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COMPARING PER CAPITA INCOME IN THE HELLENISTIC WORLD: THE CASE OF MESOPOTAMIA

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Until quite recently, GDP growth between ca. 1 CE and the late Middle Ages was considered non-existent or even negative. Recently, largely on account of increasing interest in historical national accounting, the late-medieval figures have been revised upward, in line with an upward adjustment in the estimated shares of manufacturing and pasture. Leaving GDPs dating from the ancient world unaltered would consequently generate figures indicating increased economic growth during the first millennium CE. A considerable number of studies of the late-medieval period (the object of increasing attention on the part of specialists in early economic history) have caused estimates for the ancient one to be revised upwards, essentially leaving estimates of the changes in economic development over time unaltered. These studies, however, have focused on the Roman Empire and Italia while there is a consensus in the literature that it was quite unrepresentative of all ancient societies with its relatively high share of GDP from the manufacturing sector of the economy. We therefore estimate a new per capita income for another contemporary agrarian society: ancient Mesopotamia. In addition, by examining manufacturing and pasture—the two main reasons for higher income which have been identified in the literature—we have found a tentative explanation for the fact that ancient Mesopotamia's per capita income deviated from that of Rome.

1. Introduction

Comparative scientific research into the standards of living and per capita income of pre-industrial societies has attracted increasing interest. Largely on account of a simplistic application of the theory of the Malthusian trap, nothing new of any significance was expected to emerge from this field, but in recent years several surprising phenomena, including relatively high income levels, have emerged.[1] It used to be assumed that the economies of the ancient world were based on a worldview entirely alien from the modern one (see the substantivist-modernist debate), but it is now evident that operating markets were present and have always been subject to exogenous shocks (Temin, 2002).

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[1]There have been a number of studies of various regions of medieval and post-medieval Europe, including Holland, Italy, and Spain, spanning the second through the seventeenth centuries (Álvarez-Nogal and Prados de la Escosura, 2009; Malanima, 2009; Broadberry *et al*., 2011; Van Zanden and van Leeuwen, 2011), while among recent studies of the ancient period there are several that focus on the Roman Empire (e.g. Lo Cascio and Malanima, 2009; Scheidel and Friesen, 2009), Athens (Amemiya, 2007), and Mesopotamia (Bedford, 2007).

Two main conclusions can be drawn from this new branch of quantitative studies. First, it seems that per capita income in both 1 CE and 1000 CE were significantly higher than the 500–600 G-K dollars estimated by Maddison (2007). Recently Scheidel and Friesen (2009) revised Maddison's estimates for the Roman Empire, having determined that per capita income at the time was roughly 800 G-K USD at 1990 prices.

Second, the relative positions of ancient and medieval economies remains stable, since it seems that throughout Italia during the first millennium CE per capita GDP declined (Maddison, 2007; Lo Cascio and Malanima, 2009). This finding, however, has yet to be provided with a satisfactory explanation. What we know about income in economies of the ancient world is based mostly on estimates for Rome; the medieval period fares somewhat better, in that economic data on Italy is supplemented by some from Holland, Spain, and England. It goes without saying that these economies' structures, being significantly different, guarantee that differences will be observed when it comes the evolution of income. Italy is the only one of these regions for which we can observe this evolution across the entire period under consideration. The finding of Lo Cascio and Malanima (2009) that Italian per capita income decreased after the fall of the Roman Empire is above question, supported as it is by irrefutable anthropometric evidence. Angel (1984) claims that heights in the eastern Mediterranean peaked between ca. 200 BCE and 120 CE, at a level not to be reached again until after 1500. Such a dramatic decrease in the per capita value added was most likely caused by a decline in the manufacturing sector, partly by the loss of export markets and partly by the contraction of the local market, but this pattern does not necessarily apply to other European economies; those that were focused on their own subsistence may have been far less affected by the dissolution of the western portion of the Roman Empire. In analyzing the economy of a society that has developed a standard measure of income (either a monetary unit or a single product, such as wheat), one cannot dismiss the possible effect of agricultural structure on these estimates. For example, toward the start of the fourteenth century England's share of manufacturing was far smaller than Italy's, but the pastoral sector was sufficiently significant to narrow, if not quite to close, the gap in terms of per capita income. The underlying reason may simply be that the same amount of nutritional value is produced with more resources by raising livestock than when produced by arable farming (Broadberry and Campbell, 2009).

It is for this reason that one must look not only at look at the development of GDP but also at its structure. Since both Rome and Athens had developed significant manufacturing sectors, we need an estimate for a society more dependent upon arable farming, and we find such a society in ancient Mesopotamia: a largely agricultural economy with a low share of pasture, and low level of international trade.[2] Assuming that either pasture or labor productivity outside agriculture is the

[2]It had, though, a relatively high level of urbanization. Bairoch (1988) estimated an urbanization ratio of 5 percent for the region around Ur in 2300 BCE. He assumes that Babylon's population numbered about 200,000–300,000. If we take the average of his estimate, if we estimate a population of about 30,000 for each of the nine other major cities in ancient Mesopotamia, and if we accept the population estimate of Aperghis (2009) of 4.65 million for ancient Mesopotamia as a whole, we arrive at an urbanization rate of 11.2 percent.

source of different GDP estimates, Mesopotamia should have a lower income per capita than Italia or Athens.

In this paper we cross-check the production approach for ancient Mesopotamia with both the income and the expenditure approaches, in order to arrive at a range of estimates of per capita GDP. In the next section, we will discuss the construction of Mesopotamian income. In Section 3 we move on to an analysis of the development of per capita income over the period ca. 400–50 BCE. Section 4 then treats the issue of comparability with other regions. In the final section we present our conclusions.

