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CUANTIFICAR LAS ECONOMÍAS ANTIGUAS. PROBLEMAS Y MÉTODOS

QUANTIFYING ANCIENT ECONOMIES. PROBLEMS AND METHODOLOGIES

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Índice general

Ancient Cliometrics and Archaeological Proxy-Data. Between the Devil and the Deep Blue Sea

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> *I believe it to be false to speak of the relationship between history and archaeology. At issue are not two qualitatively distinct disciplines but two kinds of evidence. There can thus be no question of the priority in general or of the superiority of one type of evidence over the other; it all depends in each case on the evidence available and on the particular questions to be answered.*[1]

> *Statistics share with sausages and legislation the property of being unappetizing to watch being made.*[2]

From data-gathering to data-processing

No honest classicist will deny that ancient economic history has a data-problem. Reliable textual data on economic matters are largely confined to qualitative aspects. Institutions or the social status of the economic agents, for instance. They tell us little about quantities of production, trade, or consumption, or about the practical use of technologies, or the extent of economic interactions or how these were configured in networks. Thousands of prices, wages, property valuations, and other

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[1] Finley 1986: 20.
[2] Hohenberg 2008: 342.

quantitative facts are recorded in papyri and inscriptions but they are spread out over nearly a millennium and scattered over more than four million square kilometres in cities, towns, and villages, kingdoms, provinces, and districts. Fortunately, archaeology greatly improves our view. Texts and inscriptions tell us roughly how many soldiers were stationed on the Rhine or the Danube, archaeology shows us where their food and drink came from and how this changed through time.

Archaeology has always contributed to ancient economic history. Until recently, however, classicists used archaeological data mostly only to illustrate inferences from textual evidence rather than as valuably primary sources in themselves. This has changed dramatically since the early 1990s as Finleian scepticism[3] eroded and classical archaeology itself made giant methodological leaps forward.

Economic archaeology is a relatively young sub-discipline. In the later half of the twentieth century archaeologists became increasingly interested in the social systems behind the material record. The realisation and conviction grew that artefacts and traces could be studied as proxies for processes that were archaeologically invisible. This approach has seen huge progress since the 1990s. Improved and more affordable scientific and ICT techniques to detect, identify, and record material remains have boosted economic data retrieval. Computer assisted statistical methods and data-modelling have greatly enhanced our ability to interpret and process archaeological data on ancient economic systems. The potential impact of these developments goes far beyond ancient economic history. Most of human history has little or no reliable archival data to work with. Economic archaeology offers a way forward to strengthen and enlarge the empirical dimension of global economic history. Economic historians have hardly even begun to realise this.

Technological advances in archaelogy have vastly increased our qualitative data base. Analyses of teeth and bone material of life-stock and fowl, for instance, now allow us to distinguish specific breeds, breeding and slaughtering cycles, care systems, fodder, use for food and raw materials or as traction or pack animals.[4] Spatial analyse of fine ceramics show shifting production sites, transport routes, and markets.[5] When it comes to quantification, however, there are still fundamental problems that obstruct the integration of economic archaeology in economic history. Scientific methods to generate data from material remains are highly advanced but proxy-data methodology itself—that is the subsequent use of these derived data to interpret historical phenomena—is not. The basic reason for this is that material data only become ‘proxy-data’ through interpretation. Annual layers of different concentrations of lead particles in ice-core are just that. They *become* proxy-data when we interpret them as indicators of something else that we cannot directly measure. Just as measuring the density of water masses by satellites informs us on the temperature of these waters. Unfortunately economic proxy-data are rarely so unequivocal. The ice-core samples will inform us on the amount of lead particles released in the atmosphere through human activity but they are not telling anything about agricultural production, or the production of stones, ceramics, textiles, or leather, not to mention services such as those provided by barbers, doctors, prostitutes, or school teachers. Even if we accept that lead pollution can be a proxy for silver production (since ancient silver was extracted from the lead-mineral galena) and if we accept the (big) assumption that the bulk of this silver was used to

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[3] Finley 1999: 137: ‘as for Lezoux and La Graufesenque, they flourish only in archaeological manuals’; p. 33 for the famous 39 sherds of *terra sigillata* scattered on 400 sqare meters belonging to a single bowl; but note also the much more nuanced and respectful view Finley 1986: 18–26.

[4] See for instance De Cupere *et al.* 2005; Fuller *et al.* 2012.

[5] See for instance Mees 2002 and the project ‘Least-Cost-Routing: Römische Wirtschaft auf Umwegen’ of the Römisch-Germanischen Zentralmuseum (http://web.rgzm.de/no_cache/forschung/schwerpunkte-und-projekte/a/article/least-cost-routing-roemische-wirtschaft-auf-umwegen/).

produce coins, the lack of comparable data on gold extraction implies that the ice-core data are useless to inform us on changes in money supply since up to seventy percent of the nominal currency base in the early Roman empire consisted of gold coins**.** Similarly the ship-wreck data from the Mediterranean are clearly distorted by the transition from *amphorae* (durable and hence archaeologically highly visible) to wooden barrels (perishable and hence archaeologically mostly invisible) but we have no way of measuring this distortion. Even if we would, the datasets we currently have for the Mediterranean are not telling anything on navigation on the Black Sea, the Atlantic, or the North Sea, the Red Sea or the Indian Ocean. So while the heuristic methodology of deriving proxy-data from raw data has greatly advanced, the interpretative methodology needed to derive information from these proxy-data on historical phenomena is lagging behind.

From a totally different perspective however ancient economic history has also progressed tremendously the past two decades in catching up with economic history—reframing its questions and answers in the language of economic historians. It has done so by borrowing concepts and models used in medieval and modern economic history. Unfortunately, when it comes to quantification vagueness and order-of-magnitude estimates prevail in this largely theoretical and conceptual approach. Cliometric studies have been pursued and published but they rely on flimsy empirical data. Ironically, despite its progress in technical firepower and methodological control economic archaeology has a hard time communicating with these new approaches in ancient economic history.

This paper explores the consequences of this gap and searches for ways to build an archaeo-cliometrics that allows economic historians to study historical economies in pre-statistical societies. I will argue than empirical cliometrics as it is usually understood in (early) modern economic history is impossible to achieve and that it is a mistake to think that economic archaeology will ever remedy this. However, I will also argue that the standard indicators that cliometrics usually tries to establish are not very good at capturing the properties that matter most in determining historical developments in real economic systems or the efficiency with which they are able to provide the resources needed for a society to exist at a given level of wealth and well-being.

Econometrics and (ancient) cliometrics

Econometrics developed in the 1930s as an attempt to give the discipline an empirical basis and provide it with the means to falsify predictions based on economic theory. The attempt was initially greeted with scepticism. Keynes dubbed it 'statistical alchemy' and 'black magic'.[6] The criticism did not abate but econometrics nevertheless gained ground. A reflexive study published in 2000 is critical of econometrics' ability to falsify economic models but stresses its contribution to economics as an inductive discipline.[7]

The backbone of econometrics are economic indicators: measures that express the performance, structure, or behaviour of an economic system. There is no theoretical limit to what qualifies as such an indicator. Any feature that can be measured or expressed in quantitative terms and mathematically related to other characteristics of that system qualifies in principle as a valid indicator. Examples include Gross Domestic Product (GDP), Consumer Price Indices (CPI), unemployment

[6] Keynes 1939, a review of Tinbergen 1939, the pioneering work of econometrics; although he hopefully added that 'Newton, Boyle and Locke all played with alchemy' and so advised to let it continue,
[7] Keuzenkamp 2000.

rates, money supplies, capitalisation rates, and so on. In practice, however, economists tend to use a relatively small set of indicators on which they broadly agree.

The best known by far are the various GDP related parameters: GDP itself of course but also for instance GNP (Gross National Product, which is GDP plus/minus income from property or labour from other countries), NDI (national disposable income = GNP plus/minus all transfers, including e.g. taxes, tribute, …). GDP forms the basis for the calculation of many other indicators. By applying a Gini-coefficient to it we can express the degree of income inequality in an economy. Tax revenues or government debt can be expressed as a proportion of GDP to indicate the share of the economy taken by governments and how vulnerable it is to creditors or the financial sector.

