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REBASING 'MADDISON': NEW INCOME COMPARISONS AND THE SHAPE OF LONG-RUN ECONOMIC DEVELOPMENT

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Abstract

Economists' understanding of long-run economic development has greatly improved thanks to the historical statistics compiled by the late Angus Maddison. Yet his method for comparing income levels across countries and over time has come under increasing criticism. New estimates of comparative income level often show markedly different outcomes than Maddison's projection (or extrapolation) method based on a single, modern-day relative income benchmark. In this paper, we draw on modern and historical cross-country income comparisons and incorporate these into a novel measure of real GDP per capita over the very long run. The resulting new version of the Maddison Project Database thereby does greater justice to historical insights and provides a fresh impetus for future research. We present applications to estimating cross-country income convergence and the Balassa-Samuelson effect and demonstrate that how our new measure of real GDP per capita is a substantial improvement. (JEL: C43, C82, E01, N10, O47)

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1. Introduction

Angus Maddison has greatly contributed to economists' understanding of long-run economic development through his Historical Statistics of the World Economy.[2] By judiciously combining estimates of comparative levels of real GDP per capita in recent periods with long-term time series of growth of GDP per capita, his database provides the broadest coverage of comparative income data and is amongst the most widely used sources of economic data in the world. Especially for the period before 1950, this is the dominant database, providing systematic and broad cross-country information on comparative income levels.[3] Since his passing, the development of the Maddison Project Database (MPD) has moved to a new generation of scholars.[4] In this paper we introduce a new approach to the measurement of real GDP per capita over the very long and introduce a new version of the database.

Most importantly, we 'rebase' the MPD by incorporating a wealth of historical data on comparative living standards and economic activity, much of which builds on Maddison's pioneering work. The latest series developed by Maddison were based on a single modern-day cross-country comparison of relative income levels, for the year 1990, projected forwards and backwards using data on growth of GDP per capita. Yet extended back over many decades and even centuries, these projections diverged substantially from independent 'benchmark' comparisons of relative income or living standards for early periods.[5] This is consistent with a recent literature on how differences in real GDP per capita between benchmarks comparisons can diverge from GDP growth from national statistics over the same period.[6] Changing economic structures and measurement error and biases in cross-country price comparisons are important explanations for such differences. But especially over longer time scales, growth figures also turn unreliable, especially when covering periods of war, rapid inflation or weak-to-non-existent statistical systems. A consequence is that research results can be sensitive to the version of a database that is used in a study.[7] This has been one reason why versions 8 and 9 of the Penn World Table (PWT) introduced real GDP series that rely on multiple benchmark comparisons of prices and income; see Feenstra, Inklaar and Timmer (2015).

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[2] See Maddison (1995, 2001, 2007).
[3] Though Barro and Ursúa (2008) have gone to great lengths to better capture data on economic fluctuations for 42 countries since 1800.
[4] See Bolt and van Zanden (2014) for a first new version.
[5] Prominent examples are Prados de la Escosura (2000) and Lindert and Williamson (2016).
[6] See Deaton (2010), Deaton and Aten (2017) and Inklaar and Rao (2017).
[7] See Johnson, Larson, Papageorgiou and Subramanian (2013) and Ciccone and Jarociński (2010).

In this paper, we implement a multiple benchmark approach for the MPD based, primarily, on (i) post-1950 price benchmarks (as also used in PWT) and (ii) pre-1950 real GDP per capita benchmarks based on a variety of historical studies.[8,9] In our new dataset on historical benchmarks we incorporate relative income levels for 36 out of the 77 countries for which there are income estimates available prior to 1950. By integrating independent comparative income estimates for earlier periods, the measurement of long-term relative income developments is more closely related to research covering this historical period. An important benefit is that subsequent new, contemporaneous price and income comparisons – such as a new round of the International Comparison Program (ICP) – can be incorporated into the MPD without these new numbers rewriting history; only new historical research can rewrite (or affirm) current estimates. In addition, we incorporate recent estimates of historical national accounts for a range of countries to provide a new version of the MPD that is state-of-the-art and provides a more extensive picture of comparative income levels than had been available thus far, with coverage for over 160 countries and the period from Roman times to the present.

The rest of this paper is organized as follows. In Section 2, we provide a guided tour of the data in the MPD, highlighting the main variables, briefly discussing their construction and indicating areas of research where they can be helpful. As in newer versions of PWT, the MPD distinguishes between a series of real GDP that is useful for comparing income levels across countries and a series that is useful for comparing growth performance over time. We also use this section to emphasize that our measurement goal is GDP per capita, i.e. an economy's productive, income-generating capacity. While GDP per capita relates to the standard of living in a country or the broader wellbeing of its population, it is certainly not the same concept; this should be borne in mind throughout. Section 3 discusses in greater detail the methodology for comparing income levels, at a point in time, but especially over a (long) period of time. Section 4 discusses the implementation of the multiple-benchmark approach including a discussion of the different types of information that are developed and used in the different periods. This also includes a discussion of how our chosen approach compares to other methods, such as indirect benchmark estimates.[10] Section 5 discusses a number of applications, highlighting where the new database sheds new light on existing questions. We examine the shape of regional

[8] With Ward and Devereux (2016) as a major contributor.
[9] Given limited estimates available for Africa, we apply an indirect method for estimating comparative income levels based on real wage comparisons, similar to Allen (2001) or Lindert and Williamson (2016), for the year 1950. See Appendix D for more details.
[10] E.g. Prados de la Escosura (2000).

economic development, the estimation of cross-country income convergence, extending Barro (2015), the relationship between relative income and relative prices – the Balassa-Samuelson effect – in history and the gap between GDP per capita in the United Kingdom and the United States. We show that our new measure of real GDP per capita based on multiple cross-country income comparisons yields more reliable estimates of cross-country income convergence and more plausible estimates of the Balassa-Samuelson effect. In Section 6 we conclude by stressing that we use this paper and this new version of the MPD not to solidify a 'true' account of relative income levels in history, but rather to provide a state-of-the-art snapshot and a statistical platform. We see this as an opportunity to acknowledge and emphasize where our current information is strongest and most reliable and in which places there are important gaps in our knowledge. This paper is thus also an invitation to other scholars to extend our knowledge and to bridge those gaps by contributing to the MPD in the future.

2. User guide to the data

The main aim of the MPD is to provide data on GDP per capita for comparisons of relative income levels across countries. This is often called 'real GDP per capita' in the international comparisons literature, where 'real' refers to the series being based on a common set of prices across countries. In the original work by Maddison (1995, 2001, 2007), such data was compiled by starting from a modern-day cross-country income comparison – for the year 1990 – and then using growth rates of GDP per capita from (reconstructed historical) National Accounts to make comparisons for earlier years. An attractive feature of those data was that the change in real GDP per capita over time matches the growth rate from those National Accounts. However, this internal consistency came at the expense of distorted real GDP per capita comparisons in earlier years; see Section 3 on how, for instance, changing consumption patterns can lead to such distortions. Limitations to data quality also means that estimating the growth of GDP per capita over many decades, or even centuries, is a hazardous undertaking that, despite the best effort of statisticians and researchers, will always be surrounded by a degree of uncertainty. As a result, earlier estimates of relative income levels diverge substantially from standalone benchmark comparisons or independent estimates of relative income for those early periods (e.g. Ward and Devereux, 2018 and Prados de la Escosura, 2000).

In the new version of the MPD, we therefore introduce a new measure of real GDP per capita based on multiple benchmark comparisons of prices and incomes across countries. The resulting measure of real GDP per capita can best be understood as based on prices that are constant across countries but depend on the current year. In keeping with the terminology used

in the Penn World Table (Feenstra et al. 2015), we refer to this measure of real GDP per capita as $CGDPpc$. This variable is expressed in 2011 US dollars by correcting for inflation in the United States to provide magnitudes that are comparable over time, but it is a 'current' measure in the sense that the (implicit) relative prices used for the cross-country comparisons differ over time. As a result, the relative income levels from this exercise more closely reflect direct historical income comparisons. We rely on a number of different types of price or income benchmarks in the construction of the MPD, which will be discussed in more detail in Section 3. We provide labels for all income observations indicating the method used to obtain it.

In addition to the $CGDPpc$ series, we provide a measure of growth of GDP per capita that relies on a single cross-country price comparison, for 2011. This series is also expressed in 2011 US dollars (and $CGDPpc = RGDPNApc$ in 2011), but its defining feature is that it tracks the growth rate of GDP per capita as given in country National Accounts (or their historical reconstructions). Following PWT, we refer to this measure of real GDP per capita as $RGDPNApc$. This series is primarily useful for comparing growth rates of GDP per capita over time. To also allow for a comparison of total GDP, the MPD provides information on population, with variable POP. For the historical (pre-1950) period, data is sometimes available for only population or only for GDP per capita, due to differences in basic data availability.

In compiling this dataset, we set a number of priorities, in line with the earlier work of Maddison. First, the primary goal is to provide measures of GDP per capita, i.e. reflecting the productive capacity of economies. GDP per capita is a measure that easily diverges from more specific measures of comparative living standards of consumers or laborers,[11] or more comprehensive measures of welfare, that account for differences in health, leisure and inequality.[12] GDP per capita is typically highly correlated with such measures of wellbeing, but important differences can be seen. For example, in oil-rich countries in the Middle East (e.g. Qatar or United Arab Emirates), GDP per capita is considerably higher than household consumption per capita. An important benefit of GDP per capita is that it can be used not only as an (imperfect) indicator of wellbeing or living standards, but can also serve as the basis for productivity comparisons, which have the potential to shed more light on the (proximate)

[11] As in e.g. Allen (2001) and Lindert and Williamson (2016).
[12] See e.g. Jones and Klenow (2016) or Gallardo Albarran (2017).

sources of cross-country income differences, such as differences in physical and human capital and productivity.[13]

Another important choice is to maximize the coverage of countries and periods, to provide a broad view on economic development in history. This, again, mirrors the approach of Maddison, but comes at the cost of a sparser set of concepts covered. For example, PWT provides an expenditure-level breakdown of GDP, as well as measures of physical and human capital and productivity for the period since 1950 (Feenstra et al. 2015). In a more historical context, Barro and Ursúa (2008) provide data on consumption per capita, in addition to GDP per capita for a smaller set of countries. While cognizant of this trade-off, we hope that by providing the broadest possible canvas, the MPD can serve as basis for future research to extend it in other directions.

By presenting two alternative real GDP per capita series, the differences become readily apparent and these can be quite substantial. For a telling example, Switzerland's real GDP per capita in 1872 is either 67 percent of the US level (according to $CGDPpc$) or over 150 percent of the US level (according to $RGDPNApc$). Put differently, $CGDPpc$ is only 43 percent as large as $RGDPNApc$. This is the (perhaps unavoidable) result of having two independent measurements, one of the relative level ($CGDPpc$) and one of the growth rate (which implies $RGDPNApc$). Both series aim to capture different concepts, so for the question of the appropriate level, we would suggest that $CGDPpc$ is the most appropriate answer. However, $CGDPpc$ should not be used to compute growth rates over time since $RGDPNApc$ is the more appropriate measure when trying to understand relative growth rates. We discuss conceptual and practical reasons for divergences between these two series in Section 3.2, but this does not lead to a reconciliation of the two or an assessment whether measurement errors are larger in particular GDP growth series or in specific relative level comparisons.

These considerations call for a degree of modesty about the precision of any given real GDP per capita number; see also the discussion of Deaton and Heston (2010) on uncertainties surrounding relative price (and thus relative income) measurement. We therefore also provide a separate set of estimates that follows the basic Maddison approach, linking his 1990 benchmark with the estimates of the growth of GDP per capita according to the official national accounts and their predecessors in historical national accounting.

[13] See e.g. Caselli (2005) or Hsieh and Klenow (2010).

3. Measurement of real GDP per capita

3.1 Measurement at a point in time

In any model of the economy that features non-traded as well as traded products, we can only measure real GDP per capita by measuring and comparing price levels across countries. One could compare real expenditure on *traded* products, using exchange rates to express nominal expenditure in real terms, but only if one is willing to assume that the law-of-one-price (LOP) holds. However, that is a strong assumption, already in modern times (e.g. Burstein and Gopinath, 2014), but even more so in historical periods when barriers to trade and limited market integration held sway (e.g. Irwin, 2005; O'Rourke, 2007). For non-traded products, there is no mechanism that would push prices towards the LOP and it is amongst the stronger empirical regularities in international economics that prices of non-traded products are systematically lower in low-income economies. This is usually explained using the Balassa-Samuelson hypothesis (Samuelson, 1994), whereby productivity differences between countries are larger in traded goods than in non-traded goods. As a country develops and its productivity in the traded sector increases, wages increase across the economy, leading to higher prices of non-traded products. As a result, differences in income levels would be substantially overstated if the comparison would be based on exchange-rate converted expenditure.

So rather than relying on exchange rates, the objective should be to estimate real GDP per capita based on a comparison of prices of traded and non-traded products. Deaton and Heston (2010) provide an extensive overview of the conceptual (as well as practical) challenges in making such comparisons. From a conceptual perspective it might be a desirable goal to compare the cost of living, so that a real expenditure comparison can be interpreted as a comparison of utility across countries. However, in a world of non-homothetic and (quite possibly) non-identical preferences, a true cost-of-living comparison faces substantial conceptual and practical challenges, though see Neary (2004) for an approach of comparing cost-of-living assuming identical but non-homothetic preferences.

A more achievable goal is to compare a weighted average of relative prices across countries, drawing on index number theory. Let $\mathbf{p}_j$ be the vector of prices in country j and let $\mathbf{q}_j$ be the vector of products. Nominal GDP in country j is then $P_j Y_j = \mathbf{p}_j' \mathbf{q}_j$, the sum of spending on (domestic) products.[14] Given these vectors for two countries, we can implement the thought

[14] This implies that imported products enter in $\mathbf{q}_j$ with a negative sign.

experiment 'what would a person in country k have to spend to purchase the same bundle of products as a person in country j' to arrive at the Laspeyres price index. The Paasche price index is the outcome of the reverse though experiment, switching the bundle of products to that of country k:

$$P_{jk}^{L} = \frac{\mathbf{p}_k' \mathbf{q}_j}{\mathbf{p}_j' \mathbf{q}_j}, P_{jk}^{P} = \frac{\mathbf{p}_k' \mathbf{q}_k}{\mathbf{p}_j' \mathbf{q}_k} \quad (1)$$

Neither of the these thought experiments is inherently preferable as there is no reason why either bundle of products should hold a privileged position. Let, therefore, be the Fisher price index be:

$$P_{jk}^{F} = \left[\frac{\mathbf{p}_k' \mathbf{q}_j}{\mathbf{p}_j' \mathbf{q}_j} \times \frac{\mathbf{p}_k' \mathbf{q}_k}{\mathbf{p}_j' \mathbf{q}_k}\right]^{\frac{1}{2}} \quad (2)$$

The Fisher index has numerous desirable properties, amongst which is that if two countries are compared where the consumer's utility function has a homothetic, quadratic functional form, this index will exactly measure the ratio of utilities u_k/u_j (Diewert, 1976).