2. Calculating Mesopotamian GDP

Several efforts have been made to "guesstimate" income levels in ancient societies (Hopkins, 1980; Goldsmith, 1984; Milanovic, 2006; Temin, 2006; Maddison, 2007; Scheidel and Friesen, 2009). Most of them are based on a feasible version of the expenditure method of GDP estimation in which GDP is usually divided into consumption, investment/savings, public expenditure, and, in case of open economies, net exports. Due to the lack of reliable and detailed information on these, however, one is obliged to make some assumptions regarding the minimum consumption needed for the population to survive, usually expressed in caloric value, and then convert this estimate into a money or grain equivalent. Another set of assumptions is needed about the extent of the rest of the equation.[3]

These methods, rough as they may be, are valuable in that they cross-check the GDP with the probable per capita kcalorie consumption. Hence, unless they increase per capita consumption by a certain percentage, they can only be considered as reliable minimum estimates. For instance, Bedford (2007, p. 327) makes a rough estimate of the minimum per capita GDP for Mesopotamia based on the average price of barley and a minimum per capita consumption. Since relying on the expenditure side alone yields only a minimum estimate, it is important to include GDP estimates from the income side as well as the output side. Since all three methods should result in the same figure for per capita income, this means that each of the underlying data and assumptions in the estimates must be consistent with all others, or else there will be a discrepancy in the outcomes of the three methods.

We begin by defining the geographical scope of our estimates. Ancient Mesopotamia extends beyond Babylonia, its borders roughly those of present-day Iraq for the period 400–60 BCE: a period that we have chosen to focus on because of its abundant price data, while for the earlier period we have information on wages and even consumption important for calculating GDP.

The size of Mesopotamia's population has been much discussed. Maddison's (2007) figure of one million seems to be a major underestimate. As Aperghis (2004) shows, tax revenue from agriculture was so high that the tax rate would have had to be astronomical if the tax base had comprised only a million people. In addition, since the amount of cultivated land necessary to support a person in an ancient

[3]Goldsmith assumes 8 percent for the share of public expenditure in GDP for Rome, while Maddison revises this to 13 percent.

society is set between 0.5 and 1 hectare (e.g. Pastor, 1997; Aperghis, 2004), feeding a million Mesopotamians would have required a minimum of one million hectares, only 2.3 percent of the total area. In the 1950s, when the population of Iraq numbered 4.8 million, approximately 10 percent of the land was effectively used, and it is possible that around 200 BCE even more land was available for cultivation (Van der Spek, 2008). If a population estimate of 1 million were valid, it would follow that much fertile land was underutilized. In fact, however, Aperghis (2004, pp. 36–40), using archaeological data mainly from Adams and Nissen (1972) and Adams (1981), calculated the population densities of several survey regions and then extrapolated them to arrive at estimates for larger regions: approximately 750,000 for the central Euphrates flood plain, and about half a million for each of the following: southern Babylonia, the Nippur region, the Diyala region (east of Baghdad), the Seleukeia-Tigres area, and the south-eastern corner of the Mesopotamian plain. In addition, there is evidence that the eastern bank of the Tigris and Northern Mesopotamia were fertile and well populated. Combining all these data, Aperghis (2004, p. 40) arrives at a population estimate of between 4 and 5 million.

It is important to bear in mind that our per capita GDP figures are not very sensitive to the actual population, since we also rely on the income and expenditure approach, none of which requires a population estimate. We therefore follow Aperghis (2009) and set the population of Mesopotamia in 400 BCE at 4.65 million.

By applying Aperghis's (2001, 2009) results to the production approach, we can arrive at a per capita GDP estimate. Aperghis estimates that the total annual agricultural output (including 10 percent pasture) ca. 300–400 BCE was about 10,000 talents. This number needs to be reduced by the value of intermediate inputs, which is assumed to be 20 percent of the gross output (based on the 1841 input–output table for England; Horrell *et al.*, 1994). Furthermore, we are obliged to make certain assumptions regarding the non-agricultural sectors. Aperghis (2009) estimates the rate of non-agricultural workers at 40 percent; we use this figure to increase our agricultural output estimate. It is arguable that this will result in an overestimation of the number of people working in manufacturing, since many of them may also be employed in the agricultural sector. Indeed, as Adam Smith argued as the manufacturing sector of an economy increases at the expense of the agricultural sector, the share of by-employment declines (Smith, 1976, pp. 15–16). Since Mesopotamia is an ancient economy with a large agricultural sector, one would hence expect a high rate of by-employment. However, as shown by Saito and Settsu (2010, figure 2), the importance of by-employment is indicated by an inverted u-curve. A very high share of agriculture also reduces by-employment. It is therefore safe to assume that when it comes to calculating per capita GDP for ancient Mesopotamia, by-employment does not pose a serious problem.

Allowing for these assumptions, we arrive at 11,200 talents total GDP, or 0.00241 talents per capita, to 8676 shekels a year, which, if we assume a price of 8.056 shekels per 1000 liters for barley (the median during the sixth century BCE), was enough to buy approximately 1077 liters annually. The kcaloric equivalent of this is 5665 kcal per day per person, which is far more than the minimum required intake, providing a surplus that could be used for trade and the purchase of non-food items. To estimate Mesopotamian GDP, Bedford (2007), following

Hopkins, relies on the production approach. Estimating a much larger population (5.5 million) and a much lower grain price (1 kur (180 l) = 1 shekel, which comes out to 5.56 shekels/1000 liters), than we do, he arrives at an agricultural-production estimate of 4965 talents and a total GDP of 12,400 talents. If we take population differences into account, this estimate, in per capita terms, is about 6 percent lower than ours.

If these estimates are to be used for comparisons over time and space, they have to be converted into a common unit; the standard one is the Geary-Khamis (G-K) international dollar at 1990 prices. This conversion is effected through the intermediary of a comparable good, either grain equivalents or gold; the choice has a significant impact on the outcome. Lo Cascio and Malanima (2009) demonstrate convincingly that, with the massive inflow of precious metals since the early modern period, the value of gold has declined sharply relative to that of other goods. As a result, using gold is bound to yield underestimated G-K dollar sums. Using grains seems preferable, but the outcome will depend on whether one uses a single grain (since the composition of staple food consumption may have varied at the regional level) or an average price of a bundle (since there was no Mesopotamia-wide standard of measurement). To complicate matters further, the method is sensitive to the choice of base year: a source, according to Lo Cascio and Malanima, of the underestimation of Roman GDP by Maddison (2007), who relies on the grain prices estimated by Gregory King for 1688, when grain prices were exceptionally low. Using a 20-year average instead, they arrive at revised estimates at least twice as high as Maddison's.