Cliometrics is the branch of econometrics that deals with economies of the past, attempting to calculate or at least estimate economic indicators of historical societies. It developed in the 1950s and became popular in the 1960s and 1970s. This 'new economic history', as it was dubbed, distinguished itself from the 'old economic history' by its use of formal mathematical models and statistical techniques. According to one eminent practitioner it 'transformed the study of economic history from a narrative to a mathematical format.'[8]

In ancient economic history cliometrics was slow to catch on because most textual data on production, distribution, or consumption are unsuitable for quantification. Nevertheless, from the 1980s onwards attempts were made to guesstimate key economic indicators such as GDP. The best known early attempts are those by the ancient historian Keith Hopkins and the economic historian Raymond Goldsmith, later reviewed and refined by Angus Maddison.[9]

Hopkins started from a minimal calorific subsistence requirement of 250 kg of 'wheat equivalent'.[10] To this he added one third for seed that needed to be set aside for the next harvest (using the canonical but highly debatable seed to crop ratio advanced by Columella[11]). This gave him a total of 333 kg of wheat equivalent per capita necessary for survival. Assuming that wheat was the cheapest calorie-provider, the price of this had to be the lowest possible GDP per capita. Based on an assumed normal average price of three sesterces per *modius* (c. 6.55 kg) Hopkins arrived at 153 sesterces per person. Multiplying this with an estimated population of fifty-four million in AD 14, he obtained 8,244 million sesterces as the survival minimum aggregate GDP. Initially Hopkins refrained from estimating actual GDP but later suggested it could reasonably have been 50% higher.[12] This leads to an estimate of 12.5 billion sesterces for aggregate GDP, implying a per capita GDP of c. 230 sesterces or 500 kg wheat equivalent.

Goldsmith started from an estimated real annual wheat consumption of thirty five to forty *modii* (236.5 – 270 kg), which he multiplied by the same assumed normal mean price of three sesterces per *modius* to obtain 105 – 120 sesterces per person per year spent on wheat. This he increased a little to 130 sesterces per capita to account for other food-grains to postulate a total average. He then assumed

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[8] Diebolt 2016: 972; 'Impressionistic judgements supported by doubtful figures and inadequate methods padded by subjective impressions have now lost all credibility.' (*ibid.* 978).
[9] Maddison 2007.
[10] Hopkins 1980.
[11] Columella, *Agr.* 3,3.
[12] Hopkins 1995 (= Hopkins 2002); in the 1980 version he merely expressed his opinion that 'gross product averaged out at less than twice minimum subsistence' 120). Bang (2008: 86–88) reproduces Hopkins' estimates but for a population of 60 million.

that this represented on average about one third of total consumer expenditure, which brought him to an 'order of magnitude' for private expenditure of approximately 350 (*sic*) sesterces per capita. The last step was to add public expenditure, loosely estimated at five percent, and private capital expenditures assumed to be 'probably even smaller' but also put at five percent.[13] The end result was a nominal figure of 380 sesterces (c. 830 kg wheat equivalent) GDP per capita. Assuming a total population of 55 million this implied an aggregate GDP of about 20.9 billion sesterces for the empire as a whole.[14]

The difference between Hopkins' and Goldsmith's estimate is considerable but derives largely from different 'topping up' rates. Both start from a similar consumption of basic staple foods: about 250 kg wheat (equivalent). Hopkins' estimate implies that two thirds of GDP per capita was needed to ensure survival. In Goldsmith's estimate subsistence accounts for less than a third of GDP. In both cases, however, the topping up factor is largely guesswork. Hopkins settled on his figure because he estimated the imperial budget at 700-900 million sesterces. Based on an actual GDP of 12.5 billion this would imply a tax burden of 5-7%. Raising the estimate of actual GDP would imply unrealistically low tax rates (in Hopkins' eyes).[15] Goldsmith's assumption, on the other hand, that expenditure of food grains represented about one third of total private consumption expenditure was based on the situation in England and Wales in 1688, loosely justified by reference to an intuitive guess found in Kahrstedt's *Kulturgeschichte der römischen Kaiserzeit*,[16] and the observation that sixteen less developed countries in the 1970s showed similar ratios.

A number of later scholars have attempted to improve on these early estimates but their approach was always very similar. Temin assumed a much lower per capita consumption of 175 kg of yearly wheat equivalent and a lower mean price of only 1.78 sesterces per *modius* but compensated this by assuming much higher non-grain and non-food related expenditures to arrive at a mean total per capita of 166.3 sesterces or 614 kg wheat equivalent—much lower than Hopkins' and Goldsmith's figures in monetary terms but nicely in the middle in terms of wheat equivalent.[17] Maddison used the estimates from Goldsmith and Hopkins with minor modifications but settled on the same per capita figure as Goldsmith (380 sesterces). He multiplied this, however, by a significantly lower population estimate (44 million).[18] Like Goldsmith Maddison used the estimates made by Gregory King in 1688 for England as the prime *comparandum*, which he also used as a link to express Roman economic performance in 1990 Geary-Khamis dollars.[19] Lo Cascio and Malanima accepted Maddison's estimates for real consumption but increased his calculation into 1990 Geary-Khamis dollars by arguing that Roman Italy in the early empire had a similar GDP per capita as England in 1688, while the rest of the empire would have been at c. 60-70% of that.[20] The currently most used estimate is by Scheidel and Friesen.[21] Contrary to Hopkins and Goldsmith, their estimate is for the

[13] Goldsmith 1984.

[14] For an estimate based on the income side, Goldsmith assumed mean daily wages of 3.5 sesterces, 225 working days, and a dependency ratio of 2.5 (based on 40% of the population being under fifteen in less developed countries in 1960, Goldsmith 1984: 271, n. 40); this leads to an estimated average labour income of 315 sesterces per person a year, topped up by twenty percent to account for non-labour income to arrive at … the same estimate of 380 sesterces GDP per capita.

[15] Hopkins 1980: 119–120; 1995: 47, 67, n. 20 (rejecting Goldsmith's estimate).

[16] Kahrstedt 1958: 211.

[17] Temin 2006; improved in 2013: 243–261.

[18] Maddison 2007.

[19] The Geary-Khamis dollar (or 'international dollar') is a virtual currency unit equal to the purchasing power (= 'purchasing power parity' (PPP)) of the US dollar in a chosen year. It is commonly used by modern economists to make sensible comparisons of economies using different currencies with different purchasing powers. As most economists working in the early 2000s Maddison used 1990 as his benchmark year.

[20] Lo Cascio and Malanima 2014 (originating in a paper presented in 2009).

[21] Scheidel and Friesen 2009.

mid-second century AD, just before the Antonine Plague when the Roman empire was at its peak. They arrive at c. 620 kg of wheat equivalent per person. They accept a price-range of two to three sesterces per *modius* arriving at a GDP per capita based on expenditure estimates in monetary terms of 189 – 284 sesterces. Using estimates on wages levels and non-labour income they arrive at a mean income range of 489 – 604 kg of wheat equivalent per person translating into a GDP per capita based on income estimates in monetary terms of 149 to 277 sesterces. They assume a total population of 70 million which yields a total GDP estimate range of 10.5 to 19.9 billion sesterces.

The results of these various estimates are reasonably consistent but they fluctuate in a wide range from 489 kg wheat equivalent (lowest estimate Scheidel and Friesen) to 830 kg wheat equivalent (Goldsmith/Maddison estimate). Scheidel and Friesen propose a 'bare bones basket' minimum of 335 kg wheat equivalent.[22] Using this 'baseline' estimate to calculate the ratio of mean income to subsistence (that is how much above subsistence Roman economic performance really was) produces a range of c. 1.5 – 2.5. This is perfectly plausible for a preindustrial agro-empire. Milanovic, Lindert and Williamson calculated the ratio of mean per capita GDP to minimum subsistence for twenty-eight historical societies (including the Roman empire, for which they used the Maddison estimates). They found these to vary between 1.5 and 6.8 times subsistence but the ratios above 2.5 were all exceptional.[23] If we accept the proposed range of 1.5 to 2.5 as 'normal' for preindustrial societies, we obtain a range for the Roman empire of approximately 500 to 850 kg wheat equivalent per capita. The high figure is certainly too high for the empire as a whole but not for its most prosperous regions, and is probably too low even for some areas, such as Latium and Campania or Baetica.