In a setting of many countries, a drawback of the Fisher index is that price comparisons are not transitive, i.e. the results depend on the base country, j here. As a result, comparing prices between j and k directly will yield a different outcome than via a third country h: $P_{jk}^{F} \neq P_{jh}^{F} \times P_{hk}^{F}$. To overcome this lack of transitivity we compare prices between j and k as the average across all possible indirect comparisons with country $h = 1, \ldots, \mathrm{C}$ to arrive at the so-called GEKS price index:[15]

$$P_{jk}^{GEKS} = \prod_{h=1}^{C} \left(P_{jh}^{F} P_{hk}^{F}\right)^{\frac{1}{C}} \quad (3)$$

The GEKS index is the most widely-used approach for comparing prices across countries, with it being the main method in the International Comparison Program (ICP) at the World Bank (2014) for computing global relative prices, or purchasing power parities (PPPs). An especially desirable property of the GEKS index is that it does not suffer from substitution bias, i.e. the GEKS index is based on the bundles of products $\mathbf{q}_j$ of all countries rather than relying on some average bundle. Maddison relied on Geary-Khamis (GK) PPPs for his international

[15] After Gini, Eltetö, Köves, and Szulc. A modern treatment and references are provided by Balk (2008).

comparisons and this index does suffer from substitutions bias. As illustrated by, for instance, Deaton and Heston (2010), this substitution bias causes the GK PPPs to understate prices in low-income countries, thereby overstating their real GDP per capita levels and thus understating the extent of cross-country income differences.

Given a relative price index as defined in equation (3), we can estimate real GDP as:

$$Y_k = \frac{P_k Y_k}{P_{jk}^{GEKS}} \quad (4)$$

which allows for comparing GDP or GDP per capita between countries j and k, evaluated at common prices.

3.2 Measuring real GDP per capita over time

The exposition so far has focused on price and comparisons across countries in a given year. Yet the main goals of the MPD is to provide data over time. The simplest approach is the so-called projection or extrapolation approach. In this approach real GDP per capita $y_{jt} \equiv Y_{jt}/N_{jt}$ (with N_{jt} as total population in country j at time t) is estimated as:

$$y_{jt-1} = \frac{y_{jt}}{1 + g_{jt}} (5)$$

where g_{jt} is the growth of GDP per capita in constant national prices. An important consequence of the approach in equation (5) is that the time series of growth in GDP per capita is the same in national prices and in PPP-converted US dollars. Furthermore, the change in the PPP implied by equation (5) is:

$$P_{jkt-1} = P_{jkt}^{GEKS} / \left[\frac{1 + \pi_{jt}}{1 + \pi_{kt}}\right], (6)$$

where $\pi_{jt} = P_{jt}/P_{jt-1} - 1$, the rate of inflation of the GDP deflator.

While straightforward, this extrapolation approach has important conceptual and practical drawbacks. The conceptual argument can be seen by considering the time-series counterpart to equation 2, so where the change in the GDP deflator (in country j) is computed between two time periods:

$$P_{jt,t-1}^{F} = \left[\frac{\mathbf{p}'_{jt}\mathbf{q}_{jt-1}}{\mathbf{p}'_{jt-1}\mathbf{q}_{jt-1}} \times \frac{\mathbf{p}'_{t}\mathbf{q}_{t}}{\mathbf{p}'_{t-1}\mathbf{q}_{t}}\right]^{\frac{1}{2}} \quad (7)$$

Equation (7) makes clear that a price index for national inflation should be computed using the bundle of products in the two periods for country j. Yet as equation (2) makes clear, a good measure of relative prices should take into account the bundle of products in country j *and* in country k. By ignoring country k's bundle in the computation of inflation in country j (and vice versa), the implicit relative price index in $t-1$ is no longer a good measure of relative prices between countries j and k. Especially if the periods under comparison are far apart, the extrapolation approach of equations (5) and (6) is likely to be a poor approximation as the bundle of products will have shifted substantially over time. This is one clear reason why subsequent benchmark estimates of relative prices are (typically) not consistent with relative inflation over the intervening period.

This conceptual problem is compounded by practical concerns. It has long been known that equation (6) does a poor job in predicting changes in PPPs over time,[16] but when the results of the ICP PPP comparison for 2011 were released (World Bank, 2014), the differences with the previous, ICP 2005, results were very large despite the serious global effort that went into both sets of PPPs. As detailed in Deaton and Aten (2017) and Inklaar and Rao (2017), part of the inconsistency was due to biases introduced in the measurement of ICP 2005 PPPs, but even after correcting for theses biases the differences remained substantial. Furthermore, shifts in the bundles of products cannot fully account for these differences, leaving 'measurement error' of some sort as the main (though not very informative) explanation.

This view matches that of Maddison, who argued that the difference between observed PPPs in successive ICP rounds and extrapolations based on relative inflation was more likely due to errors in the ICP estimates than errors in the national growth measures. Reconciling different benchmarks with the time series was in his eyes not the preferred method for long-term comparisons. The basis for this argument was a study by Kravis and Lipsey (1991), who also suggested that estimates of growth rates should be taken from the national accounts, whereas estimates of real GDP per capita should be done by benchmark studies (Maddison, 1995, p. 164).

Yet the approach of Maddison has notable limitations. For one, if any given benchmark comparison of prices and income is imperfect and perturbed by measurement error, relying fully on a single benchmark comparison would mean that the same error would affect real GDP per

[16] See Deaton and Heston (2010) for notable contributions to this discussion.

capita estimates through the decades or centuries. Second, while time series of GDP per capita growth (i.e. g_{jt}) may be considered reliable in modern times for many countries, periods like the World Wars, or periods of economic instability such as in much of Latin America in the 1980s diminish the reliability of statistics. The situation is more problematic in countries with poorly developed statistical systems, such as in many African countries, which can lead to unreliable growth figures.[17]

This was illustrated by Prados de la Escosura (2000), who argued that PPPs based on extrapolations as in equation (6) led to implausible results. His solution was to rely on the regularity of the price-income relationship to estimate what relative prices (and, as result, income levels) would have been if we had been able to observe them historically, see also Klasing and Milionis (2014). Relying heavily on such estimates is less appealing to us, most importantly because there are still important aspects of the price-income relationship that are not fully understood. For example, Hassan (2016) argues that the price-income relationship is non-linear and negative, rather than positive at the lower income levels and Zhang (2017) argues that mismeasured differences in product quality bias the price-income relationship. That said, comparing price levels rather than only income levels can serve as a useful check on relative income estimates derived according to a given methodology, see e.g. Section 5.3 on the Balassa-Samuelson effect in the MPD. For the MPD more broadly, we implement a multiple-benchmark approach as detailed in the following section, which is, we argue, the best approximation of relative levels of GDP per capita over time.

4. Implementation

4.1 The MPD measurement approach

In the new version of MPD, we implement a multiple benchmark approach based on post-1950 ICP benchmarks and historical benchmarks, i.e. independent real GDP per capita benchmarks from historical studies.[18] In keeping with Maddison (2007), we also include several estimates stretching back even further, but which should be seen as estimates of income relative to a bare-bones subsistence level rather than explicitly comparing GDP per capita between countries.

[17] See e.g. Henderson, Storeygard and Weil (2012), Young (2012) and Jerven (2013).

[18] Additionally, we use estimates of PPPs for 1960 from the study of Braithwaite (1968) and for a range of African countries, we make an indirect income comparison based on real wages and urbanization data, see Appendix D. There are a few countries that have never participated in an ICP comparison; most importantly Afghanistan and North Korea. For those countries we use the (econometrically) estimated real GDP per capita level from World Bank (2014). Cuba also requires also requires special consideration, see Appendix C for details.

Using the methodology developed for PWT (Feenstra et al. 2015), we subsequently tie the long-term income series from the MPD (2013) to the relative income levels, thereby taking into account relative price changes between the different benchmark years. This means the MPD estimates for a particular country and year can be based on direct benchmark estimates, interpolation between benchmarks or extrapolation from the first or last benchmark, following equation (5). To enable users to distinguish between these different types of observations, we introduce clear labeling in the MPD. Furthermore, given the differences in the types of benchmark, we also label which type of benchmark is used to derive a certain estimate.

As discussed in the previous section, problematic estimates in benchmarks or time series can have substantial consequences over longer periods of time. Given our stated goal of more closely aligning to our understanding of living standards in history, this requires a degree of judgement when implementing our multiple benchmark approach. In particular, it can be the case that a) benchmark relative price estimates diverge substantially from what might be expected from an estimated price-income relationship using all ICP benchmark PPPs observations; b) income levels can drop below subsistence for sustained periods of time; or c) income levels can remain high, in direct contradiction to the historical record. These observations result in a list of judgmental adjustments, by, for instance, excluding specific ICP PPP benchmarks or cutting short time series; see Appendix B for details. Category c observations consist of oil-rich economies whose current high income levels can be understood from large oil earnings, but where high income levels prior to major oil development or prior to high oil prices would run counter to the historical understanding of those countries; see Appendix E.

4.2 Historical benchmarks

Starting with the pioneering work by Rostas (1948) economists and economic historians have produced benchmarks of the relative income or output levels of economies (or parts of them, such as the manufacturing sector), including the construction of relevant PPPs to make real comparisons. Various methods have been used, making use of the output/value added approach, the income approach, and the expenditure approach. Usually, these studies compare the leading economy (US, UK) with one or more other economies (Germany, France, or Japan) (Broadberry 1998; Fukao et al. 2007). We collected the available historical economy-wide benchmarks and used them to re-anchor the historical time series following the PWT methodology described in the previous section; see Appendix A for a an overview of historical benchmarks and studies that we rely upon. As there are currently close to no historical benchmarks available for African

countries, we have created additional benchmarks for the year 1950 for African countries, making use of an indirect approach using wages and urbanization rates (see Appendix D).

In addition to the historical benchmarks, we follow Maddison's approach to also include estimates of comparative income levels for some of the very earliest (pre-1500) years. As data for these early economies is increasingly scattered and it is often impossible to estimate historical trends, economic historians (Pamuk and Schatzmiller 2014, Scheidel and Friesen 2009; Milanovic 2006) used a variety of information to assess to what extent those societies had income levels notably above the level of subsistence, i.e. was there sufficient surplus beyond subsistence for development. In particular estimates of real wages were used for this purpose. We update that approach by updating the subsistence line to $700 (2011 US dollars), in line with the $1.90/day global poverty line used by the World Bank (Ferreira et al. 2015).[19]

4.3 Updating historical series

This new version of the MPD includes all new historical estimates of GDP per capita over time that have become available since the previous update (Bolt and Van Zanden, 2014). Such updates are necessary as new work on historical national accounts appears regularly and is important as it provides us new insights in long term global development. This also allows more recent years, up to 2016, to be covered in the database.

For the recent period the most important new work is Harry Wu's reconstruction of Chinese economic growth since 1950, a project inspired by Maddison which produces state of the art estimates of GDP and its components for this important economy (Wu 2014). Given the large role China plays in any reconstruction of global inequality, this is a major addition to the dataset. Moreover, as we will see below, the new results show that the revised estimates of annual growth are in general lower than the official estimates. Lower growth between 1952 and the present however substantially increases the estimates of the absolute level of Chinese GDP in the 1950s (given the fact that the absolute level if determined by a benchmark in 1990 or 2011). This helps to solve a problem that was encountered when switching from the 1990 to the 2011 benchmark, namely that when using the official growth estimates the estimated levels of GDP per capita in the early 1950s are substantially below subsistence back until 1890, and therefore too low. This possible inconsistency in the dataset is therefore 'solved' by making use of the

[19] An income of $1.90 per person per day implies an annual per capita income of $693.50. To emphasize that these income estimates are a multiple of subsistence, rather than in observed monetary units, we round the subsistence level up by 1% to $700.

new, much improved set of estimates by Wu (2014). Most of the other additions to the Maddison project dataset relate to the period before 1914, as can be seen from Table 1.

As is clear from this overview, in particular work on the early modern period (1500-1800) is producing more new time series over per capita GDP, often however making use of indirect methods to estimate its long term development. The 'model' for making such estimates based on the links between real wages, the demand for foodstuffs and agricultural output, which has been developed by Malanima (2010), Alvarez-Nogal and Prados de la Escosura (2013) and others, has now also been applied to Poland (Malinowski and Van Zanden 2016), Spanish America (Arroyo-Abad and Van Zanden 2015), and France (Ridolfi 2016).

Table 1. New Additions to the Maddison Project Database

Country	**Period**	**Source**
Latin America		
Bolivia	1846–1950	Herranz-Loncán and Peres-Cajías (2016).
Brazil	1850–1899	Barro and Ursúa (2008).
Chile	1810–2004	Díaz Lüders and Wagner (2007)
Cuba	1902–1958	Ward and Devereux (2012).
Cuba	1960–1895	Santamaria Garcia (2005).
Mexico	1550–1812	Arroyo Abad and Van Zanden (2016).
Mexico	1812–1870	Prados de la Escosura (2009).
Mexico	1870–1895	Bertola and Ocampo (2012).
Mexico	1895–2003	Barro and Ursúa (2008).
Panama	1906–1945	De Corso and Kalmanovitz (2016).
Peru	1600–1812	Arroyo Abad, and van Zanden (2016).
Peru	1812–1870	Seminario (2015).
Uruguay	1870–2014	Bertola (2016).
Venezuela	1830–2012	De Corso (2013).
Europe		
England	1252–1870	Broadberry, Campbell, Klein, Overton and van Leeuwen (2015)
Finland	1600–1860	Eloranta, Voutilainen and Nummela (2016).
France	1250–1800	Ridolfi (2016)
Holland	1348–1807	Van Zanden and van Leeuwen (2012)
Norway	1820–1930	Grytten (2015).
Poland	1409–1913	Malinowski and Van Zanden (2017)
Portugal	1530–1850	Palma and Reis (2016).
Romania	1862–1995	Axenciuc (2012).
Spain	1850–2016	Prados de la Escosura (2017).
Sweden	1300–1560	Krantz (2017).
Sweden	1560–1950	Schön and Krantz (2015).

UK	1700–1870	Broadberry, Campbell, Klein, Overton and van Leeuwen (2015)
Asia		
China	1952–2008	Wu (2014).
China	1661–1933	Xu, Shi, van Leeuwen, Ni, Zhang, and Ma (2016).
India	1600–1870	Broadberry, Custodis and Gupta (2015).
Turkey		Pamuk (2009).
Singapore	1900–1959	Barro and Ursúa (2008).
Middle East		
Syria	1820, 1870, 1913, 1950	Pamuk (2006).
Lebanon		
Jordan		
Egypt		
Saudi Arabia		
Iraq		
Iran		
Africa		
Cape Colony/ South Africa	1700–1900	Fourie and Van Zanden (2013).