We follow Lo Cascio and Malanima in that we convert to the 1990 G-K dollar, using early modern England as reference. One should avoid using barley equivalents, however, since in Babylon barley was a preferred good whereas in England it was deemed inferior to wheat. We therefore follow Scheidel (2010), who uses a conversion factor of 0.8 to convert the caloric value of barley to that of wheat, and arrive at 861.6 liters of wheat per person per annum in Babylon ca. 500 BCE. The median wheat price in England between 1676 and 1700 was 4.25 shillings per bushel, or 0.2125 pounds per bushel. Since one bushel is equivalent to 35.239 liters, we arrive at a price of 6.03 pounds per 1000 liters. If we accept Gregory King's estimate of English per capita income of 9.958 pounds, the average person could buy 1651 liters of wheat per annum. According to Maddison's estimates, this is equivalent to 1411 G-K dollars at 1990 prices, implying an exchange rate of 1.17 liters of wheat per G-K 1990 dollar. Calculated in wheat equivalents, per capita income in Mesopotamia ca. 500 BCE thus comes out to 736 G-K dollars.[4]

The income approach serves the purpose of a cross-check. Jursa (2010, pp. 297, 300) estimates the average wage at 2.5 shekels per month for a male worker, and two-thirds and one-third of this sum for a woman and a child, respectively. It

[4]One can also convert our income estimate to the G-K dollar by, following Milanovic (2006), using the kcalorie equivalent of the per capita income (5665 kcal, in this case), which is 2.27 times the minimum calorie intake of 2500 kcal. If we convert this minimum income to 400 G-K dollars at 1990 prices, we arrive at 906 G-K dollars per person per annum. However, this approach is very sensitive to the choice of the G-K dollar equivalent of the minimum income (for example, 350 USD would reduce our estimate to approximately 790 USD at 1990 prices). We would like to express our gratitude to one of the anonymous reviewers for drawing our attention to this alternative conversion approach.

is safe to assume that each household consisted of five persons, on average, but since it is extremely unlikely that all of them were wage earners, per-household wages were probably only about 2–4 shekels per month, making for an annual wage income of 9.6 shekels, which could purchase 596–1192 liters of barley per person per annum, providing 3134–6268 kcal per person per day: figures quite close to those attained by the production method. Using the wheat-equivalents method, we arrive at an estimate of 477–953 liters of wheat per person per annum,[5] which can be converted into 407–815 G-K dollars at the exchange rate of 1.17 dollars per liter. However, this is only the wage-bill estimate; other sources of per capita income, including land rents and capital returns, modest as they may have been, cannot be ruled out. However, it is safe to assume that in an agricultural economy no more than 10 percent of total income is derived from any source other than land and labor, chiefly the latter. Without any certain knowledge of what, in fact, the ratios were, we estimate 70 percent for labor, 20 percent for land, and 10 percent for the rest, and arrive at a per capita annual income of 582–1164 1990 G-K dollars. Data regarding household income are insufficient to permit a more accurate income-side estimate, but if we assume that each household earned a total of 2.5 shekels a month, we arrive at 728 G-K dollars, which coincides nicely with the production-side estimate.

The expenditure approach obliges several assumptions concerning consumption, investment, and public spending, but trade is of little if any consequence, since high transaction costs allowed only a limited import–export activity, and the establishment of silver as the standard currency should have lead to balanced trade anyway. Jursa (2010) calculates that in ancient Babylonia food purchases constituted 76 percent of the average household's expenditures, the remaining 24 percent going to housing and other goods and services. If we assume that the average household consisted of a couple and their three children, we can estimate both an absolute minimum and a more abundant calorie intake. An Indian medical report (ICMR, 1958) suggests that a hardworking male's daily kcal requirement is about 3500–4000, a woman's about 2500–3000, and a child's, depending on age and sex, about 1500–2500; we therefore estimate an overall actual minimal kcal intake, for our five-member family, of about 2000 kcal: enough for survival, but at the price of lower productivity, lower fertility, and an increased mortality rate.

If these calories were provided exclusively and in equal amounts by barley and dates (the price of barley being set at 8.056 sh/1000 l and of dates at 7.5 sh/1000 l; Jursa, 2010), an individual would have needed to consume a minimum of 190.1–237.6 liters of barley and dates, costing 2.96–3.69 shekels, per annum. However, these figures represent only 76 percent of total consumption and total cost, which would therefore instead come to 3.89–4.86 shekels per person per annum.

While we have no direct data on savings and investments in ancient Babylonia, we can safely assume that it existed, since the construction of buildings and the sowing of crops required the purchase of tools and draft animals. However, it was necessarily only a modest amount, so we estimate it at a maximum of 15 percent of total income. Presumably government taxes took a similar bite out of income,

[5]Scheidel (2010) reports wages in wheat equivalents similar to our lower limit from 321 BCE (1.3 liters per day).

making for a total expenditure, on average, of 6.4–8.32 shekels per person per annum. Using the wheat-equivalent calculation, by which 8.676 shekels equaled 736 G-K dollars at 1990 prices, we arrive at a total expenditures estimate of 471–589 G-K dollars. It is important to remember that this calculation presupposes a minimum caloric intake derived almost entirely from barley and dates. If instead we assume that Mesopotamians could afford meat and beer from time to time and that they consumed 3000 kcal per day, we arrive at 707 G-K dollars, which is reasonably close to the previous estimates.

Since calculations based on the three approaches—production, income, and expenditure—corroborate one another, it is safe to conclude that GDP in ancient (fifth century BCE) Mesopotamia was the equivalent of 700–750 G-K dollars. However, one must bear in mind that much higher grain prices are recorded in data that have survived from subsequent centuries, particularly the third BCE, indicating that during the Hellenistic period income must have fluctuated significantly.

Our income estimate for ancient Mesopotamia is higher than the subsistence level, 400 G-K dollars, but lower than the one for the Roman Empire (e.g. Lo Cascio and Malanima, 2009; Scheidel and Friesen, 2009) or Byzantium (Milanovic, 2006). At first glance, these results seem to contradict the Malthusian theory that per capita income is consistent across space and time, but in fact average wages were similar across the societies under consideration, when expressed in their caloric equivalent; it was the price of these calories that differed significantly. It is for this reason that the production structure is a key variable when one compares the economies of any societies, but especially dissimilar ones. Predominantly agricultural ones, such as Mesopotamia and ancient China, could produce a unit calorie at a lower cost than could those with considerable pasture, such as Spain and England. As a result, even in the ancient world, the income level, when converted into a common monetary unit, was necessarily higher in societies with a relatively high rate of meat consumption (and therefore perhaps a relatively low population density).