These GDP estimates have all been used as the basis for further projections, for instance to provide estimates on social inequality or real income and purchasing power.[24] This is not the time or place to go deeper into the reliability of the estimates or of the empirical data fed into the models. Important for our purposes is that they are all based on empirically flimsy evidence. Cliometrics in ancient economic history, so far, has been almost entirely deductive—dealing with quantitative factoids, rather than quantitative data. Based on theoretical models and comparative evidence assumptions have been formulated regarding the interconnectedness of chosen parameters. Then, as many as possible of the quantitative data preserved in textual sources are fit in or explained away. While the concept of subsistence minimum provides a clear baseline in terms of 'wheat equivalent' the rest of the fabric is based on 'controlled conjecture': a combination of educated guesses and comparative evidence to provide plausibility ranges and prop up assumptions.[25] Ancient cliometrics is a 'Douglass North' type cliometrics: a search for the quantitative characteristics of an historical economic system driven by interdisciplinary theory, which is very different from the inductive, statistical cliometrics that Robert Fogel advocated.[26]

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22 Scheidel and Friesen 2009: 73.

23 Milanovic, Lindert, and Williamson 2011: 263; Siam 1929 (2.6), Java 1924 (3), Japan 1886 (3.1), Tuscany 1427 (3.3), Holland 1561 (3.8), France 1788 (3.8), Chile 1861 (4.3), England and Wales 1688 (4.7), England and Wales 1759 (5.9), Netherlands 1808 (6), England and Wales 1801 (6.7), Holland 1732 (6.8); note that Scheidel and Friesen 2009: 73 used lower estimates taken from the working paper that preceded the published article of Milanovic e.a.

24 Scheidel and Friesen 2009; Milanovic, Lindert, and Williamson 2011.

25 Cf. Scheidel and Friesen 2009: 63; famously dubbed the 'wigwam argument' by Hopkins (1978: 19–20; 1980: 43): each assumption is too fragile to rely on but as the poles of a wigwam they support each other ; for a methodologically more advanced use of guesstimation see Charemza 2002.

26 For the distinction see Diebolt 2016; for a 'Fogelian' approach in ancient economic history see Temin 2013: 27–91; Kessler and Temin 2007 but see the critique by Erdkamp 2014; Scheidel 2014.

Let me emphasize that I don't want to dismiss the results that have been achieved or trivialize their importance. As Bang describes it '[b]y giving the Roman economy a hypothetical, quantitative expression we can control our qualitative analyses with much greater precision'.[27] We now have a much better idea of what it means when we say that the Roman economy was a developed pre-industrial agriculture-based economy, and of how Roman economic performance compared to that other preindustrial societies. The problem with the results, however, is that they are extremely 'fuzzy'. Italy and Baetica were certainly wealthier than, for instance, Lugdunensis or Numidia but how much? Performance certainly varied through time everywhere but when and how much? The estimates confirm that the Roman economy was an advanced agro-economy like so many other in history but tell us little on what made it different from other historical economies.

At the same time, however, we are overwhelmed with empirical data from archaeological and climate history research. Datasets have been compiled and made available for analysis that were unimaginable twenty years ago. There is no a priori reason why these archaeological proxy-data could not be used in ancient cliometrics. Mathematical models and statistical analyses can be used to process archaeological proxy-data to produce sound quantitative facts on economic issues, for instance the production capacity of fish-salting installations or the breeding and slaughtering seasons of cattle. Clearly caution is in order when generalizing the results from individual studies. We cannot simply assume that the data we have are a representative sample. But that is a general problem in any statistical study. It is not specific to economic history and there are ways to test for it.

The difficulty lies in connecting the results of such mathematically and statistically processed archaeological proxy-data to suitable indicators that express the performance, structure, and behaviour of an economic system. So far, little progress has been made in translating the results obtained through the statistical analysis of archaeological datasets into standard economic indicators. While metrics are the problem in the Hopkins/Goldsmith approach, in the case of archaeological datasets the problem it is not the metrics but the models. We are lost in translation and for some of the best proxy-data, some of the most desirable translations are almost certainly impossible. Skeletal remains, for instance, are plentiful and provide good data on biological well-being in ancient societies.[28] Body stature has in the past been interpreted as a proxy for per capita income. Anthropometric research for early modern and nineteenth century populations, however, has shown that the correlation is weak. Economic inequality affects anthropometric indicators but so also do diet, rural/urban life-styles, and pathogens. Market integration and improved transport facilities stimulated economic growth in the nineteenth century United States, England, and the Netherlands but led to a drastic decline in body stature and overall biological standards of living. Increased income inequality was only partly to blame. Other factors were increased urbanisation under inadequate sanitary and health conditions, merging disease environments, and the newly acquired ability for farmers to sell valuable nutrients that formerly would have been consumed by household members.[29] So for a time populations became wealthier but less healthy. Without the spectacular productivity gains made possible by science and technology first in industrial production later also in agriculture western economies would soon have hit a very hard ceiling.

How problematic is this inability to translate archaeological proxy-data into standard economic indicators? Anthropometrics may not provide reliable proxies to estimate GDP per capita or income inequality but they do provide a good view of biological well-being and biological inequal-

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[27] Bang 2008: 85.
[28] For an overview see Scheidel 2012; Jongman 2007b: 607–609.
[29] Haines 2004.

ities, and, therefore, of the capability of an economic system to generate and allocate biological well-being under specific socio-ecological conditions.[30] What is the added value of standard economic indicators? How useful are they to express the real rather than the monetary performance, behaviour, or structure of an economic system?

GDP and GDP related parameters

'Gross Domestic Product' (GDP) has been the most popular indicator in economic history to track developments and compare economies. It is a measure for the size of an economy: its total production expressed in market values. GDP is an essential concept in macro-economics. It is commonly used to generate other parameters such as the fiscal burden or the amount of productive assets that are available in an economy, and it underlies estimates of other indicators, such as income or asset inequality.

The modern concept was developed by Simon Kuznets in 1934 for a report commissioned by the American congress to combat the Great Depression.[31] It became a key aggregate parameter in the *System of National Accounts*, adopted by the United Nations in 1953 and since then several times revised (last in 2008).[32] GDP represents the total market value of all goods and services produced in an economy. It includes (in principle) all goods and services that *could* be sold on the market, regardless of whether or not they are and regardless of whether they are produced by corporations, governments, non-profit institutions or households. Estimating the value of goods and services produced by households for their own final consumption, however, is extremely difficult. Excluding them would obscure a large part of economic production, particularly in developing countries where agricultural households still strongly depend for their consumption on what they produce themselves. Including them, however, 'can obscure what is happening on markets and reduce the analytic usefulness of the data.'[33] So, as a compromise, GDP estimates include goods produced by the household for its own final consumption but exclude services. These services not only consist of personal services (as nursing young children, caring for sick or older household members, etc.) but also 'do-it-yourself' activities as mending clothes, painting, repairing plumbing and so forth. Internal household services are only counted in GDP estimates in so far as they require the buying of replacement items or tools. Similarly, volunteer services or help from friends, neighbours or family are not included except in so far as there is a remuneration or compensation in kind, while goods produced by volunteers (for instance a village building its own school house or digging a common well) are included at their market value.[34] The same goes for unremunerated apprenticeships: they are included in the accounts only for the value of the goods produced by the apprentices, not for the training that the apprentice receives.[35]

This is obviously a severe limitation on the information value of GDP. The Canadian bureau of statistics estimated the value of household services in 1992 between 33 – 49.8% of the country's

[30] Duff, Timothy. "Historical Anthropometrics". EH.Net Encyclopedia, edited by Robert Whaples. August 29, 2004. URL http://eh.net/encyclopedia/historical-anthropometrics/; see also Komlos and Baten 2004
[31] Kuznets 1934.
[32] System of National Accounts (2008) 2011 ; for previous versions and a short history see The System of National Accounts (SNA) 2017
[33] System of National Accounts (2008) 2011: 6.
[34] System of National Accounts (2008) 2011: 409.
[35] System of National Accounts (2008) 2011: 8.