Finally, we have extended the national income estimates for all countries in the database to include the most recent years, up until 2016, using various sources. The Total Economy Database (TED) was used to extend the GDP per capita up to 2016 for all countries included in TED, similar to what has been done for the latest update of the Maddison Project database (Bolt and van Zanden, 2014). For those countries not present in TED, we have used national accounts estimates from the UN to extend the GDP per capita series. We have also used the TED and the US Census Bureau's International Data Base to extend the population estimates up until 2016.[20] Recently, the TED revised their China estimates from 1950 onwards based on Wu (2014). As discussed above, we also included Wu's (2014) new estimates in this update. Lastly, we have extended the series for the former Czechoslovakia, the former Soviet Union and former Yugoslavia, based on GDP and population data for their successor states.

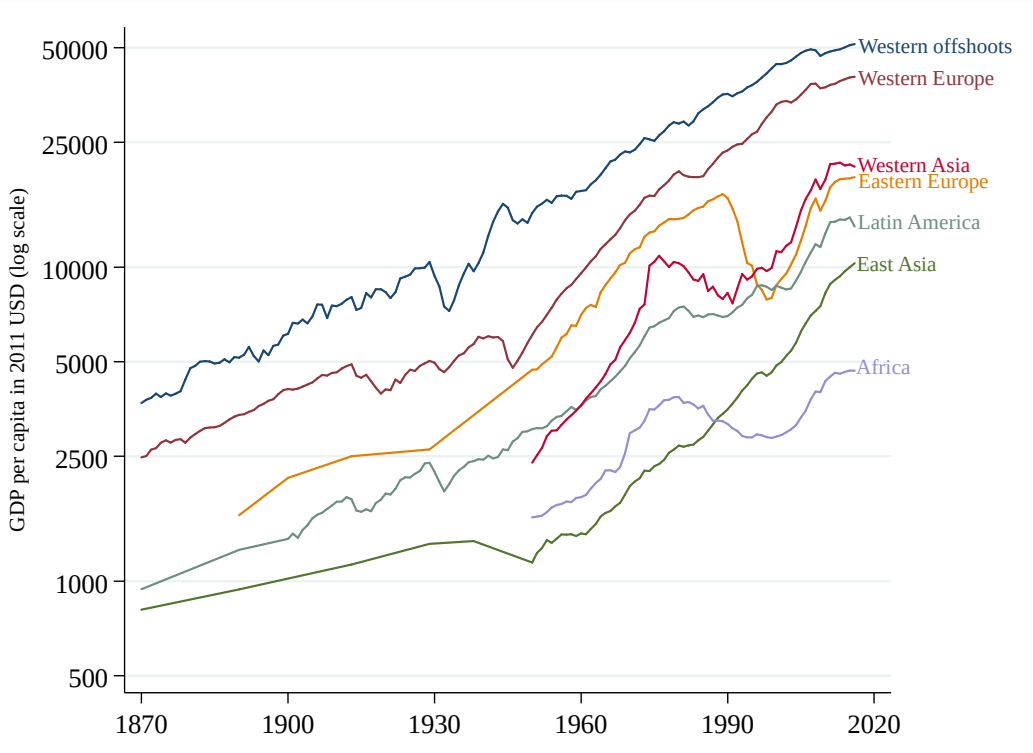
[20] As Palestine is not included in these sources, we used data from the World Development Indicators.

5. Applications

5.1 Shape of world income differences: regional perspective

Combining the multiple (historical) benchmarks with the long term series of per capita income from the Maddison Project database changes the pattern of long term income development compared to the original income series. In this section we discuss the major changes between the original series and the updated series presented in the paper on a regional level. It is important to realize though, that sometimes the effect is not only driven by switching from the 1990 benchmark of Maddison to a new set of relative prices but could also be the result of updates of the underlying national account statistics.[21]

Figure 1. Average real GDP per capita across regions, 1870–2015



Notes: Figure shows $CGDPpc$ by region, using population to compute a regional GDP per capita level.

Figure 1 illustrates the long-run improvement of real GDP per capita, following the regional organization of Maddison, with the United States as part of 'Western Offshoots'. The figure illustrates a Great Divergence period, with especially East Asian income levels barely

[21] Note that for the period after 1950, we rely, as far as possible, on official statistics for GDP at current and constant prices, population and relative prices from ICP comparisons or regional comparisons, such as done by Eurostat. We take these at face value, even in cases where there may doubts about the quality or veracity of the statistics (for example, Argentina, see Cavallo, 2013). The only exception is China, see Section 5.4.

improving relative to the richest regions until 1950. The figure also illustrates that patterns of rapid improvement alternate with period of relative decline, as in Western Asia in the 1980s, Eastern Europe in the 1990s and Africa in both the 1980s and 1990s.

Table 2. Real GDP per capita by region and major countries for new and previous methodology, in 2011 US dollars

	1870		1910		1950		2011	
	MPD	Extrapolation	MPD	Extrapolation	MPD	Extrapolation	MPD	Extrapolation
Western Offshoots	3692	3758	7518	7627	14867	14913	48569	48569
United States	3736	3736	7586	7586	15241	15241	49675	49675
Western Europe	2480	3643	4624	5812	6078	8163	38046	38046
United Kingdom	3846	5716	5917	7567	9441	10846	34971	34971
France	2383	3086	4551	4878	6869	8531	36691	36691
Germany	2362	3715	5386	6763	5536	7840	43189	43189
Western Asia					2386	4296	21298	21298
Saudi Arabia	795	2495			4272	10703	48470	48470
Iraq	917	4197			2820	9542	11484	11484
Eastern Europe					4716	5414	17939	17939
Poland	1267	1921	2169	3287	3141	4760	21837	21837
Latin America	943	1423	1792	2358	3048	4222	13899	13899
Brazil	751	1405	686	1283	1549	2898	14831	14831
Argentina	2514	2578	6547	6713	8542	8759	20003	20003
Mexico	789	1246	1690	2667	2648	4179	15210	15210
East Asia	811	808			1147	1005	8829	8829
China	751	754			757	637	10221	10221
India	878	710	1371	927	1417	824	4768	4768
Japan	985	1160	1741	2052	2519	3023	34979	34979
Africa					1596	1775	4487	4487
Egypt	1146	1999			1983	3219	10737	10737
Nigeria					1503	1961	5136	5136
South Africa	1681	1916	2397	2731	5278	6015	11838	11838

Note: 'MPD' is based on the real GDP per capita figures based on the variable $CGDPpc$, column 'Extrapolation' is based on the figures for $RGDPNApc$, which are computed following the methodology as originally employed by Maddison for estimating real GDP per capita over time.

Table 2 contrasts the real GDP per capita figures based on $CGDPpc$ with those based on $RGDPNApc$, i.e. MPD vs. extrapolations. For the two poorest regions in the dataset, Africa and East Asia, the pattern of long term development does not change drastically. For Africa, the average level of GDP per capita in 1950 is a bit lower in the new database compared to the original income estimates, while for East Asia it is roughly the same in both databases. However, for individual countries, the change in early income estimates are sometimes quite

substantial. For Africa as a whole, the main difference between the two series is the more severe drop in incomes during the so called 'lost decades' of the 1980s and 1990s.

Using multiple benchmarks result in substantially lower relative income levels for Latin America, most notably for the mid-20th century, where relative average income drops to 23 percent of the US level, down from 32 percent based on the extrapolation method. The new methodology also clearly affects the pattern of average income development in Western Asia and Eastern Europe, again particularly after 1910. Incomes for Eastern Europe are now higher until the mid-1980s, with income levels on par with Western Europe around 1960 (which is also partly due to lower incomes in Western Europe, see below). In Western Asia the effects of using more relative income estimates translates mainly in much lower incomes up until the mid-1990s after which increasing oil prices result in enormous increases in average incomes.[22]

Western Europe is the region for which most relative income estimates are available. Incorporating this the new information results in substantially lower income estimates for the region compared to US incomes. The extrapolated method of Maddison indicates that the US and Western Europe were about on par around 1870, after which the US forged ahead of Europe until the end of WW2. Thereafter Europe's economies expanded rapidly, until average incomes reached around 73 percent of the US level during the 1970s. After this, relative incomes remained fairly stable until the present. As a result of integrating the historical benchmarks, Europe seems behind the US already substantially in the 1870. Growth rates of both the US and Europe's economies are then very similar until roughly the Great Depression. Then incomes initially diverge somewhat until the end of World War 2, but Europe's incomes grow faster after 1950s to roughly 77 percent of the level of US incomes in 2011.

In Table 3, we compare real GDP per capita relative to the United States based on the MPD ($CGDPpc$), on extrapolation ($RGDPNApc$) and on Maddison's 1990 benchmark combined with the most recent time series of GDP per capita growth. Especially in the early two benchmark years, 1870 and 1910, the Maddison estimates are typically in between the MPD and extrapolation estimates. In several cases, the MPD estimate is also closer to Maddison than to the extrapolation; for example for Western Europe or Latin America in 1910. This could reflect that the 2011 ICP benchmark (from which the extrapolated series start) is a further two decades removed from those older periods, but also that Maddison had made judicious choices in his

[22] For a detailed discussion on income estimates for oil-rich countries, see Appendix E.

benchmarks and time series. In either event, using the multiple-benchmark approach of the MPD prevents the real GDP per capita estimates from drifting further from conventional historical views in a way that relying on the ICP 2011 income estimates would not have.

Table 3. Comparing real GDP per capita: MPD 2017 versus Maddison (US=1)

	1870			1910		
	MPD	Extrapolation	Maddison	MPD	Extrapolation	Maddison
Western Offshoots	0.99	1.01	0.99	0.99	1.01	1.00
United States	1.00	1.00	1.00	1.00	1.00	1.00
Western Europe	0.66	0.98	0.88	0.61	0.77	0.68
Western Asia						
Eastern Europe						
Latin America	0.25	0.38	0.33	0.24	0.31	0.27
East Asia	0.22	0.22	0.25			
Africa						
	1950			2011		
	MPD	Extrapolation	Maddison	MPD	Extrapolation	Maddison
Western Offshoots	0.98	0.98	0.97	0.98	0.98	0.97
United States	1.00	1.00	1.00	1.00	1.00	1.00
Western Europe	0.40	0.54	0.48	0.77	0.77	0.67
Western Asia	0.16	0.28	0.17	0.43	0.43	0.23
Eastern Europe	0.31	0.36	0.27	0.36	0.36	0.27
Latin America	0.20	0.28	0.24	0.28	0.28	0.24
East Asia	0.08	0.07	0.07	0.18	0.18	0.20
Africa	0.10	0.12	0.10	0.09	0.09	0.06

Notes: Table shows real GDP per capita relative to the United States in every year. MPD is based on $CGDPpc$, extrapolation is based on $RGDPNApc$ and Maddison is based the Maddison 1990 benchmark and current time series, made available in a separate data file.

5.2 Convergence analysis

The long time span of the MPD lends itself well to analyzing convergence dynamics; the question whether countries with low income levels subsequently tend to show faster economic growth. Such a relationship is expected based on many growth models and, empirically, there is much support for such a relationship. As discussed and shown in Barro (2015), it seems reasonable to conclude that income levels converge at rate of approximately 2 percent per year, conditional on (fixed) country characteristics. Yet to condition on country characteristics using country fixed effects, it is very important to have time series spanning 140 years or more. As

Barro (2015) argues, Hurwicz-Nickell bias[23] is sizeable in datasets of only 50 years, with a downward bias to the convergence coefficient of 0.056 and econometric approaches to correcting for this bias are found wanting. Once the length of the time series exceeds 140 years, the bias drops below 0.018, down to 0.010 for 200 years.

The results of Barro (2015) can be usefully re-examined using our new version of the MPD. Most importantly, the new version of the database allows us to combine the preferred measure of growth in real GDP per capita, based on $RGDPNApc$, with the preferred measure of the level of real GDP per capita across countries, $CGDPpc$. We would not expect different outcomes regarding the rate of convergence, but we rather view the results in terms of measurement error in the independent variable: an improved measure of the level of real GDP per capita ($CGDPpc$ rather than $RGDPNApc$) should lead to a more accurate estimate of the rate of convergence. This is helpful in itself, but also for tests of Schumpeterian growth theory, where typically the interaction between a country's distance to the (productivity) frontier and a variable of interest plays a central role; see Aghion, Akcigit and Howitt (2014) for a survey and Madsen (2014) for an example in a long-term perspective. More reliable measures of the relative position of countries – i.e. smaller measurement error – will make it easier to establish the information content of such models.

Another reason to revisit the analysis of Barro (2015) is that we have a more extensive dataset. Barro (2015) used the dataset of Barro and Ursúa (2008), which covers 28 countries with annual data since 1896. As discussed in Section 4.3, the new MPD, incorporates data of Barro and Ursúa (2008) for some countries as well as new source material developed by economic historians for numerous other countries. This allows us to extend the start of the analysis period to 1820 and broaden the range of countries to 38, including data for countries such as Indonesia, India and South Africa – each important for establishing the breadth of a finding of cross-country income convergence.

We follow Barro (2015) and estimate the following model:

$$\hat{Y}_{i,t}^{5} = \alpha_i + \alpha_t + \beta \log Y_{i,t-5} + \gamma_k X_{k,i,t} + \epsilon_{i\,t} \quad (7)$$

[23] This bias stems from including lagged dependent variable alongside fixed effects and forces down the coefficient on the lagged dependent variable. Since countries with lower income levels are expected to grow faster, the estimated coefficient is more negative than it should be.

The dependent variable is average annual growth of real GDP per capita over a five-year period, $\hat{Y}_{i,t}^{5} = \left(\frac{RGDPNApc_{i,t}}{RGDPNApc_{i,t-5}}\right)^{\frac{1}{5}} - 1$, the equation includes country and year fixed effects and in our preferred estimation $Y_{i,t-5} = CGDPpc_{i,t-5}$ though we also estimate equation (7) with $Y_{i,t-5} = RGDPNApc_{i,t-5}$ to compare to earlier studies. Additional control variables X_k are also considered, though the scope is limited by the long time span required. The equation is estimated using data for non-overlapping periods, so 1820–1825, 1825–1830, …, 2010–2015.