3. An Estimation of Changes in Per Capita Income in an Agricultural Society: Mesopotamia ca. 400–50 BCE

Now that we have a benchmark level of per capita GDP, the next step is to determine whether this level remained stable over time or whether it was affected by changing economic circumstances during this 300-year period. This also allows us to compare this level with estimates for Athens and Rome for later periods. Unfortunately, we largely have price data, so we must develop a method to predict developments of per capita income using price data exclusively. This method, which to our knowledge has not been used before, cannot be more than tentative however, given the limited availability of data.[6]

The method that we use is based on the premise that income level determines how income is spent. The primary concern of those living at or near the subsistence level is to consume food that contains a quantity of calories sufficient for survival,

[6]The data are for Babylon and are derived from Slotsky (1997), Vargyas (2001), and Slotsky and Wallenfels (2010). A reworked dataset was kindly made available to us by Van der Spek.

whereas among those who are better off the quality of those calories—taste—becomes a significant factor in food choices.

A simple model suffices to show that in a society close to the subsistence level the prices of basic foodstuffs are, as rule, proportionate to their caloric values. This model obliges several other assumptions, which we list below.

1. We assume that the society cultivates and consumes two staple crops: this assumption is valid for Babylon (barley and dates) as well as England (barley and wheat). However, the model can theoretically be extended to include more than two crops.
2. We assume that the society comprises two groups with different income levels: one, dubbed "poor (p)," whose per capita income is subsistence level ($y^{\min}$); and another, dubbed "rich (r)," whose per capita income is at the opposite end of the scale ($y^{\max}$). The shares of the two groups in the society are λ and $1-\lambda$, respectively. The total income of the two groups is $Y^r = (1-\lambda)y^{\max}N$ and $Y^p = \lambda y^{\min}N$, where N denotes the population.
3. We assume that the society's "poor" group has linear preferences: that is, it maximizes its calorie intake under given budget restrictions, a situation described by $U^p = c_1Q_1^p + c_2Q_2^p$, where U^p is the utility of the poor, c_1 and c_2 denote the calorie content of the two crops, and Q_1^p and Q_2^p denote the quantities of the two crops consumed by the poor (in the case of Mesopotamia, barley and dates).
4. The "rich" group has its own preferences, for example, a Cobb–Douglas type, such as (the notation is the same as that used for the "poor" group, above) $U^r = (Q_1^r)^\gamma (Q_2^r)^{1-\gamma}$. The parameter gamma is above 0.5 if product 1 is preferred to product 2: in the case of ancient Mesopotamia, barley and dates, respectively.
5. We assume that the quantities of crops 1 and 2 (S_1 and S_2) are fixed: this is not only necessary to keep the model simple, but also plausible, since when the actual consumption decisions are made the supply can no longer be adjusted, because changing the production structure in agriculture is a difficult and time-consuming process. Of course, supply is a function not only of the production process but also of storage capacities: by storing a portion of their crops, producers could temporarily reduce market supply and thereby force prices to rise. However, this possibility can be safely dismissed in the case of ancient Mesopotamia, since, as it turns out, preindustrial societies did not make use of crop storage to a significant extent (McCloskey and Nash, 1984; van Leeuwen *et al.*, 2011). In the absence of storage systems, the supply is inelastic, and prices are a function of demand only.
6. Agents are subject to their respective budget constraints, represented by the equations $Y^r \geq p_1Q_1^r + p_2Q_2^r$ and $Y^p \geq p_1Q_1^p + p_2Q_2^p$, with two equations of equilibrium conditions: $S_1 = Q_1^r + Q_1^p,\ S_2 = Q_2^r + Q_2^p$.
7. We assume that both the "poor" and the "rich" groups attempt to maximize their utility independently of each other: that is, there is no single representative agent or social planner for the entire economy. The choices of the two groups are, however, interdependent because both are subject to a single set of prices and supply constraints.

We begin by deriving the first-order conditions for the utility maximization of the two groups and express the price ratios at the optimal choice:

$$\frac{p_1}{p_2} = \frac{c_1}{c_2} \text{ for the poor and } \frac{p_1}{p_2} = \frac{\gamma Q_2^r}{(1-\gamma) Q_1^r} \text{ for the rich.}$$

We can use these, together with the budget constraints, to derive the demand functions:

$$\left(Q_1^p\right)^d = \frac{Y^p}{p_1} + \frac{p_2}{p_1} Q_2^p = \frac{Y^p}{p_1} + \frac{c_2}{c_1} Q_2^p \text{ and } \left(Q_2^p\right)^d = \frac{Y^p}{p_2} + \frac{p_1}{p_2} Q_1^p = \frac{Y^p}{p_2} + \frac{c_1}{c_2} Q_1^p \text{ for the}$$

poor.

For the rich we get the following demand functions:

$$\left(Q_1^r\right)^d = \frac{Y^r}{p_1} + \frac{p_2}{p_1} Q_2^r = \frac{Y^r}{p_1} + \frac{(1-\gamma)}{\gamma} Q_1^r = \frac{Y^r \gamma}{p_1} \text{ and}$$

$$\left(Q_2^r\right)^d = \frac{Y^r}{p_2} + \frac{p_1}{p_2} Q_1^r = \frac{Y^r}{p_2} + \frac{\gamma}{(1-\gamma)} Q_2^r = \frac{Y^r (1-\gamma)}{p_2}.$$

The demands of the two groups can be added using the equilibrium conditions:

$$S_1 = (Q_1)^d = \left(Q_1^p\right)^d + \left(Q_1^r\right)^d = \frac{Y^p}{p_1} + \frac{c_2}{c_1} Q_2^p + \frac{Y^r \gamma}{p_1}$$

$$S_2 = (Q_2)^d = \left(Q_2^p\right)^d + \left(Q_2^r\right)^d = \frac{Y^p}{p_2} + \frac{c_1}{c_2} Q_1^p + \frac{Y^r (1-\gamma)}{p_2}$$