GDP, the estimate of the Australian Bureau of Statistics was between 43 – 60% of GDP in 1997.[36] These are figures for modern developed economies, in which markets are much more dominant than in preindustrial societies. The rise of the sector of paid services to households (cleaning, child-care, decorating, …) in modern economies reflects the growing participation of women on the job market but it also reflects a shift from non-market services to market-services. If the increase of market services is off-set by a decrease of unremunerated domestic services, then the performance of real services will not change (might even decrease). Another example: the fast rising sector of the 'sharing economy' is only counted in GDP insofar as products are being made or remunerations paid. P2P based sharing or open-source communities are not recorded. If enthusiasts are right that we are witnessing a transition from a market economy to an internet supported sharing economy the net result would be an increase in real performance but a fall in GDP.[37]

Another limitation for which GDP has been criticized is that depletion of natural resources is not accounted for. Based on the current methodological framework, the destruction of rain forests or fishing grounds contributes positively to GDP. This could in principle be avoided by using NDP ('Net Domestic Product') which equals GDP minus asset depreciation.[38] But the accounting methodology for depreciating fixed assets (including human made assets like machines or power plants) is unreliable. Even if an agreement could be reached on which methodology to use, the *System of National Accounts* would still fail because it considers ownership as a definitive criterion for inclusion. In the case of natural resources governments can be considered owners if the natural resources qualify for economic exploitation. But natural resources that are not government owned (like fishing grounds, or deep sea oil reserves), or that have no economic value (like clean air) are by definition excluded. The same is true for human capital. Although its value for production is not disputed 'it is difficult to envisage "ownership rights" in connection with people, and even if this were sidestepped, the question of valuation is not very tractable'.[39]

Even in market based societies, therefore, GDP is a very imperfect indicator of real economic performance. In view of these many defects the 1993 version of the System of National Accounts already states that '[c]ertain key aggregate statistics, such as gross domestic product (GDP) … are defined within the System but the calculation of such aggregates has long ceased to be the primary purpose for compiling the accounts.'[40] Rather than looking for one figure that would capture the whole economic system, we should strive for a set of metrics that together express various dimensions of economic performance.[41]

Development indicators

Human development index

Narrowly defined production indicators (such as GDP) are clearly unsatisfactory. Several development indicators exist that attempt to remedy this. The most popular and familiar today is the Human Development Index (HDI), the central indicator in the United Nations Human Development

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[36] The differences depend on the chosen method of valuation. Chandler 1994; Trewin 1997; see here appendix 2, p. 59-61 for international comparisons; most roughly fall in the range 30-60%.
[37] Or more likely a revision of the national statistics handbook in how GDP should be calculated…
[38] System of National Accounts (2008) 2011: 195–269; cf. *ibid.* 34 for GPD being conceptually inferior to NDP.
[39] System of National Accounts (2008) 2011: 43.
[40] System of National Accounts (1993) 1993: 1.
[41] Costanza *et al.* 2014.

Reports. HDI has three components: health (measured by life expectancy at birth), education (measured by mean and expected years of formal schooling), and living standards (measured by Gross National Income per capita). Various critiques have been raised against it which need not concern us here but the practical usefulness of HDI as an indicator of development in ancient societies is limited. GNI per capital is simply the main component of GDP. Estimates of HDI, therefore, inevitably suffer the same problems as GDP estimates. Estimates of formal schooling are even more fuzzy than those of GPD and the value of 'years of formal schooling' as a proxy for education itself is doubtful in pre-industrial societies. Good estimates are possible for biological standards of living based on skeletal evidence but they are impossible to translate into life expectancy.

Social Development Index

A development index specifically designed for historical societies is Ian Morris' 'Social Development Index'. It aims to capture the abilities of social groups 'to master their physical and intellectual environments and get things done in the world'.[42] It is based on four parameters: energy capture (including food-calories) as a measure of the total size of material production, organization (via urbanisation as a proxy), war-making capacity (size of armies), and information technology. Morris' index has been severely criticised.[43] As first sight, however, it has the theoretical advantage that two of its components (energy capture and organisation) may be estimated (in principle) from empirical archaeological data.

Morris argues that the archaeological data on energy capture in the Roman empire indicate levels that are much higher than what we would estimate by simply converting into kcals the GDP per capita estimates in wheat equivalent. He concludes from this that the top-ups used by the Hopkins-style cliometricians to go from subsistence minimum to real GDP must be too low.[44] His point of departure are Cook's general estimates, made in the early 1970s, for hunter-gatherer societies, early agriculturalists, advanced agricultural societies, and industrial and modern societies.[45] These are then adapted using archaeological data. The adjustments, however, are largely impressionistic ('too high', 'too low', 'I suspect that' …). In other words the raw data may be archaeological but they are not statistically or mathematically processed into estimates, nor are they embedded in a Hopkins-'wigwam style' deductive model (see above n. 26). Clearly more robust estimates are necessary.

There are also important methodological problems involved in using energy capture as a measure for social development but we will return to these later in this paper. Suffice to say here that Morris is aware of the limitations of using energy capture as a measure.[46] Energy capture needs to be combined with measures that express a society's ability to put the captured energy to use. The most important of these is organisational capacity.[47] Morris chooses urbanism as the main proxy to measure this, expanded by information technology, and war-making capacity.

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[42] Morris 2013 (p. 3 for the quote)

[43] Campbell 2013; Clark 2014.

[44] Morris 2013: 66–80; Malanima 2013 arrives at much lower estimates than Morris (although still implying that the top-ups need to be increased) but uses a different definition and is highly speculative, see the response by Morris 2013: 77–80 and the critique by Wilson 2013: 259–261.

[45] Cook 1971; popular among world historians as Morris notes.

[46] Morris 2013: 142 ('the central plank'); 2011: 148.

[47] Morris 2011: 144: 'All the energy capture in the world would not have taken a British squadron to Tinghai if they had not been able to organize it. … We need a proxy, something closely related to organizational capacity but easier to measure.'

Changes in information technology and war-making capacity are visible in the archaeological record but not in a quantifiable way. Morris' estimates for these parameters are not based on counting or measuring but on scoring using a mixture of textual evidence and subjective appreciations. I will argue later in this paper that it may be possible to capture information control, or rather knowledge and know-how, in metrics but not in the way Morris proposes.

Urbanism, however, does have a quantifiable archaeological footprint and there is a good case to be made for using it as a proxy for economic integration and development. Urban organisation itself, however, is a form of social organisation. Studying it via the archaeological record requires us to define reliable archaeological proxies. Morris takes into account only the size of the largest city as such a proxy, glossing over fundamental differences in types of urbanisation. This is problematic. It is generally accepted that urban systems that are well-connected and economically developed tend to display a lognormal distribution, with the size of each urban centre being proportional to its rank in the urban hierarchy (Zipf's rule).[48] Underdeveloped or badly connected systems deviate from this distribution to favour 'primate' cities that are much larger than expected and control significantly more resources. However, there are significant exceptions to the rule that degrees of primacy are greater in lesser developed countries. Contemporary France and Britain, for instance, show a primacy based urban system, dominated by Paris and London respectively but are both clearly highly developed countries. The phenomenon is known as the 'king effect' and can be caused by very different factors; underdevelopment and political predation (in the case of lesser developed countries) but also simple path dependence: large wealthy metropoles with a blooming cultural life and top educational institutions attract more investors, artists, and intellectuals. Morris' 'largest-city-proxy' ignores both the 'king' effect and fails to capture its underlying causes. Were Antioch or Alexandria primate cities because they were predatory centres drawing resources from extensive but underdeveloped hinterlands, or are they on the contrary 'king' cities of thriving wealthy urban networks? Rank-size analyses provide an answer (the latter scenario), simply measuring the size of the largest city does not. Using the 'size-of-the-largest-city' is too simple as a proxy for organisational capacity. 'In science things should be made as simple as possible but no simpler'.[49]

Archaeo-cliometric indicators: looking forward

There is no way to translate archaeological proxy-data into GDP or other price-based indicators and even we could the results might obscure more than they reveal given the limitations inherent in GDP and related metrics. Nevertheless, some proxy-data are clearly significant indicators for performance in terms of an economy's ability to generate real production, distribution, and consumption. The following pages are intended as an exploration towards a new set of metrics that taken together adequately and reliably capture levels of development in global economic history. Three conditions need to be fulfilled:

1° the metrics have to be based on the statistical processing of empirical data—which in the case of most pre-industrial societies means archaeological data
2° the traits they measure must be relevant to all human societies, regardless of cultural differences
3° the metrics must capture outcomes of *economic* systems, that is of societal subsystems

[48] Zipf's rule: cities in the second rank will be c. 1/2 the size of the largest city, in the third rank = c. 1/3 , and so forth (size = 1/r x size of the largest city).
[49] Einstein, quoted by Morris (2013: 26).