Table 4. Income convergence in MPD – *RGDPNApc* and *CGDPpc*

	(1)	(2)	(3)	(4)	(5)	(6)
GDP/capita measure	*RGDPNApc*	*RGDPNApc*	*CGDPpc*	*CGDPpc*	*CGDPpc*	*CGDPpc*
log(lagged GDP/capita)	-0.0259***	-0.0203***	-0.0245***	-0.0223***	-0.0207***	-0.0257***
	(0.00404)	(0.00536)	(0.00311)	(0.00443)	(0.00653)	(0.00750)
Male years of schooling		-0.000130		0.000162		0.000213
		(0.00317)		(0.00286)		(0.00283)
Female years of schooling		-0.00103		-0.00116		-0.00121
		(0.00361)		(0.00319)		(0.00315)
Democracy		-0.0168		-0.00997		-0.00933
		(0.0363)		(0.0359)		(0.0355)
Democracy-squared		0.0219		0.0174		0.0169
		(0.0320)		(0.0318)		(0.0316)
log(lagged GDP/capita), *RGDPNApc*					-0.00472	0.00404
					(0.00864)	(0.00953)
Observations	1217	912	1208	911	1208	911
Period	1820+	1870+	1820+	1870+	1820+	1870+

Notes: The dependent variable in all regressions is average annual growth in real GDP per capita, measured by $RGDPNApc$ for the 37 countries with annual data starting no later than 1890. The measure used for lagged GDP/capita differs across columns. Robust standard errors, clustered by country, are in parentheses. All regressions include country and time fixed effects. All independent variables are measured in the starting year of each five-year period, so 1820, 1825, etc.

Sources: MPD (2017), supplemented by the Polity IV dataset (www.systemicpeace.org) for democracy and Lee and Lee (2016) for years of schooling, both available since 1870. The democracy measure is computed as the Polity's democracy score minus its autocracy score, transformed from a -10 to +10 scale to a 0–1 scale, as in Barro (2015).

Table 4 shows the estimation results of equation (7) in various forms. Columns (1) and (2) use $RGDPNApc$ to measure the level of GDP per capita and are thereby closest to the results presented in Barro (2015, Table 5). The estimation differs only in the larger country coverage (37 versus 28) and the longer time period in column (1). The results are very similar to those of

Barro (2015), with an estimated convergence rate of close to 2 percent per year. The addition of control variables, in the form of measures of schooling and democracy, does not substantially affect the results, though the estimated convergence rate is somewhat reduced.

Columns (3) and (4) show our preferred approach and replace $RGDPNApc$ by $CGDPpc$ to measure the level of GDP per capita, while the growth rate is still computed using $RGDPNApc$. The estimated convergence rate is quite similar to those in columns (1) and (2), but a notable result is that the standard error on the coefficient of log(lagged GDP per capita) is 15–20 percent lower. In columns (5) and (6), we include both measures of the level of GDP per capita at the same time. The two measures are highly correlated (0.97) but in those columns, too, we find that it is log($CGDPpc$) which remains significant. We take this as further evidence that our newly introduced measure $CGDPpc$ is a more reliable measure of cross-country income differences, conditional on the belief that there is a process of conditional income convergence.

5.3 The Balassa-Samuelson effect

The Balassa-Samuelson (or Penn) effect states that the price level in a country tends to increase as it becomes richer and this effect has been a robust feature in the ICP PPP data since that program's inception.[24] Prados de la Escosura (2000) used the Balassa-Samuelson (BS) effect to propose alternative historical income estimates, after showing that the extrapolated data of Maddison implied price levels that differed substantially from what the BS-effect would predict. In this application, we estimate the BS-effect in three settings, namely based on the ICP PPP data from 1970 onwards (as in Feenstra et al., 2015), based on the historical income benchmarks ($CGDPpc$) and based on the extrapolated income series ($RGDPNApc$). In order to estimate these last two BS-effects, we need information about relative price levels alongside the relative income estimates. These are either drawn directly from the benchmark comparisons or computed based on data on nominal GDP per capita, i.e. GDP converted to US dollars using the nominal exchange rate rather than a PPP.[25] We then estimate the following relationship:

$$\ln\left(\frac{PPP_{i,t}}{XR_{i,t}}\right) = \beta_0 + \beta_1 \ln\left(\frac{NGDPpc_{i,t}}{NGDPpc_{USA,t}}\right) + \epsilon_{i\,t} \quad (8)$$

[24] See e.g. Barro (1991), Samuelson (1994), Rogoff (1996) and Feenstra et al. (2015).
[25] We thank Giovanni Federico for providing his most recent work in compiling nominal GDP data.

Where XR_{it} is the nominal exchange rate and $NGDP_{it}$ is nominal GDP, for country i at time t.[26] Over the full range of relative income levels, Hassan (2016) has shown that a linear relationship is not appropriate and he argues that a quadratic relationship is not only empirically superior but also expected based on a model of structural transformation. However, over the range of relative income levels spanned by the historical income benchmark data, a linear approximation leads to very similar results as a quadratic model in the case of the ICP PPP data and if a quadratic model is used to model the historical data this results in a concave, rather than Hasson's (2016) convex quadratic relationship. For these reasons, we rely on the simple linear model of equation (8).

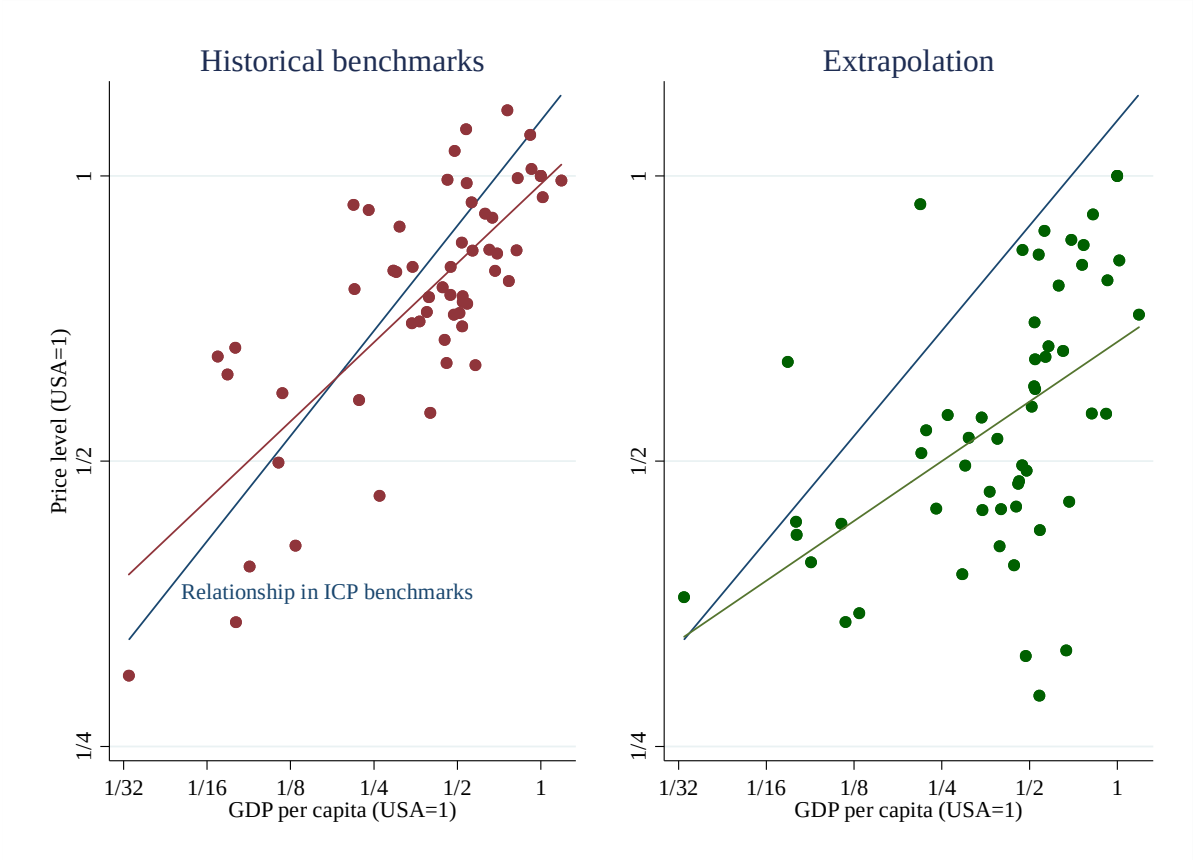
Figure 2 shows the results of the analysis. Of the 68 historical benchmarks (i.e. pre-1950 benchmarks) included in the MPD, we have nominal GDP per capita data for 57 so the two panels of the figure show 57 country observations of relative prices and (nominal) relative income levels. In the left-hand panel, we show price-income relationship using the relative prices implied by the historical benchmarks (i.e. by $CGDPpc$) while the right-hand panel shows the relationship based on extrapolated real GDP series (i.e. by $RGDPNApc$). Also shown in both panels is the price-income relationship based on ICP PPP data, estimated over the same income interval as the 57 observations.

Figure 2 shows that relative prices based on extrapolation ($RGDPNApc$) tend to be systematically lower than based on historical benchmarks ($CGDPpc$), echoing a similar observation for a more limited sample in Prados de la Escosura (2000). This is most striking in the case of the three historical benchmarks for Switzerland (1872, 1910 and 1929). The country's (nominal) relative income level was between 49 and 67 percent of the US level, while the extrapolation-based relative prices were between 28 and 31 percent. In ICP 2011, such low relative prices were seen in countries such as Bangladesh or Yemen, with nominal income levels of less than 5 percent of the US level. In comparison, the relative prices for Switzerland based on the historical benchmarks were between 71 and 98 percent of the US. While Switzerland is an extreme example, there are other countries, such as the UK, Netherlands and

[26] Equation 8 can also be estimated using real GDP per capita, but the advantage of this specification is that the choice of (implied) PPP only affects the dependent variable and not the independent variable. We also express the relationship in terms of income levels *relative* to the United States, in parallel with expression of the price level relative to the United States, to enable estimation of β_1 based on data for multiple years.

France, for which extrapolated relative price levels (of between 45 and 65 percent of the US level) are considerably lower than might be expected based on income levels.

Figure 2. The relationship between relative prices and relative income levels



Notes: Both panels show 57 country-year observations for which historical benchmark information is available and the relative price level and relative level of nominal GDP per capita can be computed. The panel 'Historical benchmarks' computes relative prices using nominal GDP per capita and $CGDPpc$, the panel 'Extrapolation' uses nominal GDP per capita and $RGDPNApc$. The blue line in both panels is the regression line estimated using ICP PPP benchmarks in the same income range as both panels: $\ln\left(\frac{PPP_{it}}{XR_{it}}\right) = 0.194 + 0.369 \ln\left(\frac{NGDPpc_{it}}{NGDPpc_{USA\,t}}\right)$. The robust standard error of the slope coefficient is 0.0083. The red line in the 'Historical benchmarks' panel shows the regression line based on the observations in that panel: $\ln\left(\frac{PPP_{it}}{XR_{it}}\right) = -0.029 + 0.277 \ln\left(\frac{NGDPpc_{it}}{NGDPpc_{USA\,t}}\right)$, with slope coefficient robust standard error 0.040. The green line in the 'Extrapolation' panel shows the regression line based on the observations in that panel: $\ln\left(\frac{PPP_{it}}{XR_{it}}\right) = -0.582 + 0.209 \ln\left(\frac{NGDPpc_{it}}{NGDPpc_{USA\,t}}\right)$, with slope coefficient robust standard error 0.044.

More generally, the historical benchmark observations show a price-income relationship that is fairly similar to the modern-day, ICP-based relationship, while the relationship based on extrapolated data differs more notably. This difference is driven in particular by high-income countries with low implied price levels based on extrapolated data and higher price levels

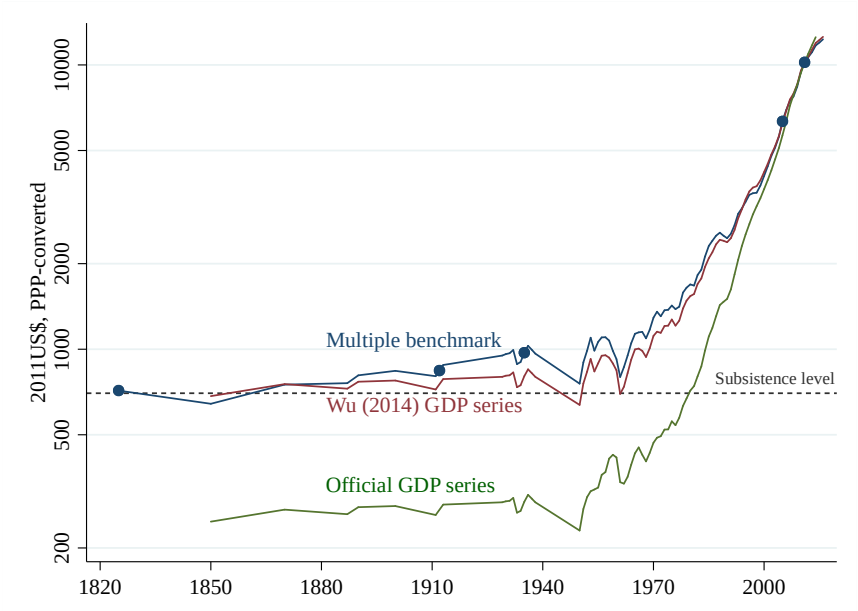
implied by the historical benchmarks. Note that these regression lines are meant to be illustrative rather than an attempt to provide a comprehensive statistical comparison. A comprehensive analysis would be challenging given the limited number of historical benchmark observations, but such a more complete model would, for example, also account for the degree of openness and differences in the monetary regime (Prados de la Escosura, 2000). The figure does illustrate that reliance on extrapolated time series risks 'unmooring' the resulting real GDP series from underlying economic relationships.

5.4. Poverty and subsistence

An important implication of using different relative price levels is that the poverty level may change. With the 1990 price levels, the subsistence level income was estimated at between 350 and 400 international dollars per year (Maddison, 2007). The poverty line was equal to around $1 per day, and was based on the first international poverty line which was set at $1.01 per day using 1985 PPP's, which was later updated to $ 1.08 per day using the 1993 PPP's (Ravallion, Datt and van de Walle, 1991; Chen and Ravallion, 2001). This made the interpretation of historical income series very intuitive. By using other relative prices, this subsistence level of income changes. The price level (in US dollars, the standard used in these calculations) increased by 59% between 1990 and 2011, bringing the poverty line to 636 dollars of 2011. In a more extensive re-benchmarking, the World Bank raised the absolute poverty line to 1.90 US dollars a day, expressed in 2011 prices.

The effects of rebasing the original Maddison estimates has the most notable effects for countries who experienced substantial price changes relative to the US between the benchmarks years. China is an interesting case in this perspective. When the 2005 PPPs were released, the prices for China had increased so much relative to the US, that total GDP per capita came out around 40% lower than China's relative income based on earlier price estimates (Deaton and Heston, 2010: 3; Feenstra et. al, 2015). This led to implausibly low historical income estimates for China, given that the original estimates were already very close to subsistence around 1950 (Maddison, 2007a). In the years after the release of the 2005 PPP's consensus arose about the 2005 shortcomings, most of which were corrected for in the 2011 ICP round (see e.g. Deaton and Aten, 2017). Still, relative prices for China relative to the US were substantially higher in 2011 compared to 1990 which lowers China's PPP adjusted income per capita in 2011 by 23%.