We can eliminate the Q_1^p and Q_2^p from the above expression by using the equilibrium conditions:

$$S_1 = \frac{Y^p}{p_1} + \frac{c_2}{c_1}\left(S_2 - Q_2^r\right) + \frac{Y^r \gamma}{p_1} = \frac{Y^p}{p_1} + \frac{c_2}{c_1}\left(S_2 - \frac{Y^r (1-\gamma)}{p_2}\right) + \frac{Y^r \gamma}{p_1}$$

$$S_2 = \frac{Y^p}{p_2} + \frac{c_1}{c_2}\left(S_1 - Q_1^r\right) + \frac{Y^r (1-\gamma)}{p_2} = \frac{Y^p}{p_2} + \frac{c_1}{c_2}\left(S_1 - \frac{Y^r \gamma}{p_1}\right) + \frac{Y^r (1-\gamma)}{p_2}$$

and thereby, in turn, express the equilibrium prices:

$$p_1 = \frac{Y^r \gamma + Y^p}{S_1 + \frac{c_2}{c_1}\left(S_2 - \frac{Y^r (1-\gamma)}{p_2}\right)} = \frac{(1-\lambda) y^{\max} N \gamma + \lambda y^{\min} N}{S_1 + \frac{c_2}{c_1}\left(S_2 - \frac{(1-\lambda) y^{\max} N (1-\gamma)}{p_2}\right)} \quad \text{and}$$

$$p_2 = \frac{Y^r (1-\gamma) + Y^p}{S_2 + \frac{c_1}{c_2}\left(S_1 - \frac{Y^r \gamma}{p_1}\right)} = \frac{(1-\lambda) y^{\max} N (1-\gamma) + \lambda y^{\min} N}{S_2 + \frac{c_1}{c_2}\left(S_1 - \frac{(1-\lambda) y^{\max} N \gamma}{p_1}\right)}.$$

It is useful to examine two limiting cases. First, when the society is extremely poor and probably at the verge of famine, we have:

$$\lim_{\lambda \to 1} p_1 = \frac{y^{\min} N}{S_1 + \frac{c_2}{c_1} S_2} \text{ and } \lim_{\lambda \to 1} p_2 = \frac{y^{\min} N}{\frac{c_1}{c_2} S_1 + S_2} \text{ that is: } \lim_{\lambda \to 1} \frac{p_1}{p_2} = \frac{c_1}{c_2}.$$

In other words, as a society approaches the famine level (an absolute minimum level of income) the closer is the equilibrium price of products (according to the assumptions we itemized above) to their calorie content. It is important to note that the supply is completely absent from the formula describing the price ratios when the society faces a famine. While this situation is counterintuitive, it is simply caused by the fact that—independent of the costs of the production process—in the event of famine, relative prices are primarily a function of calorie ratios.[7]

Second, when a society is better off, the price ratios will reflect tastes: this is evident when lambda approaches zero:

$$\lim_{\lambda \to 0} p_1 = \frac{c_1 p_2 y^{\max} N\gamma}{p_2 c_1 S_1 + p_2 c_2 S_2 - c_2 y^{\max} N(1-\gamma)} \text{ and } \lim_{\lambda \to 0} p_2 = \frac{p_1 c_2 y^{\max} N(1-\gamma)}{p_1 c_2 S_2 + p_1 c_1 S_1 - c_1 y^{\max} N\gamma}$$

$$\lim_{\lambda \to 0} \frac{p_1}{p_2} = \frac{c_1}{c_2} \frac{p_2 y^{\max} N\gamma [p_1 c_2 S_2 + p_1 c_1 S_1 - c_1 y^{\max} N\gamma]}{p_1 y^{\max} N(1-\gamma)[p_2 c_1 S_1 + p_2 c_2 S_2 - c_2 y^{\max} N(1-\gamma)]},$$ which is, under reasonable parameters, different from the calorie ratios. It can also be seen that now the price ratio depends on the supply of the two goods and of tastes (gamma) as well. It is safe to assume, however, that in a preindustrial society tastes do change significantly over the short term.

The above model indicates that, as the percentage of the poor in a given society increases, and average income therefore declines toward the subsistence level, the food preferences of the poor would dominate those of the rich, and that prices would increasingly reflect calorie ratios, as opposed to a function of quantity ratios. Although this relationship is not linear, it is possible to approximate it by functional forms linear in parameters.

Medieval England is the source of the best of the very few historical series by means of which this relationship can be tested, providing as it does both GDP and prices as well as quantities of wheat and barley, and thereby permitting us to estimate the above model and apply the resulting parameters to the estimate changes of per capita income in Mesopotamia, since we can safely assume that the inhabitants of both late-medieval England and ancient Mesopotamia maximized their caloric intake in cases of famine.

[7]This finding is independent of both the production technology and the relative supply of the two goods. Intuition would suggest that when two goods are similar in caloric value but different in terms of cost and availability, producers would be likely to set a higher price for the scarcer of the two products; however, if, as we assume, those living at the subsistence level maximize their calorie intake, they will not purchase the scarcer, more expensive product as long as they can purchase the cheaper one. As a consequence, the price of the initially cheaper product should rise, while the price of the scarcer, initially more expensive product should fall, until they converge.

TABLE 1
The Unit Root Test Results

Series	Log of the Price Ratio of Wheat and Barley	Log of Income	Log of Wages	Log of the Quantity Ratio of Wheat and Barley
KPSS	1.180	1.833	1.475	1.462
(H0: stationarity)	(p < 0.01)	(p < 0.01)	(p < 0.01)	(p < 0.01)
ADF	−8.42	−1.640	−1.336	−4.433
(H0: non-stationary)	(p < 0.01)	(p > 0.1)	(p > 0.1)	(p < 0.01)

For late-medieval England we have the price and output of wheat and barley, the two dominant staple crops, making up over 60 percent of the total kcaloric intake, a percentage that increased over time, with the decline of rye and oats consumption (Broadberry *et al.*, 2011). (Because the consumption structure changed significantly during the early modern period and the use of barley changed over time, we chose to make the end date for these data 1429.) It is to be expected that during periods of famine the price level reflects the kcaloric value of each of these two crops. If we follow Overton and Campbell (1996), who set the kcaloric value of a bushel of barley at 71,429 and of a bushel of wheat at 86,667, we arrive at a hypothetical wheat/barley price ratio, during such periods, of approximately 1.21 : 1: a plausible figure for this period, subsequent as it is to that of the Black Death, when the price ratio was on average 1.28. If the relationship we derived above holds, we should find that the price ratios, the quantity ratios, and the per capita income are cointegrated (provided they are non-stationary). To determine whether this is the case, we effect two unit-root tests (see Table 1).