(including but not limited to markets) that structure the production, allocation/distribution, and consumption of goods and services

The archaeo-cliometrics we plead for in the following pages are based on four dimensions:

a) biological standards of living (anthropometrics)
b) urbanism: the tendency of populations to create societies based on interacting nucleated settlements
c) energetics: the level of energy captured by a society and transformed into material goods and immaterial actions
d) productive knowledge and knowhow (measured through product diversity and ubiquity).

None of these alone can hope to capture enough of the specific traits of a socio-economic system to analyse its structure and behaviour. Taken together, however, they provide a reasonably complete and accurate view of a society's ability to produce and allocate resources without prior assumptions concerning the role of markets, redistributions, or reciprocity based systems. In other words, they can be integrated into a 'new cliometrics' of which the primary purpose is not to project back indicators developed to measure contemporary economic performance but to set up a coherent set of metrics that can be applied to historical economies from the stone age until today.

Anthropometrics

The finality of an economic system is the sustenance and reproduction of human lives at the highest possible level of quality. Quality of life is hard to define. Mental dispositions, convictions, values, and subjective appreciations are important ingredients. Nevertheless, psychological aspects cannot conceal the overriding importance of biological ones: physical comfort, health, life-expectancy and so on. To a large extent, biological living standards depend on nutritional status: the amount and quality of nutrients people are able to consume in proportion to their physical needs minus the effects from disease. Bearing this in mind, physical anthropology should take pride of place in any economic study of historical societies.

Anthropometrics have been the preferred methodological tool to conduct such studies. Anthropometry covers the study of all measurable physical characteristics of humans. In economic history, however, it has focused almost exclusively on measuring body height. Part of the reason for this is that most anthropometric history has so far been based on archival records—of military recruits, prison populations, hospital patients, school records and so forth.[50] Human bone and dental material from archaeological excavations provide direct information on the physical wellbeing of individuals, Ideally a survey of nutritional status based on bone material should not have to be limited to height measurements. Indicators of physical stress and diseases are visible in the bone material and can be quantified over time to provide a reasonably accurate picture of the physical wellbeing of historical populations. Only a handful of such datasets, however, have as yet been compiled and creating them would require very laborious and costly projects to restudy the preserved bone material (if it has been preserved). Datasets, however, can and have been compiled for body heights. While stature is suboptimal for assessing overall nutritional status it is generally recognized as a useful proxy.

[50] See Komlos and Baten 2004; Komlos 1992.

The first attempt by Geoffrey Kron to integrate anthropometric data of ancient populations in the debate on economic performance dates to the early 2000s.[51] The author argued that skeletal material showed that Greeks and Romans from the fifth century BC until late antiquity were on average significantly taller than their medieval and early modern European successors. These results, however, were contradicted by a much larger study by Nicola Koepke and Jörge Baeten, who found significantly smaller body stature in Roman Mediterranean Europe and the parts of Central and Western Europe under Roman control but not in Germanic and Scandinavian Europe. After the end of the western Roman Empire body stature rose again. While Koepke and Baten's study should not be considered definitive,[52] their conclusions are based on a much larger dataset than Kron's and seem to be confirmed by a number of more limited studies.[53]

Body stature is closely correlated to the consumption of dairy products and meat so the average height of persons is higher in societies with low population density and higher consumption of dairy products and meat. In addition, urban populations tend to be smaller also as a result of a more intense exposure to pathogens. To conclude from this that pastoral or rural societies were more developed than advanced agricultural societies with relatively high degrees of urbanisation makes no sense. It does make sense, however, to claim that protein intake in these societies is inversely correlated to population density and inversely correlated to urbanisation. The dataset used by Koepke and Baten indicates a trade-off between protein intake in low density populations and calorie intake in high density populations. The implication is that the cost of high protein consumption per capita in preindustrial societies is smaller communities and therefore less potential social ties and less access for individuals to benefits associated with that, ranging from protection against outside physical threats to a diversity of goods and services that can only be produced by higher levels of labour division and trade.

Clearly trade and productivity levels play an important part in protein allocation. Modern societies achieve both high protein consumption per capita and dense populations thanks to high productivity in agriculture and intense trade in meat and dairy products. This was hard to achieve with preindustrial transport facilities, food preservation technologies, and agricultural productivity levels. High per capita protein intake and high biological standards of living reduce mortality rates, which (unless birth rates also drop) lead to a population increase until the carrying capacity of a region is reached. The degree to which a society succeeded in combining both, therefore, is a valuable indication of that society's ability to sustain a high average quality of life against population pressures to the contrary.

Koepke and Baeten show that population density is the most determining negative factor affecting body stature. Highly urbanised preindustrial societies, therefore, tend to have populations with a smaller average body height. But the correlation found was not straightforward. Urbanism has a corrective influence on the negative effects caused by population density. The authors hypothesize that the 'human capital-deepening effects of urban agglomerations partly outweigh other negative effects associated with urbanism (such as exposure to pathogens and hygiene problems)'.[54] Putting it

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51 Kron 2005.

52 We still await the results of Klein Goldewijk and Jongman's research (for preliminary results see Jongman 2007a: 193–195); no synthetic studies have as yet been attempted for Asia Minor, Egypt, or Northern Africa.

53 The published results used height measurements for 9477 individuals from 360 sites (Koepke and Baten 2005; 2008) from the first century AD to the eighteenth century; the full database used in Koepke's PhD Dissertation consisted of 18,502 individuals from 484 sites from the eighth century BC to the eighteenth century (Koepke 2008); compared to 927 individuals from 49 Italian sites dating from 500 BC to AD 500 in the case of Kron (2005: 72); for corroborating studies see for instance Giannecchini and Moggi-Cecchi 2008; Barbiera and Dalla-Zuanna 2009 (but note that the latter found indications that although body height increased in the early Middle Ages, life expectance did not); see also Scheidel 2012: 324–329.

54 Koepke and Baten 2005: 88.

more bluntly: given the same levels of population density urbanised societies are able to ensure higher protein production and allocation than non-urbanised societies. Presumably because they have greater organisational capacity, increasing their ability to co-ordinate production and allocation of nutrients.

We should note here also that physical wellbeing alone is not a straightforward criterion to express economic performance. Studies of Roman skeletal material appear to indicate high disease burdens.[55] But does that mean that overall well-being was lower because the empire deprived many of its inhabitants of vital nutrients[56] or that Roman society was able to sustain individuals burdened by health problems who in other societies would not have survived?[57] No modern social scientist would argue that the high proportion of GDP spent by modern western societies on health care indicates low levels of physical well-being. Arguably, societies that are able to cope with high disease burdens are more developed than those who are not, even though the *average* physical well-being of its people may be lower than that of less developed societies.