Figure 3. Historical income series China in 2011 US dollars



The case of China is interesting more broadly, as illustrated in Figure 3. The green line shows GDP per capita as implied by the official National Accounts GDP series from 1952 onwards, extended backwards with historical growth estimates, tied to the ICP 2011 benchmark. Those official growth rates imply that before 1979, Chinese GDP per capita was below the $700 subsistence line. This stretches credibility past the breaking point, as this would imply utter destitution for considerably more than a century. By contrast, the country with the lowest GDP per capita level in the ICP 2011 comparison was the Democratic Republic of Congo, at $680. This implication of the official Chinese growth rates had been recognized by Maddison who, jointly with Harry Wu, developed alternative growth estimates that aimed to correct for the substantial overestimation of official growth. The most recent work in this line is by Wu (2014), whose growth series from 1952 onwards is used for the GDP per capita line shown in red in Figure 3. In blue, we show the new MPD version that relies on multiple benchmarks: the ICP 2011 results, the adjusted ICP 2005 results (Inklaar and Rao, 2017), and the historical benchmarks for 1935 (Fukao et al. 2007), 1912 (Ye and de Jong, 2017), 1840 (Broadberry, Guan and Li, 2013) and 1825 (van Zanden and Li, 2012). This blue line implies that, even if we had not relied on Wu's (2014) GDP growth series, we would have avoided the extreme destitution before 1979 that is implied by official GDP statistics because the historical benchmarks peg China's income level close to, but still above subsistence level.

Looking more broadly into the subsistence threshold, the original Maddison project dataset includes 6 countries whose income was below 400 (1990) dollars per year for 10 years or more

(Afghanistan, Botswana, Cuba, Democratic Republic of Congo, Malawi and Romania) and an additional 15 countries, many of these in Africa, with shorter spells. Using the new, multiple benchmark approach, there are 15 countries with an average income below 700 (2011) dollars per year, including Brazil, Cambodia, Chile, Democratic Republic of Congo, Ethiopia, Laos, Lesotho, Liberia, Mali, Mexico, Mozambique, Nepal, Peru, Romania and Rwanda. Most of these below-subsistence observations are in Africa, especially prior to 1960 or during periods of civil war. Given that we know still too little about economic development in Africa in earlier years,[27] we would need more information about relative incomes for earlier periods to sensibly interpret relative development levels. The development of an independent (indirect) 1950 benchmark (Appendix D) represents useful progress in this direction, but this would need to be extended to cover more formerly French African countries and especially Mozambique and Angola to provide a more comprehensive picture of the continent.

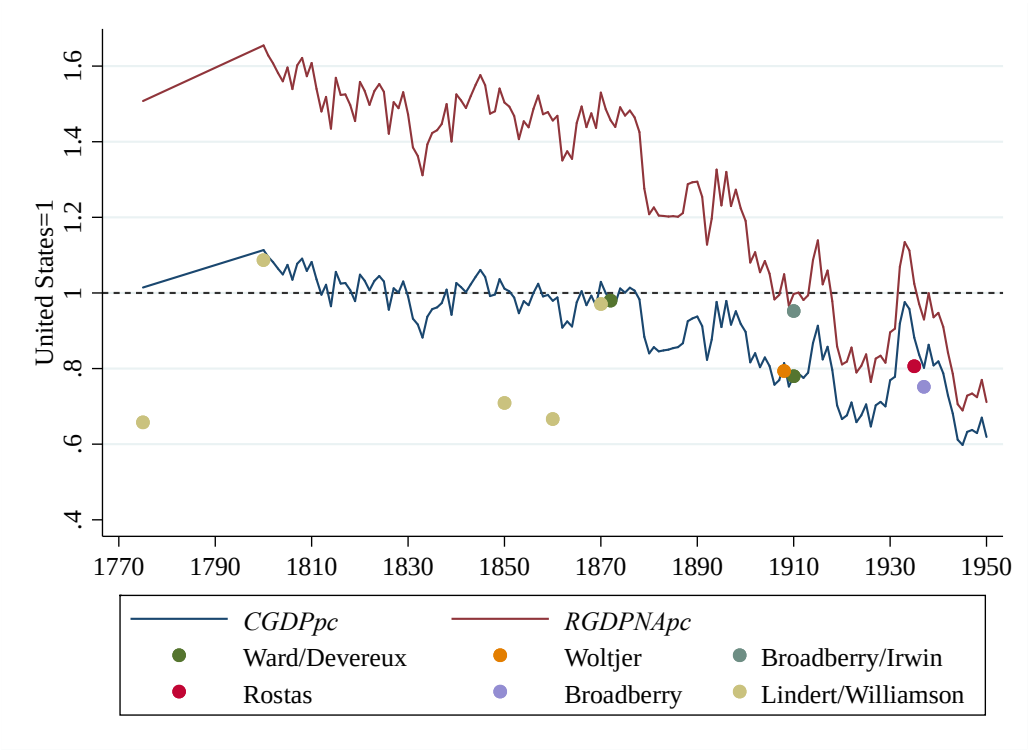
5.5 When did the US overtake the UK?

One of the debates in the study of long term economic growth has focused on the relative performance of the UK and the USA, and in particular the question when the USA overtook the UK. Maddison's approach based on backward projection implied that until the 1870s the UK's income level was about 40% higher than that of the USA, and that only after the 1870s the USA gradually overtook the UK; see Figure 4, the $RGDPNApc$ series. Broadberry (1998, 2003) came to similar conclusions, based on a benchmark comparison in 1937. These results have, however, been criticized recently by Ward and Devereux (2003, 2018), who created a set of independent benchmarks for 1872 and 1910 period, and by Lindert and Williamson (2016) who did similar research for the 18th century, indicating that the USA was at least on par with the UK at the time. Our new approach makes use of the new Ward/Devereux benchmarks for the 1872-1910 period, using those as anchors. Figure 4 shows the new results, with series $CGDPpc$, showing the two countries roughly on par until 1870, after which point the US economy gained a sustained income advantage. The fact that one of the Lindert and Williamson (2016) estimates, the estimate by Woltjer (2015), by Rostas (1948), and by Broadberry (1998, 2003) are on, or close to, the $CGDPpc$ series is an independent outcome. These independent matches provide a greater degree of plausibility to this new $CGDPpc$ series, in our view, though the fact that three of the Lindert/Williamson benchmarks deviate substantially suggests a degree of uncertainty.

[27] Also the more recent income estimates for many African countries are sometimes of dubious quality (Jerven, 2013; Henderson et al. 2012).

That said, if anything the UK's income level relative to the US may have been lower rather than the much higher relative level implied by $RDPNApc$.

Figure 4. Real GDP per capita in the United Kingdom relative to the United States



6. Concluding remarks

This paper has introduced a new version of the Maddison Project Database (MPD), the successor to Angus Maddison's historical statistics. The main novelty of our approach is to combine the full range of modern-day and historical estimates of relative GDP per capita with improved time series on growth in GDP per capita to provide a comprehensive, global picture of real GDP per capita from Roman times to the present. In contrast to Maddison's last work, which is still widely used, the new MPD directly relies on the best current evidence of living standards and income across countries in the present day and in history – by construction. This feature is of great importance, not just to provide a more historically-grounded perspective of real GDP per capita through history, but also as an invitation to the research community. By incorporating new estimates of historical income levels, the MPD can serve as a platform through which such new research results can be placed in international perspective and provided to a broader audience. To provide a bridge to research based on Maddison's prior cross-country benchmark in 1990 dollars, we also make available series of real GDP per capita linked to this benchmark.

The incorporation of many historical benchmarks has an important effect on our understanding of long-term income trends. For example, the original Maddison statistics showed that it was not until the early 20th century that real GDP per capita in the United States overtook the level of real GDP per capita in the United Kingdom. But as historical evidence has accumulated, it has become increasingly clear that real GDP per capita in the United States was at comparable levels as in the United Kingdom already from the mid-19th century onwards. More broadly, we find that in the 19th century, the United States was farther ahead of countries around the world with, in particular, lower levels of real GDP per capita in Western Europe and Latin America. In a broader cross-country setting, we show that our new measure of comparative real GDP per capita is a more reliable measure for assessing the degree of income convergence and implies more plausible relative price levels than the Maddison method of extrapolating from a modern-day income comparison.

These new results do not claim to be the final word on these topics. Despite our inclusion and estimation of numerous historical benchmarks, our understanding of comparative income levels becomes based on sparser data as we move back further in time. This is particularly pressing in regions such as Africa and large parts of Asia, but there also important gaps in 19th century Latin America. Our hope is that our research contributes a fresh impetus to improving our understanding of historical income differences as this can only sharpen our understanding of why a relatively small set of countries managed to become much richer and to what extent those countries were different. As an example of what such research can achieve, take Broadberry and Wallis (2017), who find that avoiding a shrinking economy has been much more important than stimulating growth for reaching higher income levels. More fine-grained information and more comparative studies are crucial to broadening and deepening such understanding.

Finally, we fully recognize that developing estimates of real GDP per capita is but a first step to a broader understanding of wellbeing. A fuller picture of well-being would (at least) distinguish between consumption and investment and, more generally, incorporate additional dimensions of wellbeing, such as health, leisure and inequality. A better understanding of differences in income and living standards would require information on the factors of production – human and physical capital – and productivity. Yet all such subsequent work relies heavily on reliable and informative data on income per capita and we hope that our new data serves as a useful starting point and platform for further research.

Appendices

A. Overview of historical benchmarks and new historical time series

Table A.1: List of historical benchmark studies included in the paper.

Benchmark	Country	Source		Remarks
1820	Netherlands	Frankema, E., P. Woltjer and J.P. Smits (2013). Changing Economic Leadership, a new benchmark of sector productivity in the United States and Western Europe, ca. 1910, Tijdschrift voor Sociale en Economische Geschiedenis (The low countries social and economic history), Vol 10, No. 3, pp. 80-113	Page 104, table 6	Original benchmark is Netherlands versus Great Britain
1825	China	Li, B. and J.L. van Zanden (2012). 'Before the Great Divergence? Comparing the Yangzi Delta and the Netherlands at the Beginning of the Nineteenth Century', The Journal of Economic History 72 (4) (2012) 956-989.		Original benchmark is China versus the Netherlands
1850	Netherlands	Frankema, E., P. Woltjer and J.P. Smits (2013). Changing Economic Leadership, a new benchmark of sector productivity in the United States and Western Europe, ca. 1910, Tijdschrift voor Sociale en Economische Geschiedenis (The low countries social and economic history), Vol 10, No. 3, pp. 80-113		Original benchmark is Netherlands versus Great Britain
1860	Indonesia	Van Zanden, J.L. (2003). '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 40, 1-23.	p. 10-11	Original benchmark is Indonesia versus the Netherlands
1860	Germany	Fremdling, R., Productivity comparison between Great Britain and Germany, 1855–1913, Scandinavian Economic History Review 39 (1), 28-42		
1870	India	Heston, A. and R. Summers, 1980. Comparative Indian Economic Growth: 1870 to 1970, American Economic Review, vol. 70 (2), pages 96-101	page 99, table 2	

1872	Australia	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	United States	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Belgium	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Canada	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	United Kingdom	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Switzerland	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Denmark	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Netherlands	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Germany	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Norway	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	France	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Sweden	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1872	Italy	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	

1910	Australia	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	United States	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Belgium	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Canada	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	United Kingdom	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Switzerland	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Denmark	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Netherlands	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Germany	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Norway	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	France	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Sweden	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	
1910	Italy	Ward, M. and J. Devereux, 2018. New Perspectives on Productivity and Living Standards for the Late 19th Century. Mimeo	page 22, table 4	

1912	China	Ma, Y. and de Jong, H. (2017), Unfolding the Turbulent Century: A Reconstruction of China's Historical National Accounts, 1840–1912. Review of Income and Wealth (forthcoming). doi:10.1111/roiw.12314	Appendix table 3	
1913	Turkey	Pamuk, S. (2006), Estimating economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.	table 1, page 7	
1913	Syria	Pamuk, S. (2006), Estimating economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.	table 1, page 7	
1913	Lebanon	Pamuk, S. (2006), Estimating economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.	table 1, page 7	
1913	Jordan	Pamuk, S. (2006), Estimating economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.	table 1, page 7	
1913	Egypt	Pamuk, S. (2006), Estimating economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.	table 1, page 7	
1913	Saudi Arabia	Pamuk, S. (2006), Estimating economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.	table 1, page 7	
1913	Iraq	Pamuk, S. (2006), Estimating economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.	table 1, page 7	
1913	Iran	Pamuk, S. (2006), Estimating economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.	table 1, page 7	
1929	Australia	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		

1929	Austria	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Belgium	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Canada	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Czechoslovakia	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Denmark	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Finland	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	France	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Germany	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Hungary	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Ireland	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Italy	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Netherlands	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	New Zealand	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Norway	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Spain	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Sweden	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Switzerland	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Turkey	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1929	Great Brittain	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		

1929	Yugoslavia	Clark, C. 1957. The Conditions of Economic Progress. London: MacMillan & Co. Ltd		
1935	Germany	Broadberry, S.N. (2006), Market Services and the Productivity Race, 1850-2000: Britain in International Perspective. Cambridge: Cambridge University Press.	page 219, table 9.3	Original benchmark is Germany versus Great Britain
1935	Japan	Fukao, K., D. Ma, and T. Yuan (2007) "Real GDP in pre-war East Asia: a 1934–36 benchmark purchasing power parity comparison with the U.S" *Review of Income and Wealth*, 53(3): 503–537.	Table 8, p. 513	
1935	Taiwan	Fukao, K., D. Ma, and T. Yuan (2007) "Real GDP in pre-war East Asia: a 1934–36 benchmark purchasing power parity comparison with the U.S" *Review of Income and Wealth*, 53(3): 503–537.		
1935	South Korea	Fukao, K., Ma, D. and Yuan, T. (2007), REAL GDP IN PRE-WAR EAST ASIA: A 1934–36 BENCHMARK PURCHASING POWER PARITY COMPARISON WITH THE U.S.. Review of Income and Wealth, 53: 503–537. doi:10.1111/j.1475-4991.2007.00243.x		
1935	China	Fukao, K., D. Ma, and T. Yuan (2007) "Real GDP in pre-war East Asia: a 1934–36 benchmark purchasing power parity comparison with the U.S" *Review of Income and Wealth*, 53(3): 503–537.		
1950	India	Broadberry, S. and B. Gupta, 2010. The historical roots of India's service-led development: A sectoral analysis of Anglo-Indian productivity differences, 1870–2000, In Explorations in Economic History, Volume 47, Issue 3, pp. 264-278, ISSN 0014-4983, https://doi.org/10.1016/j.eeh.2009.09.004.	table 5, p. 268	
1955	Soviet Union	Bergson, A. (1972). The Comparative National Income of the USSR and the United States, NBER, http://www.nber.org/chapters/c5095, pp. 145-224	table 2, p. 149	

1958	Thailand	Usher, D. (1963). The Thai National Income at United Kingom Prices. Bulletin of the Oxford University Institute of Economics & Statistics, 25: 199–214. doi:10.1111/j.1468-0084.1963.mp25003003.x	table 1, page 199	Original benchmark is Thailand versus Great Britain

Time series

This new version of the MPD includes all new historical income estimates that have become available since the previous update (Bolt and Van Zanden, 2014). For sources of all series not updated as indicated in the table below, please consult Bolt and Van Zanden (2914).