The KPSS test indicates that all three series are non-stationary, while the ADF test rejects the null hypothesis of non-stationarity for the price and quantity ratios. Since both sets of results are plausible (although the KPSS test is generally considered superior to the ADF test), we are obliged to perform a Johansen test of cointegration; if the series are stationary, the coefficient matrix will be of full rank (three in this particular case).

Based on the information criteria we opted for a VAR model with three year lags when we used income and with four year lags when we used Allen's wage index. The results of the Johansen test are reported in Table 2.

The test indicates the presence of two cointegrating relations: a plausible finding, since not only output and prices but also prices and per capita income should be correlated. Taking into account this restriction, we arrive at the following two cointegrating relations (normalized at per capita income or wages):

$$\ln y_t = 1.457 + 6 \cdot \ln\left(\frac{p_t^{wheat}}{p_t^{barley}}\right)$$
$$\text{t-stat: } (8.56) \quad (37.0)$$

$$\ln\left(\frac{p_t^{wheat}}{p_t^{barley}}\right) = 0.506 - 0.184 \cdot \ln\left(\frac{Q_t^{wheat}}{Q_t^{barley}}\right)$$
$$\text{t-stat: } \quad (17.8) \quad (-10.7)$$

TABLE 2
COINTEGRATION TEST RESULTS

No. of Cointegration Vectors (r)	With Log of Income Per Capita		With Wages	
	Trace-Test	Maximum Eigenvalue Test	Trace-Test	Maximum Eigenvalue Test
0	95.51 ($p < 0.01$)	56.80 ($p < 0.01$)	78.69 ($p < 0.01$)	56.14 ($p < 0.01$)
1	38.71 ($p < 0.01$)	33.45 ($p < 0.01$)	22.56 ($p < 0.01$)	20.03 ($p < 0.01$)
2	9.16 ($p < 0.1$)	5.26 ($p < 0.1$)	2.52 ($p < 0.1$)	2.52 ($p < 0.1$)

Note: The null-hypothesis of the trace-test is that the number of cointegrating relations is r; the alternative hypothesis is that it is three (all series being stationary). The null-hypothesis of the maximum eigenvalue test is that the number of cointegrating relations is r; the alternative is that it is r + 1.

with wages:

$$\ln w_t = 2.484 + 3.945 \cdot \ln\left(\frac{p_t^{wheat}}{p_t^{barley}}\right)$$
$$\text{t-stat: } (16.3) \quad (17.0)$$

$$\ln\left(\frac{p_t^{wheat}}{p_t^{barley}}\right) = 0.551 - 0.447 \cdot \ln\left(\frac{Q_t^{wheat}}{Q_t^{barley}}\right)$$
$$\text{t-stat: } (12.6) \quad (-8.21)$$

That there are two cointegrating relationships is not surprising; it simply means that two equilibrium mechanisms are working simultaneously in the economy. The first cointegration vector represents the mechanism central to this study—namely, that the greater the percentage of the poor in a given society the greater the impact of their consumption preferences on that society's economy which requires that the relationship between relative prices and real income (wages) is positive. The second cointegration vector, which describes the equilibrium relationship between the relative quantities of the two goods and the price ratio, again yields the expected negative sign.

$$\ln y_t = 4.092 + 0.795 \cdot \ln\left(\frac{p_t^{wheat}}{p_t^{barley}}\right) - 0.958 \cdot \ln\left(\frac{Q_t^{wheat}}{Q_t^{barley}}\right)$$
$$\text{t-stat: } (48.7) \quad (4.82) \quad (-10.0)$$

$$\ln w_t = 3.729 + 1.687 \cdot \ln\left(\frac{p_t^{wheat}}{p_t^{barley}}\right) - 1.009 \cdot \ln\left(\frac{Q_t^{wheat}}{Q_t^{barley}}\right)$$
$$\text{t-stat: } (31.1) \quad (7.11) \quad (-7.03)$$

In other words, in both cases we find the elements of the cointegrating vector of the expected sign. In the case of per capita income, the long-run elasticity of income per capita with respect to the price ratio of the two main crops is roughly 0.8. It is not surprising to find that the elasticity is higher once we have real wages on the left side of the equation, since those more dependent on wage income were more sensitive to relative, barley-to-wheat, price changes.

However, for our purposes it is more useful to estimate a single cointegrating vector, which essentially yields coefficients that can be understood as weighted averages of the two cointegrating relationships and allows us to obtain long-run coefficients of the price ratio based on the assumption that the ratio between the supply of wheat and the supply of barley remains constant.

To apply this approach to ancient Mesopotamia, we use the price ratios of barley and dates both expressed in silver shekels per 1000 liters. Barley and dates constituted roughly 60 percent of kcaloric consumption.[8] For England we use the ratio between the prices of wheat and barley because wheat was the preferred staple, whereas for Babylon we use the ratio between barley and dates because barley was the preferred staple. Since the caloric values of barley and dates are very similar, at 1920 and 1928 kcal/l, respectively, one would expect that if lambda equals one (agents maximizing their calorie intake) the price ratio will be one. However, a portion of barley is inedible, reducing its caloric value by 20 percent. Although ancient Babylonians—like other ancient peoples—had no notion of caloric values, they did appreciate a sense of satiety, to which such roughage contributed, instead. Still it seems that over the long term, people arrived at a reliable estimate of the caloric value of barley; the price ratio reflects the fact that 20 percent of barley's volume contributed no calories: between 384 and 60 BCE the average ratio between barley and date prices was 1.74, with a maximum of 5.2 and a minimum of 0.45, and 28.8 percent of the time was below one. Of course, since a sudden increase in the barley supply could also account for its low price relative to that of dates, extreme poverty was not always necessarily the cause of these low barley-to-date-price ratios.

In the absence of estimates of elasticities in ancient Mesopotamia, we use those that we have for medieval England to estimate changes in per capita income, since it is safe to assume that throughout human history, and despite geographical and climatic variations, the behavior of those on the verge of famine has remained virtually unchanged.