Urbanism

The concepts of urbanisation and what makes up a 'city' are notoriously hard to define but the link described by Charles Tilly between urbanisation and 'the appearance and expansion of large-scale co-ordinated activities in a society' is obvious. Large-scale activities—regardless of whether they are political, administrative, economic, or religious—require social positions with co-ordinating roles such as merchants in the case of high-level long-distance trade or high-priests in the case of organised religions. This implies lines of communication enabling co-ordinators to instruct and direct other agents involved in the process. Large-scale co-ordinated activities stimulate the formation of cross-cutting social relations that break through traditional arrangements such as kinship or tribal relations. According to Tilly the combined effects of coordinators, communication lines, and cross-cutting relationships are broadly similar in different societies: (a) *differentiation* of social positions for different segments of the activity; (b) *standardization* of procedures, vocabularies, norms, and organisational forms; (c) *changes in the quality of social relationships* towards impersonal, instrumental relations; and last but not least, (d) the *concentration of population* to where the large-scale activities are being co-ordinated and controlled.[58] Urbanism, therefore, reflects the capacity of a societal system to structure and regulate interactions between a large number of agents, beyond the possibilities of smaller communities with low levels of social differentiation.[59]

While urbanisation is not always the result of economic developments, it is commonly considered to stimulate the growth of secondary and tertiary sectors in an economy.[60] The concentration of people offers craftsmen and retailers the opportunity to specialise, thereby stimulating division of labour. Flourishing urban centres indicate flourishing rural hinterlands to provide these centres with food and raw materials. Roads between important cities are more frequently used and better maintained, stimulating the circulation of ideas, goods, and services.

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55 See for instance Paine *et al.* 2009; Lazer 2017.
56 See in this sense Koepke 2008: 144–150.
57 Cf. Lazer 2017.
58 Tilly 1980: 16–17 (italics in the original text).
59 Which does not by definition mean that urbanisation is the only solution to co-ordination problems in large group activities, as the Mongol invasions illustrate.
60 For a discussion see Wilson 2011.

In addition cities (or nucleated settlements to use a more neutral term) are highly visible in the archaeological record. We can count them, measure their surface, and classify them based on recognisable traces of the services and functions they provided. We can measure the density of urban networks and calculate the centrality measures for urban centres.

Developing metrics of urban systems to express relevant traits of economic systems, therefore, is both meaningful and feasible. The relation between cities and economic performance, however, is again not straightforward. The number of cities in a particular region is not in itself an indication of the proportion of the population living in urban centres—the urbanisation rate. Residential preferences can be motivated by economic considerations (proximity to clients/resources/land…) but also by safety concerns (protection by walls, strength from numbers), political motivations (proximity to the power centre), social considerations, or cultural traditions. A large urban centre can indicate a large countryside densely populated with peasant farmers on the brink of starvation, or a less densely populated countryside with flourishing market oriented farms. Small centres, such as the majority of Greek *poleis*, are often agro-towns whose residents cultivate small (or larger) farms near the town. Flourishing cities adorned with splendid monuments and long walls are not necessarily very populous. Lowly-skilled rural workers or younger members of peasant households can be brought in as 'commuters', or as seasonal or project-workers. Functional differences between cities, however, are not very strict. Different residential preferences tend to combine in the formation of urban centres. Even smaller *poleis*, for instance, were political and religious centres, market places, and homes to artisans in addition to being agro-towns. Cities create a range opportunities regardless of why they were established.

For all these reasons we cannot limit the metrics of urbanism to the size of the largest city or even urbanisation rates.[61] The co-ordinating capacity of an urban system is more than the aggregate of the cities in it. It depends on their geographic distribution and connections, and on the degree and type of integration between them. In addition to the number of urban centres and the total urban surface in a region we must take into account how centres were related to each other and (if possible) to the rural population. Archaeological data on dispersed rural habitation, especially of peasant farmers, are harder to retrieve and interpret than those of urban centres. Spatial network analysis and rank size analyses, however, provide useful tools to study the interrelation of urban centres.[62]

Rank-size analyses of modern urban systems indicate that well (market)integrated systems tend to conform to Zipf's law: when cities are ranked according to their size, the highest ranked city is twice as big as the second ranked, three times as big as the third and so on. When plotted on a double logarithmic graph this results in a lognormal distribution with a downward sloping line in an angle of 45°. The phenomenon is known as the 'rank size rule'. No real urban system ever perfectly conforms to lognormality of course but the rank size rule provides a baseline to measure deviations from perfectly integrated urban systems.[63]

One of the most common deviations is primacy; some cities are much larger than lognormality would predict. Most developing countries in the modern world have strongly primate urban

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[61] See in this sense also Smith 1995.
[62] Central Place Theory provides an alternative approach but implies the *ex ante* assumption of a functional hierarchy and has proven hard to apply in historical studies, see Vries 1995: 48–49; for a possibly operational use of CPT in studying the history of urbanisation, however, see Rozman 1978.
[63] Note that 'baseline' should not be confused with 'norm'; there is no reason to believe that urban systems naturally 'mature' into systems conforming to the rank-size rule; cf. Vries 1995: 50–52, contra Smith 1995.

systems. However, primacy alone is not an indicator of underdevelopment since a majority of the world's wealthiest nations (such as France with Paris, or England with London) also have primate systems. Primacy is a measure for the ability of the leading city (or cities) to claim a disproportionate share of the system's resources than predicted. As such it is an important trait to describe an urban system even though it is not the result of functional characteristics but of historical contingency.[64]

Primacy, however, is not the only common and probably not even the most significant departure from the rank-size rule. Premodern urban systems show varying degrees of convexity or concavity, or of linear distributions with flatter or steeper slopes than the rank-size rule would produce. The first (convexity or flatter slopes) indicates that lower ranked centres are larger than the rank-size rule would 'predict', the latter (concavity or steeper slopes) that they are smaller. The causes for these patterns vary but they generally indicate limited labour mobility and large swaths of the population not participating in commercial transactions.[65] Convexity and flat slopes indicate relatively larger degrees of autarchy of lower ranked centres vis-à-vis higher ones. Concavity and steeper slopes indicate dominance of higher ranked centres. In both cases, however, distributions may be segmented, with head or tails showing different slopes.

Regional studies of urban systems in the Roman empire so far have suggested a dominance of convex deviations from lognormal rank-size distributions and large regional primate centres with population figures up to and exceeding 100,000 inhabitants.[66] This probably indicates an overall 'dendritic' organisation, with regional primate centres and imperial Rome as 'king of kings'. The concentration of administrative and commercial functions in regionally primate centres, boosted their size (and probably population). A similar pattern seems to have prevailed in the Seleucid and Ptolemaic empires but it is strikingly different with that of late medieval and early modern western Europe, where there were less large cities but many more medium sized centres of 10,000 or more inhabitants.[67] The convex pattern emerging below the primate centres suggest the relative autonomy of the middle ranking centres in terms of their ability to control local resources. The steep(er) tail of the regional distributions suggests relative dependence of small more village-like towns.

Regional differences, however, were considerable. The densely populated eastern provinces, particularly in the Aegean were much more urbanised than in the west and had older more 'organically' grown urban systems. The province of Lusitania as well had an almost perfect lognormal distribution.[68] John Hanson's recent comprehensive study of urban geography in the Roman world suggests that primacy was less outspoken on the imperial level—at the 'head' of the rank-size distribution—with Alexandria being only little less than half the size of Rome and Carthage and Antioch and Carthage nicely following suit at one third.[69] Hanson also argues that convexity was not very strong and is greatly reduced when surface sizes are translated into population figures.

This, however, illustrates a major caveat in archaeological rank-size analyses. Zipf's rule and the lognormal distribution associated with it is based on population figures, while archaeological rank-size analyses are based on surface estimates. This is not true only for Greco-Roman antiquity,

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[64] Several primacy indices have been developed; see for instance Walters 1985 for a 'Standardized Primacy Index'.
[65] Smith 1995: 33; for a measure expressing convexity/concavity in archaeologically observed urban systems see Drennan and Peterson 2004.
[66] Wilson 2011; Marzano 2011; Hanson 2011; 2016; Ligt 2012; Willet forthcoming.
[67] Zuiderhoek 2016: 52–54 (and there for more references)
[68] Marzano 2011.
[69] Hanson 2016; contrary to Erdkamp 2012: 243–245; Scheidel 2007: 79–80.

of course. Rank-size settlement analyses have been common in archaeological research since the 1970s. It is, however, a very different approach from that commonly used by urban historians of late medieval/early modern Europe or China, who use population estimates based on a variety of archival and other textual sources.

