using old figures (not marked with *) are estimated relative first to the old national accounts figures for the United States and then to the figures for the United Kingdom using the United States to United Kingdom GDP ratio implied by the latest national accounts figures. To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.15
China and United States: GDP benchmark, 1986

Country	GDP *(Millions of local currency units)*	Geary-Khamis PPP	GDP *(Billions of 1990 dollars)*
China	1 156 140	0.7926	1 651.8
United States	4 590 155	1.000	5 197.9

Source: Prepared by the author, on the basis of A. Maddison, *Chinese Economic Performance in the Long Run, 960–2030 AD, Second Edition, Revised and Updated*, Paris, Organisation for Economic Co-operation and Development (OECD), 2007; *Chinese Economic Performance in the Long Run*, Paris, Organisation for Economic Co-operation and Development (OECD), 1998.

Note: GDP levels for countries using old figures (not marked with *) are estimated relative first to the old national accounts figures for the United States and then to the figures for the United Kingdom using the United States to United Kingdom GDP ratio implied by the latest national accounts figures. Nominal GDP for China is taken from Maddison's (2007) benchmark for China updated by the estimates from this study for United States GDP in 1929 international dollars and United States GDP in current local currency units from the World Bank World Development Indicators. The Geary-Khamis PPP converter is taken from Maddison (1998).

Table A1.16
Selected countries: World Bank International Comparison Programme GDP benchmarks, 1990

Country	GDP (Millions of local currency units)	Geary-Khamis PPP	GDP (Billions of 1990 dollars)
Australia	403 934	1.352	289.95
Austria	1 888 097	13.899	131.84
Belgium	6 898 418	38.362	174.52
Canada	692 997	1.274	527.91
Czechoslovakia	1 027 897	6.120	163.00
Denmark	855 557	8.700	95.44
Finland	541 121	6.219	84.44
France	6 910 809	6.450	1 039.8
Germany	2 851 678	2.052	1 348.7
Greece	15 517 392	129.55	116.25
Ireland	29 840	0.688	42.09
Italy	1 410 629 836	1 384.11	989.10
Japan	453 608 500	185.27	2 376.1
Netherlands (Kingdom of the)	572 258	2.084	266.50
New Zealand	76 167	1.5574	47.46
Portugal	11 222 139	91.737	118.72
Spain	54 544 966	105.71	500.77
Sweden	1 527 964	8.979	165.15
Switzerland	357 608	2.160	161.08
Union of Soviet Socialist Republics	644 200	0.520	2 076.5
United Kingdom	615 673	0.587	1 017.9
United States	5 979 589	1.000	5 803.2

Source: Prepared by the author, on the basis of A. Maddison, *The World Economy: A Millennial Perspective*, Paris, Organisation for Economic Co-operation and Development (OECD), 2001; *Monitoring the World Economy, 1820–1992*, Paris, Organisation for Economic Co-operation and Development (OECD), 1995.

Note: Updating the nominal GDP figures with the latest data often implies per capita GDP relative to the United States that is closer to Maddison (1995) than to Maddison (2001), whose figures are often higher. We conjecture that between 1995 and 2001, the United States national accounts were updated and incorporated methodological changes more quickly than other countries' and hence there is a slight upward bias in Maddison's (2001) 1990 benchmark for the relative GDP levels of the United States. To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.17
Selected countries: World Bank International Comparison Programme GDP benchmarks, 1996

Country	GDP (Millions of local currency units)	Geary-Khamis PPP	GDP (Billions of 1990 dollars)
Lebanon*	21 512 808	1 026	16.77
Syria	663 457	15.68	36.35
United Kingdom*	903 029	0.652	1 108.0
United States	7 544 268	1.000	6 638.23
United States*	8 100 201	1.000	6 638.23

Source: Prepared by the author, on the basis of official figures.

Note: GDP levels for countries using old figures (not marked with *) are estimated relative first to the old national accounts figures for the United States and then to the figures for the United Kingdom using the United States to United Kingdom GDP ratio implied by the newest national accounts figures. To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.18
Selected countries: World Bank International Comparison Programme GDP benchmarks, 2011

Country	GDP *(Millions of local currency units)*	Geary-Khamis PPP	GDP *(Billions of 1990 dollars)*
Japan	491 408.50	107.454	2 793.3
United Kingdom	1 635 060	0.698	1 430.5
United States	15 517 930	1.000	8.935.1
Venezuela (Bolivarian Republic of)	1 357 500	2.713	305.59

Source: Prepared by the author, on the basis of official figures.
Note: GDP levels for countries using old figures (not marked with *) are estimated relative first to the old national accounts figures for the United States and then to the figures for the United Kingdom using the United States to United Kingdom GDP ratio implied by the newest national accounts figures.To the extent possible, country and territory names reflect the designations used during the period of analysis.