Another crucial variable is the ratio between quantities. There are indications that during the second half of the first millennium BCE the ratio of barley to date production diminished, possibly on account of both soil salinization, reducing the barley harvest, and governmental policies favoring the cultivation of date; yet barley maintained its popularity, and was no doubt preferred by the rich. However, in the absence of solid evidence, we can only assume that there was no such diminution in the barley supply. Using these data we create an index in which we give a value of 100 to our estimate of subsistence-level income: i.e., the point at which, in this case, the prices of barley and dates drop to the same level. Assuming that, at this point, per capita income equals 450 G-K dollars at 1990 prices, which seems a safe assumption for a subsistence level of income, we can arrive at an estimate of fluctuations of per capita income. While the price ratio provides a more

[8]Jursa (2010, p. 300) calculated that in ancient Babylon barley and date consumption constituted 45.5 percent of total consumption. However, this calculation does not include beer, which was consumed in significant quantities and which, whether made from barley or from dates, had a high caloric content.

TABLE 3

Per Capita Income in Mesopotamia, ca. 384–60 bce

Period (bce)	Average Per Capita Income Index	Average Per Capita Income (1990 G-K USD)
Persian Empire (5th century bce)*		700–750
Persian Empire (384–331)	160.5	722
Hellenistic Empire (330–141)	137.1	617
New Persian Empire (240–60)	174.3	784

*Taken from direct estimates from Section 2 for the fifth century bce.
Source: Authors' calculations.

detailed picture of income fluctuations, it is not necessarily the best indicator of per capita income, since price ratios are affected by numerous shocks. It is therefore safer to filter out the effect of these shocks by taking averages of the estimated index and to use those filtered averages, instead, as an indication of per capita income movements (Table 3).

Whereas the Achemenid Empire (550–330 bce) had been characterized by stability, the Hellenistic period in Mesopotamia was characterized by internal conflicts, culminating in the victory of the Parthians in 141 bce. These military conflicts account for the decline in per capita income described in Table 3. The Hellenistic period was probably characterized by population growth as well, but this would not necessarily have translated into economic growth; that is, one must bear in mind that this society was subject to Malthusian laws. These days growth in per capita income is considered an indicator of growing prosperity, but in a premodern society, governed as it would have been by the Malthusian regime, income growth usually signified that there had been a catastrophic population decline, and population growth was associated with a decline in per capita income: what we see in Babylonia during the third century bce. The Parthian victory halted this income decline and even led to economic progress during the reign of Mithridates II (124–88 bce), but the decline soon resumed.

4. Comparing National Incomes in the Hellenistic World

Our estimate of the Mesopotamian GDP/cap between ca. 400 and 50 bce, 600–800 G-K dollars, is between the generally accepted subsistence minimum of 400 dollars and the estimates for Rome and Athens. This is in line with the fact that ancient Mesopotamia was an agricultural society with a relatively low per capita GDP. Looking at another agricultural region, the Levant, Maddison (2007, p. 54) estimated per capita GDP at 550 G-K dollars for 1 ce. However, his estimate for the Levant is based on a considerable lower GDP per capita estimate for the Roman Empire as a whole than is arrived at by Scheidel and Friesen (2009). We therefore increase the estimate of Maddison for the Levant by the ratio of the Roman GDP of Scheidel and Friesen (2009) and Maddison (2007, p. 54) thereby arriving at 772 G-K dollars for the Levant, which is almost identical to our own a figure for Mesopotamia around 100 bce.

When it comes to estimated per capita GDP in more developed regions, it is Athens that provides a useful benchmark. Amemiya (2007) estimates its total annual GDP during the fourth century BCE at 4430 talents, of which 2477 were generated in its most important sector, manufacturing. Applying a population estimate of 220,000 to our calculations, we arrive at a per capita GDP of 0.020136 talents, or 523.5 grams of silver (the talent of silver weighing, at the time, 26 kg). Von Reden (2008) reports a barley price of 37 grams of silver per 100 liters, enough to purchase 1415 liters of barley (the caloric equivalent of 1132 liters of wheat). Using the 1.17 liters wheat/G-K dollar ratio, we arrive at an estimate of 967 1990 G-K dollars, significantly (30–40 percent) higher than our estimate for contemporary Mesopotamia.

Such a significant difference cannot be explained by a difference in diet (including meat consumption) alone, but rather is an indication of significantly different economic structures, particularly the relative proportions of the manufacturing and pasture sectors (e.g. Broadberry and Campbell, 2009). Indeed, 56 percent of the Athenian economy consisted of manufacturing (Amemiya, 2007), which paid for food imports, compensating for the reduction in the agricultural output.

As for using the Roman Empire for purposes of comparison, we have a number of competing estimates. While Maddison (2007) and Goldsmith (1984) estimate per capita GDP in the Roman Empire at 570 G-K dollars, Lo Cascio and Malanima (2009) set it at 900 G-K dollars while Scheidel and Friesen (2009) set it 100 G-K dollars lower than that.[9] Evidently Rome's political power was rising, whereas Mesopotamia's was waning; per capita GDP in Mesopotamia ca. 100 BCE was 784 G-K dollars, 2–13 percent inferior to Rome's, a gap that, in light of Mesopotamia's long-term economic troubles, probably began to widen during the first century CE.

The gap is even wider if we confine our calculations to the Italian part of the Roman Empire, where Lo Cascio and Malanima (2009) set per capita GDP as high as 1400 G-K dollars. However, Scheidel and Friesen (2009) argue that this figure is based on an overestimation of average consumption. Using their estimate for the entire Roman Empire and the subdivision by Maddison (2007, table 1.12), we arrive at a per capita GDP for peninsular Italy of 1203 G-K dollars: almost twice as much as the figure, of 750 GK dollars, that we have for Mesopotamia.

A comparison of grain wages provides further evidence that the Roman Empire was more productive than Mesopotamia: even if it was at the lower end of Scheidel's estimate of 6–17 liters, this was considerably more than Babylonia's 2.5 liters. In any case, if we look at urbanization, a standard manufacturing indicator (e.g. Álvarez-Nogal and Prados de la Escosura 2009; Malanima 2009), we see that in ca. 1 CE 27 percent of the Italian portion of the Roman Empire's population was urban (Geraghty, 2007, pp. 1044 fn. 39, 1048):[10] significantly higher than the 10 percent estimated for Mesopotamia. If we assume that labor productivity in manufacturing was about twice as high as in agriculture, the difference in structure

[9]The estimate of Lo Cascio and Malanima is for the first century CE, whereas that of Scheidel and Friesen is for the middle of the next one, but they maintain that the two periods are comparable.