It is commonly accepted that within the same urban system and the same region population density in cities that are functionally similar is fairly constant. Surface size, therefore, can be used as a proxy for regional studies, although clearly caution is necessary in defining the region and local conditions should always be taken into account.[70] Datasets from different regions, however, should not be lumped together. Primate centres usually have a much higher population density (because primacy indicates a greater ability to draw in resources). Hanson (see above) further differentiates density levels to accommodate for other functional differences but this is not so clear-cut. The greatest difficulty, however, is that most surface estimates are based on city walls. These are by definition static. Newly built walls can encompass zones that were not at the time already built. New neighbourhoods can grow outside existing walls.[71]

Rank-size analysis, combined with density and centrality measures allow us to differentiate between urban systems as proxies for organisational capacity. Dense urban systems, with high degrees of average centrality and rank-size distributions in which the bulk of urban centres are close to lognormality score high on systemic organisational capacity.

Energetics

Energy capture forms the basis of Morris' Social Development index. This makes sense but the empirical study of energy flows, or energetics, has advanced considerably since the estimates of Cook. The energetic threshold of a society is determined by the energy needed for its physiological and reproductive requirements plus the energy needed for the interaction with the environment necessary to procure this biological minimum.[72] This obviously depends on the availability of nutrients in the ecological system but nearly all such systems are in fact socio-ecological systems (SES) resulting from a combination of the social system and the biophysical 'natural' ecosystem. Humans stand out for their unparalleled ability to capture, harness, and direct energy with which to control and change their environment to suit cultural as well as biological needs. Cultural and social expectations pervade human interactions so much that even activities that are directly oriented towards sustaining life are usually enveloped in them. The satisfaction of some socio-cultural needs practically coincides with the satisfaction of biological needs; commensality for instance satisfies hunger, strengthens social bonds, and signals the social and cultural capital held by the participants. Other socio-cultural needs/desires, however, require substantial amounts of energy without being clearly directed towards the satisfaction of biological needs—such as the building of stone houses or the transport of wool or textiles. Some of these 'surplus' activities are imposed by social norms, such as house-holding, participating in social or religious events or going to school. Others are wholly discretionary such as playing or doings sports. All, however, require energy.[73]

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[70] See Marzano 2011.

[71] For a discussion see the introduction to Chandler 1987.

[72] This obviously includes the energy spent on the social interaction inherent in the co-operation for interacting with the environment, cf. Human energy requirements 2004.

[73] See White 1943 on the relation between energy and cultural evolution.

A society's ability to change and control its environment and in some cases to extend its geographical boundaries depends on its ability to transform energy into purposeful action and material changes. Throughout history the majority of populations in most societies lived close to subsistence and therefore little above the energetic subsistence threshold. Economic development occurs when technology and societal organisation raise levels of energy harvesting and control. Much of this energy in pre-industrial societies comes from muscle power but more than any other species humans have succeeded in plying the muscle power of other animals to their use creating more suitable variants through selective breeding techniques. In contrast to any other species, moreover, humans have acquired the ability to extract energy from fuels, water, and wind. Unfortunately, much of this remains archaeologically invisible or at least impossible to quantify. We can of course estimate an 'energetic threshold' by estimating population numbers and carrying capacity under soil and climate conditions but apart from the uncertainties involved in population estimates the exercise would not be very informative. It would merely be a variant to the Hopkins-style minimum GDP estimates—a different proxy for the same thing. The proxy we need has to signal the real *ability* of an historical society to capture and control surplus energy. There are currently no datasets available (as far as I know) that make this possible but there are two broad fields that offer the perspective to build such datasets in the near future: architectural energetics and fuel consumption.[74]

Architectural energetics was first developed by archaeologists of pre-Columbian America. It was famously applied to the Roman world by Janet Delaine in her study of the Baths of Caracalla.[75] Abrams argued that monumental architecture serves as an indicator of social complexity and hierarchy because it shows the presence of an elite that is capable of mobilising labour resources to create durable structures beyond the possibilities of households or egalitarian societies. Thus, monumental architecture reflects 'the system's increased scale of political organization and power.'[76] Trigger similarly argues that monumental architecture contradicts Zipf's universal 'principle of least effort' because it signifies the dominance of those on whose behalf it is created.[77] Thus '[a]t the most elementary and general level, political power is universally perceived as the ability to control energy'.[78] Not all monumental architecture, however, is merely a wasteful affirmation of social inequality and dominance. Defensive walls increase residents' security. Roads, port facilities, and storehouses enhance a society's productive capacity. Public baths, theatres, and *fora* enhance social integration.[79] Obviously functions overlap. The Baths of Caracalla were an ostentatious statement of imperial power and grandeur as much and more than they were an 'investment' in social integration. Seating arrangements and rituals in Roman theatres and amphitheatres confirmed social hierarchies.[80] Regardless of their purpose, however, monumental architecture signals both the availability of surplus energy in a society and the power to control it.

Regrettably, however, no reliable dataset has yet been collected for a sufficient number of architectural environments to transcend the casuistic level. Janet DeLaine estimated the total man-

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[74] There is an extensive literature on the energetics of agricultural systems (sometimes distinguishing 'cultural energy' and 'solar energy') but few applications in archaeology; cf. Stanhill 1984; Stout 1990.
[75] DeLaine 1997; see now also Kardulias 1995; Pickett forthcoming (see there for a survey of the methodology) and compare Pickett *et al.* 2016; for Classical Greece see Burford 1969; Salmon 2001; Stanier 1953 is early example but too much focused on monetary costs.
[76] Abrams 1989 (58 for the quote); see also Kardulias 1995.
[77] Trigger 1990: 122–123: 'all human groups seek to conserve energy in activities that relate to the production and distribution of food and other material resources'; cf. Zipf 1949.
[78] Trigger 1990: 125
[79] Cf. Abrams 1989: 62.
[80] Cf. Kolendo 1981; Edmondson 1996; Rawson 1987.

power needed to build the Baths of Caracalla. Kardulias estimated the architectural energetics for the sanctuary at Isthmia in the early Roman period and the early Byzantine fortress. Clearly, these two are not enough to use as templates to extrapolate from. We need more studies, preferably on a variety of building types with a variety of materials. The result may be used to integrate energetics data into the 3D digital reconstructions of buildings, roads, aqueducts, and other constructions that are becoming increasingly popular and, with procedural modelling technologies, increasingly feasible.[81]

Even less work has been done on fuel energetics. Robyn Veal developed a model for the fuel consumption of Pompeii.[82] A model to estimate the fuel consumption of the public baths and pottery sector is now available for the city of Sagalassos in the second century AD which is bring expanded to include household needs. The associated tool used for the calculation (XylArch) can be used for similar estimates for other communities.[83] Gradually, therefore, the tools are becoming available to estimate fuel consumption at some sites but we are still far away from having adequate datasets.

The amount of energy captured and used by a society correlates with its degree of control over the resources in its environments but the correlation is not straightforward. The productivity with which captured energy is transformed into power or directly consumed, depends on the efficiency of the technology and coordination mechanisms used. Roman public baths, for instance, were not made possible because wood was abundant (sometimes it was not) but because the techniques used were energy efficient. Hypocaust systems were greatly more efficient than burning logs in open furnaces or charcoal in braziers.[84] Roman construction required vast amounts of animal and human muscle power, hence energy,[85] but the use of concrete makes simple comparisons of the energy balance with Greek or medieval building projects misleading. While the ability to capture energy is clearly an important element in economic development, the quantity of captured energy is often less relevant than the efficiency with which it is put to use.[86] This brings us to the greatest black hole remaining: how to measure technological change and innovation? In contemporary economies innovation metrics usually focus on investments in Research and Development (R&D) and patents, complemented by bibliometrics, formal education, and employment in high-technology sectors. None of these are useful for preindustrial economies.[87] The problem, however, is more complex than establishing levels of technology or innovation. The efficiency with which energy (including muscle power) is used to produce goods and services does not just depend on technology but even more on how efficient work is divided and co-ordinated. This doesn't just require technical skills and know-how but also social skills (including the ability to communicate) and on the part of workers a willingness to follow procedures and guidance. How can we hope to capture into archaeology-based metrics this array of technical and social skills as well as the willingness and ability to co-operate?