Table A2: New historical time series included in the paper

Country	Period	Source
Latin America		
Bolivia	1846–1950	Herranz-Loncán, A. and Peres-Cajías (2016). "Bolivian GDP per capita since the mid-nineteenth century" *Cliometrica* 10: 99-128
Brazil	1850–1899	Barro, R.J. and J.F. Ursua, 2008. "Macroeconomic Crises since 1870," Brookings Papers on Economic Activity, Economic Studies Program, The Brookings Institution, vol. 39(1 (Spring), pages 255-350
Brazil	1947 onwards	National accounts data
Chile	1810–2004	Díaz, J.B. Lüders, R. and Wagner, G. (2007) Economia Chilena 1810 - 2000, Producto total y sectorial una nueva mirada, Pontificia universidad Catolica de Chile, Insituto de Economia, Documeno de Trabajo no. 315
Chile	2004 onwards	National accounts data
Cuba	1902–1958	Ward, M. and Devereux, J. (2012). The Road Not Taken: Pre-Revolutionary Cuban Living Standards in Comparative Perspective. *The Journal of Economic History, 72*(1), 104-132. doi:10.1017/S0022050711002452
Cuba	1960–1895	Santamaria Garcia, A. (2005). Las Cuentas nacionales de Cuba, 1960 - 2005', mimeo
Mexico	1550–1812	Arroyo Abad, L., & Van Zanden, J. (2016). Growth under Extractive Institutions? Latin American Per Capita GDP in Colonial Times. *The Journal of Economic History, 76*(4), 1182-1215. doi:10.1017/S0022050716000954
Mexico	1812–1870	Updated data based on Prados de la Escosura, L., 'Lost decades? Economic performance in post-independence Latin America', Journal of Latin America Studies, 41 (2009), pp. 279–307.
Mexico	1870–1895	Bèrtola, L. and Ocampo, J. A., The economic development of Latin America since independence (Oxford, 2012).

Mexico	1895–2003	Barro, R.J. and J.F. Ursua, 2008. "Macroeconomic Crises since 1870," Brookings Papers on Economic Activity, Economic Studies Program, The Brookings Institution, vol. 39(1 (Spring), pages 255-350
Mexico	2003–2015	OECD National Accounts
Panama	1906–1945	De Corso, G. and S. Kalmanovitz (2016). Una estimación del PIB de Panamá: 1906-1945, *Tiempo&Economía* 3 (1).
Peru	1600–1812	Arroyo Abad, L., & Van Zanden, J. (2016). Growth under Extractive Institutions? Latin American Per Capita GDP in Colonial Times. *The Journal of Economic History*, *76*(4), 1182-1215. doi:10.1017/S0022050716000954
Peru	1812–1870	Seminario, B. (2015). El Desarrallo de la Economía Peruana en la Era Moderna, Universidad de Pacifico, Lima
Uruguay	1870–2014	Bertola, L. (2016). El PIB per Capita de Uruguay 1870 - 2016: una reconstruccion. PHES working paper No 48
Venezuela	1830–2012	De Corso, G. (2013). El crecimiento economico de Venuzuela, Desde la Oligarquia Conservadora Hasta La Revolucion Bolivariana: 1830-2012. Uno Vision cuantitativa *: Venezuelan Economic Growth From The Conservative Oligarchy To The Bolivarian Revolution (1830-2012), Revista De Historia Económica / Journal of Iberian and Latin American Economic History, 31(3), 321-357. doi:10.1017/S0212610913000190
Venezuela	2012 onwards	National accounts data

Europe

England	1252–1870	Broadberry, S.N., B. Campbell, A. Klein, M. Overton and B. van Leeuwen (2015), *British Economic Growth 1270-1870* Cambridge: Cambridge University Press.
Finland	1600–1860	Eloranta, J., Voutilainen, M. and Nummela, I. (2016). "Estimating Finnish Economic Growth Before 1860" mimeo.
France	1250–1800	Ridolfi, L. (2016) "The French economy in the longue durée. A study on real wages, working days and economic performance from Louis IX to the Revolution (1250-1789)" Dissertation IMT School for Advanced Studies, Lucca, available at http://e-theses.imtlucca.it/211/1/Ridolfi_phdthesis.pdf
Holland	1348–1807	van Zanden, J. L. and van Leeuwen, B., 'Persistent but not consistent: the growth of national income in Holland 1347–1807', Explorations in Economic History, 49 (2012), pp. 119–30.
Norway	1820–1930	GDP from Grytten, O.H. (2015). Norwegian gross domestic product by industry 1830 - 1930, Norges Bank Working paper 19/2015. Population from Maddison (2006).
Poland	1409–1913	Malinowski, M. and Van Zanden (2017), Income and its distribution in preindustrial Poland, Cliometrica 11 (3): 375 - 404. https://doi.org/10.1007/s11698-016-0154-5
Portugal	1530–1850	Palma, N. and J. Reis (2016). From Convergence to Divergence: Portuguese Demography and Economic Growth, 1500-1850. GGDC Research Memorandum 161
Romania	1862–1995	Axenciuc, V. (2012). Produsul intern brut al Romaniei, Vol. 1, Institutl de Economie Nationala, Bucarest
Romania	1996–2002	ESA (1995) national accounts data
Romania	2002–2016	ESA (2010) national accounts data
Spain	1850–2016	Prados de la Escosura, L. (2017), Spanish Economic Growth, 1850-2015 (London: Palgrave Macmillan)

Sweden	1300–1560	Krantz, O. (2017) "Swedish GDP 1300-1560 A Tentative Estimate" *Lund Papers in Economic History: General Issues*; No. 152.
Sweden	1560–1950	Schön, L., and O. Krantz (2015) "New Swedish Historical National Accounts since the 16th Century in Constant and Current Prices" *Lund Papers in Economic History* no. 140.
UK	1700–1870	Broadberry, S.N., B. Campbell, A. Klein, M. Overton and B. van Leeuwen (2015), *British Economic Growth 1270-1870* Cambridge: Cambridge University Press.

Asia

China	1952–2008	Wu, Harry X. (2014), "China's growth and productivity performance debate revisited – Accounting for China's sources of growth with a new data set" *The Conference Board Economics Program Working Paper Series* EWP#14-01.
China	1661–1933	Xu, Y. Z. Shi, B. van Leeuwen, Y Ni, Z Zhang, and Y Ma, (2016) 'Chinese National Income, ca. 1661-1933', *Australian Economic History Review* 57(3), 368–393.
India	1600–1870	Broadberry, S.N., Custodis, J. and Gupta, B. (2015), "India and the great divergence: an Anglo-Indian comparison of GDP per capita, 1600–1871" *Explorations in Economic History*, 55: 58-75
Turkey		Pamuk, S. (2009). "Estimating GDP per capita for the Ottoman Empire in a European Comparative Framework, 1500-1820", paper presented at the XVth World Economic History Congress, August 2009, Utrecht.
Singapore	1900–1959	Barro, R.J. and J.F. Ursua, 2008. "Macroeconomic Crises since 1870," Brookings Papers on Economic Activity, Economic Studies Program, The Brookings Institution, vol. 39(1 (Spring), pages 255-350
Singapore	1960–2016	current national accounts data

Middle East

Syria	1820, 1870, 1913, 1950	Pamuk, S. (2006), Estimating Economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.
Lebanon	1820, 1870, 1913, 1950	Pamuk, S. (2006), Estimating Economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.
Jordan	1820, 1870, 1913, 1950	Pamuk, S. (2006), Estimating Economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.
Egypt	1820, 1870, 1913, 1950	Pamuk, S. (2006), Estimating Economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.
Saudi Arabia	1820, 1870, 1913, 1950	Pamuk, S. (2006), Estimating Economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.
Iraq	1820, 1870, 1913, 1950	Pamuk, S. (2006), Estimating Economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.
Iran	1820, 1870, 1913, 1950	Pamuk, S. (2006), Estimating Economic Growth in the Middle East since 1820, The Journal of Economic History, vol 66, no. 3, pp. 809 - 828.

Africa

Cape Colony/South Africa	1700–1900	Fourie, J. and Van Zanden, J.L. (2013). GDP in the Dutch Cape Colony: the Nationals Accounts of a Slave-Based Society, South African Journal of Economics, vol. 81 (4): 467 - 490

B. Multiple benchmark implementation

Combining relative income comparisons with very long time series of economic growth can yield results that are impossible to square with information from other sources. Relying on multiple benchmark comparison can alleviate such problems, but especially when a comparison is the first in a time series, it can also be a source of problems. We identified three categories of problems, related to either problematic benchmark comparisons or time series:

1. *Too low:* For a long and persistent period of time, income levels drop below the absolute poverty (or subsistence) level of $1.90 per day (approximately $700/year, in 2011 prices). While poverty can be widespread – indicating that a substantial fractions of the population lives on less than $700 per year – it is rare outside periods of severe conflict for the average income level in a country to be lower than $700. For illustration, in ICP 2011, only the Democratic Republic of Congo was below this level at $680 and this country had an income level above $700 before 1996 and since 2012, showing such below-subsistence spells are mostly temporary rather than persistent.
2. *Too high:* While it is no rule that the United States should be the highest-income country in the world, higher incomes are typically only observed in countries with substantial oil exports (in ICP 2011: Qatar, Norway, Kuwait and United Arab Emirates) or in otherwise unique and particular circumstances (Luxembourg, Singapore and Switzerland). So if we find that, for example, oil-exporting countries already had high income levels according to official growth statistics, before oil exports began or before the 1973 rise in oil prices, these are reasons for worry.
3. *Large swings:* Especially before the more thoroughly vetted procedures of ICP 2005 and ICP 2011, benchmark price comparison differed substantially in quality across countries and comparisons. For example, there are cases where a particular country in a particular year relied on the exchange rate as the PPP for a sizeable share of its product categories. Also, if countries happen to be in unstable macroeconomic conditions around the time of a benchmark price measurement – such as Zimbabwe in 2005 or some Latin American countries in 1980 – the resulting benchmark level may be uncertain and distorted. These may exhibit as large swings in relative income levels between benchmarks.
4. *PWT estimation:* Problematic time series of real GDP may not only stem from the historical or ICP benchmarks, but may instead be related to the data and methods used in the Penn World Table (PWT) for interpolating between benchmarks or extrapolating from the first (or last) benchmark comparison. While in the MPD, we only have information on GDP

levels, PWT price levels are computed using prices and expenditure for major expenditure categories: household consumption, government consumption, investment, exports and imports. Relative cross-country price information for exports and imports is available separately and detailed National Accounts deflators are used to in extrapolation. These data and methods can result in large swings in real GDP between benchmarks or trends that seem hard to square with observed GDP information. One reason can be that the expenditure-level deflators are inconsistent with GDP deflators. In such cases, we do not use the estimated relative prices from PWT, but instead interpolate or extrapolate at the GDP level

We also rely on the Balassa-Samuelson relationship between the (log) price level and (log) GDP per capita level as a diagnostic tool. Following Hassan (2016), we estimate a quadratic function (i.e. including log GDP per capita and log GDP per capita squared) based on all benchmark comparisons, using the GDP per capita level relative to the United States to put the independent variable on an equal basis as the price level variable.

On a country-by-country basis, we examined trends in income levels, identifying the type of problems discussed above (income levels that are too low, too high, or change too rapidly between benchmarks). Especially in cases where the observed price level from a benchmark comparison is substantially higher or lower than expected based on the Balassa-Samuelson relationship we see good reasons for omitting that benchmark comparison from the computation of the dataset. Below, we list these choices by benchmark comparison. Especially in cases of oil-exporting countries, the problem of income levels that are too high cannot be resolved by eliminating benchmarks, so in those cases we choose to truncate the time series. The list of these choices also follows. Note that real GDP data based on all benchmarks and time series can be found in PWT, so users interested in series without our selection should turn there.

Historical benchmarks	Year	Reason
Indonesia	1820	Too low
China	1840	Too low
Greece	1929	Too low
Poland	1929	Too low
Thailand	1958	Too high

Braithwaite (1968)	Year	Reason
Bolivia	1960	Too low
Brazil	1960	Too low
Chile	1960	Too low
Colombia	1960	Too low
Ecuador	1960	Too low
Guatemala	1960	Too low
Honduras	1960	Too low
Haiti	1960	Too low
Peru	1960	Too low
Uruguay	1960	Too low

ICP PPPs	Year	Reason
Iran	1970	Too low
Iran	1975	Too low
Sri Lanka	1975	Too low
Marocco	1980	Too low
Tunisia	1980	Too low
Argentina	1980	Large swings
Egypt	1985	Too low

ICP PPPs	Year	Reason
Iran	1985	Too low
Sierra Leone	1985	Too low
Zimbabwe	1985	Large swings
Equatorial Guinea	1996	Too low
Iran	1996	Too low
Guinea	1996	Too low
Lebanon	1996	Too low
Nigeria	1996	Large swings
Syria	1996	Large swings
Zimbabwe	1996	Too low
Iran	1970	Too low
Iran	1975	Too low
Sri Lanka	1975	Too low
Marocco	1980	Too low
Tunisia	1980	Too low
Argentina	1980	Large swings
Egypt	1985	Too low
Iran	1985	Too low
Sierra Leone	1985	Too low
Zimbabwe	1985	Large swings
Equatorial Guinea	1996	Too low
Iran	1996	Too low
Guinea	1996	Too low
Lebanon	1996	Too low
Nigeria	1996	Large swings
Syria	1996	Large swings
Zimbabwe	1996	Too low

Omitted time series	Period	Reason
Algeria	Before 1970	Too high
Angola	Before 1975	Too high
Bahrain	Before 1970	Too high
Kuwait	Before 1974	Too high
Qatar	Before 1974	Too high
Peru	Before 1855	Too low
Romania	Before 1875	Too low
United Arab Emirates	Before 1993	Too high

C. Latin America

Providing new estimates of income levels in Latin America has proven to be a particular challenge as the combination of relative price benchmarks with current National Accounts data often leads to notably lower income levels with especially implausible implications over the long run. This appendix discusses how the new estimates relate to those of Maddison (2006, Table A2-g), motivating our main decisions and their drawbacks along the way.