[10]For the whole of the Roman Empire, Goldsmith (1984, pp. 272–73) estimated the proportion of urban population at 9–13 percent.

alone would account for 18 percent of the income gap between Rome and Mesopotamia.[11]

Another factor that may have contributed to the income gap concerns the extent of pasture (Broadberry and Campbell, 2009). Since in terms of caloric value the cost of meat is approximately 10 times that of grain (e.g. Broadberry *et al.*, 2011), and since—according to Malthusian theory, which is generally accepted—income in the ancient world was at the subsistence level, the amount of pasture must have been proportional to per capita GDP, whether measured in terms of a currency or a crop. Anthropometric evidence indicates that the ancient Mesopotamians' diet featured significantly less meat than did that of the ancient Greeks; the fact that the size of Mesopotamian skeletons does not differ significantly from Greek ones (Jursa, 2010, p. 797, based on the data of Wittwer-Backofen, 1983) may be thanks to the high protein (as well as carbohydrate and sugar) content of dates and to the fact that they were a mainstay of the Babylonian diet—a hypothesis corroborated by Jursa's finding of a high degree of tooth decay in Babylonian remains from the third millennium BCE. Indeed, Sołtysiak (2007) reports that the Hellenistic Near East was characterized by an increase in infections and malnutrition-related diseases, indicating that pasture was not extensive, and that grain crops constituted a scanty portion of the ancient Greek diet.

The role of pasture was much larger in parts of the Roman Empire. By the beginning of the second millennium CE, Byzantium's per capita GDP was considerably higher than in ancient times, associated as it was with an expansion of pasture (but not of the manufacturing sector) over the course of the previous 1200 years. For example Wick *et al.* (2003, p. 671) report a decrease in the presence of pollen from the genus *Quercus* (oak) and an increase in the presence of *Artemisia* (a genus that includes the species sagebrush and wormwood) in Lake Van, in south-eastern Turkey. Since plants in the genus *Artemisia* have a strong aroma and a bitter taste that discourage herbivory, the increase in the presence of its pollen is indicative of increasing pasture (Wick *et al.*, 2003, p. 671).

The higher share of pasture in the Roman Empire is also visible elsewhere. Evidence from Roman provinces around the Danube indicates a considerable increase in cattle and pig breeding (e.g. Bokonyi, 1988), pointing to a meat-consumption rate similar to that in Byzantium ca. 1000 CE. Meat rations in the army were roughly 60 kg per annum (Milanovic, 2006, table 1) and on average close to 30 kg for the population as a whole. As Milanovic points out, current meat consumption in Turkey is roughly 40 kg per year, so this estimate is plausible. In Milanovic's estimates, meat purchases would therefore have represented 17.5 percent of the food budget, and the livestock that produced the meat would have required twice the pasture that existed in ancient Mesopotamia. If we add to our calculation other animal products such as wool, cheese, and milk and assume that food purchases accounted for 80 percent (and meat alone 14 percent) of total

[11]Given that a third of the Roman population is urban, and assuming that productivity in urban areas is twice as high as that in rural areas, we arrive at a total labor productivity of $(1/3)*2 + (2/3)*1 = 1.3$. For Babylonia, the figures are $(1/10)*2 + (9/10)*1 = 1.1$, making for a productivity level 18.2 percent lower than Rome's, a difference due entirely to the fact that Rome's manufacturing sector was significantly more extensive than Mesopotamia's.

expenditures, we can safely increase the contribution of pasture to GDP to 28 percent. If, for simplicity's sake, we assume that meat consumption in Italy was the same as in Byzantium, that agricultural output was composed entirely of grain crops, and that food produced from pasture (meat and dairy products) was ten times as expensive per kcalorie as grain and other crops, agricultural value added would have been $0.28 \times 0.1 + (1 - 0.28) = 74.8\%$: that is, differences in manufacturing and pasture account for 30.5 percent of the difference in per capita income in Italia and Babylonia.[12] The observed difference in income per capita (at 1203 and 736 dollars, respectively) is, in fact, only slightly higher than this figure, at 38.8 percent. In other words, using this method, we can explain roughly 75 percent of the income discrepancy between Rome and Mesopotamia. Whether or not these figures, tentative as they are at this point, are confirmed or undermined by future research, the most important result of our exercise is our renewed conviction that an accurate understanding of economic structure is necessary to an understanding of why both economic growth and income vary from one society to another.

5. Conclusion

Recent upward revisions of estimates of income in various medieval and ancient societies have made the issue of income-level estimation increasingly important. At first glance, this would seem to suggest that the start date for modern economic growth should be pushed back, but in fact recent research has indicated that income in ancient societies has been underestimated, too. The observed income differences can be caused not only by divergent development paths analogous to today's First vs. Third World division but also by differences in economic structure. Until recently, all that we knew about income in ancient economies was derived from estimates for Rome and Athens, and both regions had a large manufacturing sector and extensive pasture. Mesopotamia, in contrast, was much more dependent on food crops (specifically, barley and dates).

We conclude that per capita GDP in Mesopotamia ca. 400 BCE was at 700–750 G-K dollars. Using an approach that takes into account the fact that consumption preferences are largely a function of income level, we tracked the evolution of per capita GDP there, and found that it peaked ca. 110 BCE, plunging thereafter, on account of the chaos that accompanied the war against and then the victory of the Parthians, in 141 BCE. Thus even at its peak Mesopotamian per capita GDP was lower than that of Athens. This gap is largely due to a significant difference in the sizes of the two societies' manufacturing sectors. Likewise, Rome's per capita GDP and her pasture and manufacturing sectors surpassed Babylon's. However, anthropometrical evidence that there was little height difference between the two peoples means that any difference in their caloric intake was insignificant.

[12]Eighteen percent (income difference from manufacturing) + 25 percent (income difference in agriculture because of larger pastoral sector)*0.5 (share of the agricultural sector in Rome) = 30.5 percent income difference between Rome and Mesopotamia. This is, however, a slight overestimation, since the calculation does not take into account a productive, though admittedly small, pastoral sector in Mesopotamia.

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