Economic complexity indicators

We now venture into unknown terrain (where 'there be monsters') but a promising potential proxy could be product diversity processed into an 'economic complexity indicator' (ECI). The

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[81] Cf. Pickett forthcoming; for procedural modelling applied to ancient cities and buildings see Saldaña 2015.
[82] Veal 2017; 2012; 2013.
[83] Janssen *et al.* 2017
[84] On ancient fuel consumption, its interpretation, research methodologies see Wilson 2012; Janssen *et al.* 2017; Veal 2013.
[85] Cf. DeLaine 1997.
[86] Cf. in this sense already White 1943: E x F = P in which E = Energy, F = efficiency of mechanical means to spend energy, P = produce
[87] Cf. the manual compiled by the OECD for studying innovation: Frascati Manual 2002; Oslo Manual 2005.

concept and its methodology was developed by César Hidalgo, director of the Collective Learning Group at the MIT. Hidalgo considers products as packets of physical order or 'information'—matter organised in a particular way with a specific purpose in mind (food, clothing, transport, …). This purpose is present in the imagination of producers who control the knowledge (explicit) and knowhow (implicit) needed to make the products or extract the raw resources needed. Technology is merely a part of this wider set of knowledge and knowhow. In that sense products are both 'embodied information' and 'embodied imagination'. The knowhow and knowledge of individuals (termed 'personbytes' in Hidalgo's model), is limited but societies combine 'personbytes' to create collective knowledge and knowhow. This collective knowledge and knowhow is contained in societal networks and the rules/institutions that govern them. Both the quantity of collective knowledge and knowhow that a network is able to hold and the efficiency with which it can be used to transform energy and matter into products is determined by the network's structural properties. Thus, economic performance is not only determined by the number of nodes—the 'aggregate' of personbytes—but by how well they are linked (the network density), the type of links, whether and how these are multi-layered, how robust the network structure is, and so on. These networks, moreover, are nested structures: 'what we consider to be a network at one scale becomes a node in the next. Networks of neurons become nodes when we abstract them as people, and networks of people become nodes when we abstract them as networks of firms.'[88] The larger an economic network becomes, the more it needs standards (such as a common language, weights, measures, …) to function efficiently.

Societies become economically more developed as they increase their collective knowledge and knowhow to produce more diverse 'packets of embodied imagination/information' to satisfy wants/needs.[89] A developed economy is a complex system that allows potential producers easily to access and activate productive knowledge and knowhow held by others either collectively or individually. Markets play a role in this. They incite producers to use knowledge and knowhow to create or trade products, because in return it will give them access to the products created by the knowledge and knowhow of others. Thus markets are societal systems that link the productive knowledge and knowhow embedded in societies with high levels of social differentiation. Networks based on market links have advantages. Market-based networks can be very open and highly flexible because they are based on links that are weak, voluntary (in principle), not intrinsically hierarchical, and impersonal. The downside, however, is that the links are highly volatile, which makes them unsuitable for complex or enduring co-operations. Co-operation based on market principles needs to be backed up by non-market institutions that help guide selection processes (through recommendations, diplomas, licenses …), clarify realistic mutual expectations, and create the necessary trust that commitments will be honoured. To borrow neo-institutionalist terminology: without strong institutional backup market relations face inhibitive transaction costs—search costs, bargaining costs, and enforcement costs. Throughout history, therefore, market-links have been grafted on non-market ones. This is as true of today's developed economies, which rely on firms and legally sanctioned contracts to co-ordinate production,[90] as of pre-industrial economies which embed market relations into multiplex social networks. The amount of collective knowledge and knowhow that can be embedded in market-networks that remain isolated from non-market societal networks is highly limited. Consequently, neo-classical theory is of limited use to analyse economic development.

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88 Hidalgo 2016 ebook chapter 7: 'Links are Not Free'.
89 Hidalgo 2016.
90 See famously Coase 1937 and Williamson 2000; 2008 for an overview.

Development, growth, and wealth are not the same thing. Societies can be rich but economically underdeveloped. While value creation is always the result of knowledge and knowhow (from hunting or berry-picking to building space-ships), wealth can be appropriated through entitlements not based on productive knowledge and knowhow—as in the case of countries that depend on reserves of natural resources, or in the case of tributary or colonial empires. The wealth of these countries (or of individuals in them) derives in the first example from property rights over natural resources (which ironically derive their value from the ingenuity of another society), in the second example from military or political entitlements. While real economic growth is ultimately always the result of developments in societal knowledge and knowhow, economic growth in one society can be fed by the appropriation of products created in another, for instance because the appropriating society excels in military or politically manipulative knowledge and knowhow.[91] Similarly within societies the wealth of rent-seeking elites is based on the appropriation of wealth created through the knowhow and knowledge of others.

Going back to the Roman economy the question becomes: was wealth creation merely the result of extraction and use of natural resources that just happened to be present in the Mediterranean, with collective knowledge/knowhow embedded in small relatively isolated communities? The answer is evidently no, since the same resources and small communities had been present thousands of years before and were still available during the 1000 years after the peak of energy capture and material output that archaeology is evidencing. So increased wealth creation must have been the result of real development, i.e. an improved collective capacity to 'embody information' into production and trade thanks to new institutions that boosted co-operation (including but not necessarily limited to forced co-operation) and investments in real and human capital. On the other hand, it is equally clear that the empirically observable regional inequalities were at least in part the result of political appropriation and that the wealth of patrimonial elites cannot only be ascribed to their contribution to wealth-creating processes.

In order to measure and explain real economic development rather than shifts in appropriation we need indicators that measure development, rather than growth. This is the objective of the 'Economic Complexity Indicator' devised by Hidalgo and Hausmann. It measures the complexity of products and countries as a proxy for the 'complexity of the set of capabilities available in a country'.[92] These sets of capabilities are 'chunks of productive knowledge',[93] some modularized on the level of individuals, others grouped into organisations and networks. The degree of economic complexity is an indicator for a society's ability 'to hold and use a larger amount of productive knowledge'.[94]

The economic complexity index developed by Hausman and Hidalgo should be appealing to archaeologists and historians, because contrary to most other indicators its focus is not on size of production or trade but on diversity. The index is based on network models and combines two parameters: diversity—the number of items a country produces—and ubiquity—the number of countries a particular item is produced in. By combining textual and archaeological data it should be possible to map the diversity and the ubiquity of ancient production and how this changed through time. The metrics resulting from such an exercise could then be used as a proxy for the level of productive knowledge and knowhow in ancient societies. In addition the ECI is closely connected to the theoretical field of complexity economics, which provide us with the theoretical framework needed to el-

[91] Cf. Hidalgo 2016 ebook chapter 4: 'Out of Our Heads': 'Economic development is not the ability to buy but the ability to make'.
[92] Hidalgo and Hausmann 2009: 10575.
[93] Hausmann and Hidalgo 2013: 16.
[94] Hausmann and Hidalgo 2013: 18.

evate the metrics of archaeological proxy-data to the heart of economic theory, without being forced to squeeze the date into the more traditional metrics used in macro-economics.

Conclusion

This essay has been an exploration and a plea for a research programme to integrate economic archaeology fully into global economic history. Without archaeology economic history is condemned to stare myopically at the handful of societies which over the few recent centuries have left enough textual evidence for statistical analyses. I have argued that archaeological proxy-data can be quantified and mathematically processed but not translated into the econometrics that cliometric history tries to establish. This, however, should not stop us from working on the development of what I call archaeo-cliometrics because the commonly used econometric indicators are not good at capturing the performance or the structure of real economies in premodern societies. The discipline of economics is richer than the neoclassical synthesis that non-economists often confuse it with. Its subject is not markets or equilibrium theory but how societies organise themselves to ensure the welfare and wellbeing of their populations. Meaningful econometrics should capture how (un)successful a society is in achieving this. Economic archaeology is indispensable to achieve this for preindustrial societies. I have argued therefore for an empirically based archaeo-cliometrics that captures the determinants of real economic systems in global history. At this moment four promising fields can be distinguished: (a) anthropometrics to measure biological standards of living, (b) rank-size and network analyses to compare the structural features of urban systems, (c) energetics of architecture and fuel consumption to measure levels of ability to capture and control energy, and (d) product diversity and ubiquity as a proxy for the collective productive knowhow and knowledge embedded in societal networks. The overarching theoretical framework is that of complexity economics. Clearly the datasets that are currently available are insufficient. Expanding them, however, and building the required new ones is now methodologically feasible.

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