Table A1.19
Selected countries: World Bank International Comparison Programme GDP benchmarks, 2017

Country	GDP *(Millions of local currency units)*	Gini-Éltetö-Köves-Szulc (GEKS) PPP	GDP *(Billions of 1990 dollars)*
Argentina	10 936 200	10.254	539.62
Australia	1 808 607	1.466	641.55
Austria	370 296	0.770	249.93
Bangladesh	6 528 900	37.94	369.49
Belgium	446 365	0.773	300.30
Brazil	6 536 000	2.185	1 569.1
Bulgaria	102 308	0.674	78.91
Canada	2 141 981	1.205	924.47
Chile	180 211 290	411.3	227.84
China	82 075 400	4.184	10 200.4
Colombia	920 194 000	1.315	363.91
Denmark	2 175 106	6.852	165.06
Egypt	4 127 100	3.267	656.93
Finland	225 785	0.863	135.96
France	2 295 063	0.766	1 557.0
Germany	3 244 990	0.741	2 278.4
Greece	180 218	0.576	162.67
Hungary	38 835 221	134.4	150.29
India	166 225 600	20.65	4 186.0
Indonesia	13 587 212.6	4.696	1 504.6
Iran (Islamic Republic of)	16 954 812	13.06	674.97
Iraq	206 530 100	560.76	191.50
Ireland	297 131	0.791	195.29
Italy	1 736 602	0.687	1 315.3
Mexico	21 911 894	8.871	1 284.3
Netherlands (Kingdom of the)	738 146	0.778	493.02
New Zealand	282 741	1.453	101.15
Norway	3 295 382	9.922	172.70
Pakistan	4 942 900	44.05	515.03
Peru	688 000	1.749	204.50
Poland	1 989 351	1.737	595.38
Republic of Korea	1 835 698 237	871.7	1 095.0
Romania	857 896	8.94	278.026
South Africa	4 715 200	6.427	381.50
Spain	1 161 878	0.630	958.78
Sri Lanka	13 317 300	49.39	140.18

Country	GDP *(Millions of local currency units)*	Gini-Éltetö-Köves-Szulc (GEKS) PPP	GDP *(Billions of 1990 dollars)*
Sweden	4 621 046	8.719	275.56
Switzerland	669 542	1.180	295.05
Taiwan Province of China	17 501 200	15.73	578.52
Thailand	15 452 000	12.845	625.52
Turkey	3 110 650	1.373	1 178.0
United Kingdom	2 071 667	0.682	1 579.1
United States	19 519 423	1.000	10 149.3
Uruguay	1 707 100	23.29	38.11
Former Union of Soviet Socialist Republics			2 960.68
Armenia	6 241 800	158.82	18.56
Azerbaijan	65 600	0.491	72.38
Belarus	105 500	0.602	90.27
Estonia	22 800	0.528	23.19
Georgia	45 200	0.810	26.36
Kazakhstan	50 044 800	118.12	233.21
Kyrgyzstan	700 800	18.313	16.28
Latvia	26 800	0.479	28.75
Lithuania	41 300	0.435	49.76
Moldova	220 800	5.827	16.69
Russian Federation	87 180 000	23.64	1 991.2
Tajikistan	61 200	2.359	14.25
Turkmenistan	132.7	1.623	42.53
Ukraine	2 983 900	5.905	262.27
Uzbekistan	302 536 800	1 432.9	109.77
Former Czechoslovakia			299.44
Czechia	5 047 267	12.38	212.03
Slovakia	84 517	0.503	87.41
Former Yugoslavia			204.62
Bosnia and Herzegovina	31 376	0.676	24.12
Croatia	366 426	3.327	57.26
Montenegro	4 299	0.351	6.38
North Macedonia	618 106	19.04	16.88
Serbia	4 754 369	40.80	60.60
Slovenia	42 987	0.568	39.38

Source: Prepared by the author, on the basis of official figures.