Table C1. GDP per capita in 1980 for 16 Latin American countries based on current market exchange rates

	ICP 1980		Current National Accounts		Current
	USD (XR)	USA=1	USD (XR)	USA=1	NA/ICP 1980
Argentina	7384	0.65	11100	0.89	1.50
Bolivia	942	0.08	631	0.05	0.67
Brazil	2059	0.18	1537	0.12	0.75
Chile	2477	0.22	2615	0.21	1.06
Colombia	1295	0.11	1660	0.13	1.28
Costa Rica	2119	0.19	2616	0.21	1.23
Dominican Republic	1192	0.10	1468	0.12	1.23
Ecuador	1463	0.13	1771	0.14	1.21
El Salvador	743	0.06	774	0.06	1.04
Guatemala	1085	0.09	958	0.08	0.88
Honduras	674	0.06	949	0.08	1.41
Panama	1816	0.16	1919	0.15	1.06
Paraguay	1403	0.12	1255	0.10	0.89
Peru	1196	0.10	926	0.07	0.77
Uruguay	3459	0.30	3438	0.28	0.99
Venezuela	4621	0.40	4304	0.35	0.93
United States	11448	1.00	12468	1.00	1.09

Sources: ICP 1980 from United Nations (1987, Table 1), Current National Accounts based on Maddison GDP series and United Nations National Accounts Main Aggregates Database (https://unstats.un.org/unsd/snaama/), December 2015; except El Salvador (World Bank, World Development Indicators).
Notes: USD (XR) refers to United States dollars, converted using exchange rates. Maddison (2006, Table A2-g) reports that GDP levels were adjusted upwards after the ICP 1980 report to correct for underestimation of the informal sector for Argentina (+36%), Peru (+6.5%) and Venezuela (+17.2%). The reported figures in this table incorporate these adjustments. The 'Current National Accounts' figures rely on the source's 'IMF-based exchange rates' . The 'Current NA/ICP 1980' column divides the two USD (XR) GDP/capita figures.

For most countries in Latin America, Maddison (2006) relied on the ICP 1980 benchmark (United Nations, 1987), which he subsequently extrapolated to 1990.[28] For most countries, this 1980 comparison is also the first benchmark comparison that is incorporated in the new Maddison series and thereby the anchor for earlier years, making it a sensible starting point of this discussion. Table C1 compares the GDP per capita figures used by Maddison and figures based on current vintage data, from the UN National Accounts Main Aggregates Database. Both sets of figures are converted to US dollars using market exchange rates, so the principal difference between the two sets are revisions to National Accounts data.[29,30] Such revisions can relate to changing accounting systems, such as from the System of National Accounts (SNA) of 1968 to SNA 1993 and SNA 2008, but also to changes of the benchmark year and source revisions. These revisions are known to be substantial, see for an overview of the impact of the adoption of SNA 1993 in Latin America, see Olinto Ramos, Pastor and Rivas (2008). They show that the adoption of new accounting rules and the change in benchmark year led to sizeable changes in the level of nominal GDP, ranging from -8.2 to +19.2 percent.

National Accounts revisions are typically considered to lead to an improved perspective on economic activity. However, these revisions pose a challenge for the pre-revision period. Ideally, a country's statistical office would rework its previous set of National Accounts based on new accounting rules and estimation methods. In practice, a typical revised set of National Accounts will include estimates for several years based on updated methodologies. However, extending revisions for longer periods of time is usually not a priority at statistical agencies, so a more common practice is to 'splice' together the old time series and the new, i.e. assume that the new level is a better reflection of economic activity but that economic growth was not mis-measured in the past.[31] Prados de la Escosura (2016) criticizes this 'retropolation' approach, specifically for the case of Spain, and proposes an alternative interpolation method. However,

[28] Exceptions are Jamaica and Mexico, neither of which gives rise to particular concerns, so we focus on the 16 countries from ICP 1980.

[29] Note also that several of these countries underwent one or more currency reforms or switched to or from using US dollars. We assume these changes to the unit of account have been appropriately carried out. This is not guaranteed as UN National Accounts data imply that GDP levels in El Salvador (in US dollars) were only one third of the level before the change from Colones to US dollars, while the World Bank's World Development Indicators show a level that is broadly comparable.

[30] Population estimates may also be revised; for instance the current estimate of the population of the United States in 1980 is 229.6 million compared to 227.7 million in United Nations (1987). In most cases these revisions are small, though in some cases they represent a notable part of the overall change in GDP per capita figures. For example, in Colombia population increased from 25.79 to 27.74 million, a revision of 7.6 percent.

[31] One prominent counterexample is the US Bureau of Economic Analysis, which maintains a current database of National Income and Product Accounts from 1929 onwards.

to what extent this approach would be generally applicable is hard to assess. Furthermore, the challenges in the Latin American context are greater because of the numerous episodes of macroeconomic instability in the twentieth century, with large swings in prices and exchange rates and currency reforms or dollarization.

Table C2. GDP price level in 1980 for 16 Latin American countries

	ICP 1980, GK	ICP 1980, GEKS	PWT
Argentina	1.42	1.66	1.71
Bolivia	0.59	0.72	0.67
Brazil	0.62	0.70	0.72
Chile	0.68	0.86	0.92
Colombia	0.47	0.54	0.58
Costa Rica	0.68	0.77	0.81
Dominican Republic	0.59	0.69	0.92
Ecuador	0.57	0.69	0.71
El Salvador	0.52	0.61	0.64
Guatemala	0.47	0.60	0.63
Honduras	0.56	0.67	0.71
Panama	0.56	0.76	0.82
Paraguay	0.67	0.80	0.85
Peru	0.45	0.55	0.57
Uruguay	0.83	0.86	0.91
Venezuela	0.73	0.94	0.93
United States	1.00	1.00	1.00

Sources: ICP 1980, GK from United Nations (1987, Table 1); ICP 1980, GEKS computations based on ICP 1980 data; PWT: price level of GDP^o (pl_gdpo) from PWT 9.0, normalized to USA=1, see Feenstra, Inklaar and Timmer (2015).
Notes: GDP price level is the PPP for GDP divided by the exchange rate. GK stands for Geary-Khamis and GEKS for Gini-Elteto-Kovecs-Szulc as two alternative PPP computation methods, see e.g. Diewert (2013).

Beyond revisions to GDP per capita figures, changes to the computation of purchasing power parities (PPPs) is another source of differences between Maddison (2006) and current estimates. Table C2 provides three estimates for the 1980 GDP price level, defined as the PPP for GDP divided by the market exchange rate. The first column, 'ICP 1980, GK', is the main relative price level as reported in United Nations (1987), computed from detailed price and expenditure data using the Geary-Khamis method. This method has come under increased criticism in the period since the ICP 1980 data were released, primarily because the method suffers from

substitution bias, see e.g. Diewert (2013). The alternative GEKS method, does not suffer from this shortcoming and is currently the method of choice for computing PPPs (see e.g. World Bank, 2014).

`The 'ICP 1980, GEKS' column shows that this change in computation method has a substantial effect on price levels, increasing prices of all countries relative to the United States, by an average of 20 percent. The final column, 'PWT', uses the relative price data as provided in the Penn World Table, version 9.0. The main reason for differences with the GEKS column is that PWT includes estimates of PPPs for exports and imports of goods, see Feenstra et al. (2015). This further increases price levels, by an average of 6 percent, though for the Dominican Republic the effect is much larger. These two differences together serve to depress relative income levels in Latin America compared to Maddison's (2006) estimates.

Table C3. GDP per capita in PPP-converted US dollars in 1980 for 16 Latin American countries

	GDP per capita in USD (PPP)		Relative GDP per capita (US=1)	
	Original	Rebased	Original	Rebased
Argentina	5210	6488	0.46	0.52
Bolivia	1591	938	0.14	0.08
Brazil	3337	2144	0.29	0.17
Chile	3622	2836	0.32	0.23
Colombia	2784	2874	0.24	0.23
Costa Rica	3137	3240	0.27	0.26
Dominican Republic	2006	1601	0.18	0.13
Ecuador	2583	2509	0.23	0.20
El Salvador	1418	1204	0.12	0.10
Guatemala	2324	1529	0.20	0.12
Honduras	1204	1334	0.11	0.11
Panama	3220	2345	0.28	0.19
Paraguay	2108	1481	0.18	0.12
Peru	2663	1634	0.23	0.13
Uruguay	4180	3771	0.37	0.30
Venezuela	6317	4625	0.55	0.37
United States	11448	12468	1.00	1.00

Sources: see Tables C1 and C2

Notes: GDP per capita in USD (PPP) is computed as GDP per capita in USD (XR) from Table 1 divided by the GDP price level from Table 2. For example, the 'Original' estimate for Argentina is computed as 7384/1.42=5210, while the 'Rebased' estimate is computed as 11100/1.71=6488.

Table C1 showed the impact of GDP per capita revisions and Table C2 showed the impact of changes in PPP computation methods. Table C3 combines these two factors in estimates of PPP-converted GDP per capita. As the final two columns show, the combination of factors result in lower levels of GDP per capita relative to the United States, with the changes from GK to GEKS PPPs as the most systematic factor. Heterogeneity across countries is substantial, with Colombia's relative income level remaining almost unchanged, while Peru's relative income level declines from 23 percent to 13 percent of the US level. This heterogeneity is primarily due to differences in GDP per capita revisions (Table 1): in Columbia GDP per capita has been revised upwards, while in Peru it has been revised downwards.

Table C4. GDP per capita in PPP-converted 2011 US dollars for 16 Latin American countries – 1800-2011

	1800	1850	1900	1950	1980	2011
Argentina	1594	2144	4925	8542	14431	20003
Bolivia			790	1627	2229	5331
Brazil	600	600	606	1549	5052	14831
Chile		1011	2533	4399	7041	19705
Colombia	819	681	946	2984	6825	11788
Costa Rica				2855	8012	12366
Dominican Republic				1663	3969	11679
Ecuador			903	2441	5826	9985
El Salvador				1370	2754	7607
Guatemala				2130	3793	6650
Honduras				1838	3168	4421
Panama				2073	5569	16762
Paraguay				1306	3517	7377
Peru			604	2048	3900	10044
Uruguay	1643	2205	3027	6269	9825	17211
Venezuela	514	903	885	4055	11355	17746
United States	1980	2825	6252	15241	29613	49675

Notes: The column 1980 implies the same relative income levels as the 'rebased' figures from Table C3; e.g. for Argentina 15409/29613=0.52. The difference in figures is because the numbers in Table 3 were 1980 US dollars, while all figures in this table are expressed in 2011 US dollars.

As may be expected, these changes to the 1980 benchmark levels have substantial effects on long-run income levels. Table C4 shows the PPP-converted GDP per capita figures for the 16 Latin American countries since 1800 (or the earliest available year), denominated in 2011 US dollars. This points to the importance of a more extensive set of benchmark comparisons for these countries, to establish whether these patterns, implied by the time series of economic growth and the different benchmarks accords with the historical reality.

The Case of Cuba[32]

Cuba deserves special attention because it is a country of 11 million that used to be a prosperous, middle-income country before its Communist revolution (Ward and Devereux, 2012) and has been on a downward (relative) trajectory since. However, due (at least in part) to its current political system, it has not actively participated in the ICP before the 2011 round, leading to a paucity of information that can be used to compare income levels. Moreover, even its participation in ICP 2011 did not lead to estimates of real GDP per capita that were deemed reliable enough to publish. The ICP 2011 report only reports Cuba's relative price level, at 32.2 percent of the US level, but: "The official GDP of Cuba for reference year 2011 is 68,990.15 million in national currency. However, this number and its breakdown into main aggregates are not shown in the tables because of methodological comparability issues. Therefore, Cuba's results are provided only for the PPP and price level index" (World Bank 2014, p. 29). The reported price level of 32.2 percent of the US level seems low, on a similar level as that of India, while the official GDP per capita level, valued at current exchange rates, is much higher for Cuba (12 percent of the US level) than for India (3 percent). The predicted relative price level at Cuba's level of GDP per capita is between 52 and 59 percent of the US level, depending on the Balassa-Samuelson relationship. Similarly, the crowd-sourced price comparison website Numbeo shows a relative cost-of-living in Havana that is 67 percent of the US level.[33]

One clear conclusion from this discussion is that combining the ICP 2011 relative price level for Cuba with official GDP per capita data does not result in plausible real GDP per capita figures and would substantially overestimate Cuba's comparative income level. It would thus be more sensible to treat Cuba as a 'non-benchmark' economy, like Afghanistan and North Korea, and use an econometric estimate of its real GDP per capita level than a direct

[32] We would like to thank John Devereux for helpful suggestions and discussions on this topic

[33] https://www.numbeo.com/cost-of-living/region_rankings_current.jsp?region=019, consulted on January 4, 2018.

measurement. An estimate by the United Nations for its Human Development Report (2016) seems plausible, as deemed by Cuba's statistical office and experts of the region. This puts Cuba's real GNI per capita in 2011 at 6821 (in 2011 US dollars). Using the GDP/GNI ratio from the World Development Indicators, this implies a real GDP per capita level in 2011 for Cuba of 6928 in 2011 US dollars. Compared to the figures in the final column of Table C4, this puts Cuba in the lower part of Latin America's income levels, which seems more plausible than the $19068 implied by the official GDP per capita data and the ICP 2011 price level, which would have put Cuba at a similar income level as Chile. We therefore use the $6928 as the benchmark level for Cuba in 2011.

D. Africa

The new methodology for extending income levels back in time appear to have limited consequences for the income estimates of the far majority of Sub-Saharan African countries. For a number of African countries the new methodology results in substantially different income levels compared to those originally published by Maddison (2006). This appendix discusses how the new estimates and the original estimates relate to each other.

Maddison (2006) relied on the Penn-World tables 5.6 for his estimates of the 1990 benchmark GDP levels for all African countries except Equatorial Guinea, Sao Tome and Principe, and five very small countries. For those countries Maddison (2006: 221) assumed that the 1990 GDP per capita was equal to the average of the 50 African countries covered by the PWT. When using the multiple benchmarks, for 26 out of 47 countries this in effect means using the 2011 and the 2005 PPPs. For the other countries, various earlier benchmarks are available. Kenya is the first Sub-Saharan African country to participate in an ICP round in 1970, and in 1985 already 15 countries participate in the ICP program. Using the multiple benchmark approach leads to very similar relative income estimates compared to the original Maddison series for about half of the African countries. For most other countries the multiple benchmark approach leads to slightly different but we think still reasonable income estimates. However, for some of the countries, the earlier income estimates deviate away from previous patterns when using multiple benchmarks. This leads to a reshuffling in the order of countries compared to the original series, when we rank them from poor to rich. The best way forward would be to have benchmarks for 1950 for all African countries, as that would provide the best comparison of relative income levels in that year allowing us to 'anchor' the annual series.

As there currently exists no such anchor, we created benchmarks for African countries for the year 1950 based on the indirect approach. This indirect approach has been developed in the context of estimating trends in GDP per capita, within countries, over time, for periods in which data constraints make it impossible to estimate GDP in the usual way. The method used was pioneered by Malanima (2010, for Northern Italy 1300-1850), and has now been used for many country studies (of, amongst others, Germany (Pfister 2003), France (Ridolfi 2016), Spain (Alvarez-Nogal and Prados de la Escosura 2013), Poland (Malinowski and Van Zanden 2016), Mexico and Peru (Arroyo-Abad and van Zanden 2015). Here we propose adapting this approach from a time-series to a cross-country within Africa setting.

We first explain the approach, and then present the resulting GDP pc levels for the African countries for which we could obtain the underlying data. The starting point of the indirect approach is to assume each country can usefully be represented as a two-sector economy, consisting of an agricultural sector (a) and a non-agricultural sector (n). Nominal GDP in country i is then defined as:

$$P_i Q_i = P_i^a Q_i^a + P_i^n Q_i^n, (D1)$$

where Q denotes the price level and Q denotes net production. If all variables in equation (D1) were known, it would be straightforward to compare real GDP between countries i and j. If we follow Feenstra et al. (2015) and assume an economy-wide translog function that is homogenous of degree one in factor endowments and has identical second-order parameters on factor endowments across countries, we can express relative real GDP per capita as the following Törnqvist index:[34]

$$\log\left(\frac{Q_i}{Q_j}\right) = \frac{1}{2}\left(\frac{P_i^a Q_i^a}{P_i Q_i} + \frac{P_j^a Q_j^a}{P_j Q_j}\right)\log\left(\frac{Q_i^a}{Q_j^a}\right) + \frac{1}{2}\left(\frac{P_i^n Q_i^n}{P_i Q_i} + \frac{P_j^n Q_j^n}{P_j Q_j}\right)\log\left(\frac{Q_i^n}{Q_j^n}\right) (D2)$$

Yet the absence of sufficient data is what motivates this indirect approach, so we have to impose more structure and assumptions on the problem to arrive at a method that can be implemented in practice. First, assume that food production equals food consumption, $F \equiv Q^a$ (dropping country subscripts for conciseness). As discussed in Allen (2000), net food trade accounted for only 10 percent of food production around 1800 in the Netherlands and United Kingdom, two of the most open economies at the time, so violations of this assumption are not likely to be substantial. Second, assume that food consumption per capita is primarily determined by income per capita w:

$$\frac{F}{N} \equiv f = w^{\beta} (D3),$$

where N_i is the population in country i. The crucial parameter here is β, the income elasticity of food demand, whose choice we discuss below.

We approximate income per capita by the real wage level of laborers. This measure, pioneered by Allen (2001), relates nominal wages of building laborers to the cost of a basket of goods that

[34] A Törnqvist index is a superlative index, like the Fisher index (Diewert, 1976) and in many practical situations the two indexes provide very similar results.

would ensure a minimum level of subsistence, i.e. consume a sufficient amount of calories, other nutrients, fuel, clothing and shelter to survive.

Third, we assume that labor productivity in non-agriculture is a common multiple p of that in agriculture:

$$\frac{Q^n}{L^n} = p \times \frac{Q^a}{L^a} \ (D4),$$

where L^x is the labor input in sector x.

Fourth, we assume that labor input in agriculture relative to labor input in non-agriculture is equal to the ratio of the population in rural (N^a) relative to urban areas (N^n):

$$\frac{L^a}{L^n} = \frac{N^a}{N^n} = \frac{(1-u)}{u} \ (D5),$$

where u is the urbanization rate – the share of the population living in urban areas. These assumptions imply the following expressions for the main variables in equation (D2):

$$Q^a = Nw^\beta \ (D6a),$$

$$Q^n = pQ^a \frac{u}{1-u} = pNw^\beta \frac{u}{1-u} \ (D6b),$$

$$Q = Q^a + Q^n = N_i w_i^\beta \left(\frac{1+(p-1)u}{1-u}\right) (D6c),$$

$$\frac{Q^a}{Q} = \frac{1-u}{1+(p-1)u} \equiv s^a \ (D6d).$$

An implication of the assumption in equation (D4) is that there is no systematic difference between the volume share of sectoral output in GDP and the value share of sectoral output in GDP. Expressing equation (D2) in per capita terms, so $q = Q/N$ and applying the expressions from equation (D6a-d) allows us to write relative GDP per capita between countries i and j as:

$$\log\left(\frac{q_i}{q_j}\right) = \frac{\beta}{2}\left(s_i^a + s_j^a\right)\log\left(\frac{w_i}{w_j}\right) + \frac{1}{2}\left(1 - s_i^a + 1 - s_j^a\right)\log\left(\frac{w_i^\beta \frac{u_i}{1-u_i}}{w_i^\beta \frac{u_j}{1-u_j}}\right) (D7)$$

That leaves us with two observed variables, the real wage rate w and the urbanization rate u and two parameters, the income elasticity of demand for food β and the multiple of labor productivity in non-agriculture relative to agriculture, p. The literature has produced a set of

price and income elasticities which are plausible for the pre-industrial societies that are studied. Allen (2000) assumed an income elasticity of demand of 0.5; Malanima (2010) selected 0.4 and Alvaraz Nogal and Leandro Prados de la Escosura (2013) chose 0.3. For our estimates we took the middle range value of $\beta = 0.4$. We set the parameter p equal to 2, which is an assumption that seems a reasonable reflection of both the contemporaneous and historical record. Gollin, Lagakos and Waugh (2014) find that value added per worker in agriculture is, on average, half that in the rest of the economy, once correcting for observable differences in human capital and working hours. They also find that this labor productivity ratio does not vary systematically with the country's income level. In an historical context, the work of Broadberry et al. (2015), and Van Zanden and Van Leeuwen (2012) provide further justification for this assumption.

We use this approach to estimate relative GDP per capita for African countries in 1950 relative to South Africa. Real wage information is obtained from the work of Frankema and van Waijenburg (2012), Bolt and Hillbom (2015), for former British Africa. For former French African countries we include newly constructed real wage information based on archival material. Table D1 shows the results of this exercise, where we South Africa as the base country. The reason for this is that these countries are more likely to be similar in structure to the richest country in Sub-Saharan Africa, South Africa, rather than the advanced economies in Europe and America. This logic is also applied in ICP, where price and income comparison are first made within regions and only then across regions. While this structure has roots in the administrative setup of ICP, Deaton and Heston (2010) argue that this structure has an important advantage in comparing more-similar countries first, before comparing less-similar countries. As Table D1 shows, the indirect benchmark estimates are mostly very similar to the estimates based on extrapolation for most countries. The main exceptions are several countries for which the original extrapolation leads to very low income levels: Burkina Faso, Mali and Nyasaland (present-day Malawi). Given South Africa's GDP per capita level of $5278 in 1950, this puts all countries above subsistence levels, while this is not the case for the extrapolated estimates for Burkina Faso, Mali and Nyasaland. We therefore use the estimates in Table D1, linking them to the rest of the database using South Africa's GDP per capita level in 1950.

Table D1. Indirect benchmark estimates of relative GDP per capita in 1950

	Urbanization rate	Relative level (ZAF=100) of:		Extrapolation
		Real wages	GDP/capita	GDP/capita
South Africa	0.25	1.00	1.00	1.00
Mauritius	0.29	0.23	0.60	0.74
Senegal	0.17	0.20	0.44	0.30
Ghana	0.15	0.22	0.44	0.29
Gambia	0.10	0.16	0.35	0.24
Sudan	0.11	0.14	0.34	0.32
Sierra Leone	0.07	0.17	0.33	0.13
Cote d'Ivoire	0.10	0.14	0.33	0.37
Nigeria	0.09	0.11	0.28	0.26
Kenya	0.06	0.11	0.26	0.25
Burkina Faso	0.04	0.12	0.26	0.08
Botswana	0.03	0.14	0.25	0.13
Mali	0.09	0.07	0.24	0.10
Tanganyika	0.04	0.11	0.24	0.19
Guinea	0.07	0.07	0.23	0.16
Benin	0.05	0.08	0.23	0.20
Uganda	0.03	0.10	0.22	0.17
Niger	0.05	0.07	0.22	0.16
Nyasaland	0.04	0.05	0.17	0.08

E. Oil-rich countries

Some of the largest differences between the original Maddison 1990 benchmark figures and more recent figures can found in oil-exporting economies. Table E1 illustrates this for 13 countries with data for 1990. Not all these countries were major oil exporters already in 1990, but for most of these countries substantial differences can be seen between GDP per capita based on the original Maddison 1990 figures and the new estimates based on multiple (ICP) benchmarks (MBM). The most extreme case is United Arab Emirates, whose income level was 61 percent of the US level in 1990 according to Maddison, but 343 percent of the US level according to the multiple benchmarks estimates.

Table E1, Relative income levels and oil dependence in 1990 for selected countries

Country	ISO code	Oil share	GDP per capita (USA=100)			ICP coverage
			Maddison	MPD	Difference	
Equatorial Guinea	GNQ	0	7	5	-2	2005, 2011
Iran	IRN	18	15	13	-2	All except 1980
Iraq	IRQ	3	11	20	9	2005, 2011
Venezuela	VEN	20	35	20	-15	1980, 1996, 2005, 2011
Algeria	DZA	12	12	22	10	2011
Trinidad and Tobago	TTO	29	40	26	-14	1985, 1996, 2011
Oman	OMN	45	28	30	2	1996, 2005, 2011
Bahrain	BHR	15	18	39	21	1996, 2005, 2011
Saudi Arabia	SAU	32	38	48	10	2005, 2011
Kuwait	KWT	40	28	63	36	2005, 2011
Libya	LBY	n.a.	13	66	52	none
Qatar	QAT	59	30	94	64	1996, 2005, 2011
United Arab Emirates	ARE	4	61	343	282	2011

Notes: 'oil share' is the share of fuels and lubricants exports in real GDP (source: PWT 9.0). Maddison GDP per capita figures are computed based on the Maddison (2008) database, MPD is the new Maddison Project Database figures.

Since many of these countries did not participate in ICP benchmarks before 2005, the MPD estimates for 1990 are predominantly based on extrapolations using National Accounts figures. The heavy reliance on oil exports means that swings in terms of trade will have a substantial effect on GDP and places a substantial burden on statistical offices in the countries to produce accurate price and volume estimates. The required statistical capacity is not uniformly available

in this set of countries. It is therefore sensible to also present the 2011 relative income and price levels, in Table E2.

The table illustrates that even in this benchmark year, several countries show levels of GDP per capita that are close to or (substantially) exceed US levels. The relative price levels, in turn, are comparatively low as income levels increasing towards those in the US would normally imply relative price levels rising to similar levels as well.

Table E2, Relative income and price levels and oil dependence in 2011 for selected countries

Country	ISO code	Oil share	GDP/capita (USA=100)	Price level (USA=100)
Equatorial Guinea	GNQ	82	88	55
Iran	IRN	15	36	44
Iraq	IRQ	35	23	43
Venezuela	VEN	30	36	61
Algeria	DZA	25	27	41
Trinidad and Tobago	TTO	38	60	61
Oman	OMN	44	89	48
Bahrain	BHR	0	73	61
Saudi Arabia	SAU	39	98	48
Kuwait	KWT	53	155	62
Libya	LBY	n.a.	27	50
Qatar	QAT	60	313	57
United Arab Emirates	ARE	41	131	61

Notes: see Table D1. Price level refers to the price level of GDP^o from PWT 9.0.

To illustrate the peculiarity of GDP per capita figures in this set of countries, it is helpful to also compare the level of domestic absorption per capita (consumption plus investment, i.e. GDP excluding net exports) and consumption per capita (including household and government consumption). Table E3 shows this comparison for 2011. Especially relative consumption levels are substantially lower than relative GDP, with Equatorial Guinea as a striking example, where GDP/capita was 88 percent of US level, but consumption/capita only 13 percent. All countries in this comparison have consumption/capita levels well below those in the US.

So a first conclusion has to be that for this set of countries in particular, GDP per capita is a poor measure of current living standards, with so much of income not consumed or invested

domestically, but invested abroad. “Squaring the circle”, whereby GDP per capita would accurately reflect current living standards would, in turn, require unrealistically high price levels of GDP.[35] A second conclusion, based on the comparison between Tables E1 and E2, is that some of the National Accounts time series are suspect. For instance, why would the United Arab Emirates have a GDP/capita level in 1990 that is even higher than in 2011 while oil exports where only one-tenth as large (relative to GDP)?

Table E3, Relative levels of GDP, domestic absorption and consumption in 2011

Country	ISO code	GDP	Dom. Absorp.	Consumption
Equatorial Guinea	GNQ	88	45	13
Iran	IRN	36	31	28
Iraq	IRQ	23	19	19
Venezuela	VEN	36	29	27
Algeria	DZA	27	23	20
Trinidad and Tobago	TTO	60	44	43
Oman	OMN	89	61	46
Bahrain	BHR	73	55	50
Saudi Arabia	SAU	98	72	52
Kuwait	KWT	155	76	64
Libya	LBY	27	n.a.	n.a.
Qatar	QAT	313	164	61
United Arab Emirates	ARE	131	99	76

Source: PWT 9.0

Note: 'Dom. Absorp.’ is domestic absorption.

For the final comparison, it is helpful to contrast the Maddison 1990 income levels with the relative price levels implied by these income levels. This requires additional data on GDP per capita converted to US dollars using market exchange rates. To put the magnitudes of these

[35] To be more precise: for the relative level of GDP/capita in (for example) Equatorial Guinea to be equal to its relative consumption/capita level would imply a GDP price level of 372 percent of the US, a level never observed in international price comparisons.

relative price levels in context, the final column presents standardized residuals, based on comparing the implied price levels to predicted price levels from a Balassa-Samuelson price-income regression for (the log of) all benchmark price level observations and (the log of) GDP per capita converted to US dollars using market exchange rates. It is clear that the price levels required to arrive at the Maddison 1990 relative income levels are often unrealistically high and sometimes unrealistically low, using a standardized residual of approximately ±2 as a standard for realism. So the third conclusion would be that Maddison 1990 income estimates are not a plausible alternative to the MBM income estimates.

Table E4, Relative income and price level in 1990 based on Maddison and price residual

Country	ISO code	GDP/capita (USA=100)	Price level (USA=100)	Standardized Residual
Equatorial Guinea	GNQ	7	22	-1.97
Iran	IRN	15	47	0.03
Iraq	IRQ	11	489	7.10
Venezuela	VEN	35	28	-2.39
Algeria	DZA	12	81	1.98
Trinidad and Tobago	TTO	40	44	-1.21
Oman	OMN	28	98	1.49
Bahrain	BHR	18	232	4.42
Saudi Arabia	SAU	38	79	0.43
Kuwait	KWT	28	137	2.38
Libya	LBY	13	236	4.93
Qatar	QAT	30	218	3.40
United Arab Emirates	ARE	61	193	1.75

Note: 'Standardized residual' is the difference between the relative price level implied by Maddison's relative income estimates and the price level predicted by the Balassa-Samuelson price-income relationship, standardized by the standard deviation.

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