Bridging the gap: agrarian roots of economic divergence in Eurasia up to the late middle ages

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Summary

Recently there is a revived interest in national accounts for pre-industrial cultures, especially in the late-medieval period. There is one conclusion that can already be drawn from this new stream of research: per capita income turns out to have been higher than what had been assumed before. This revision of income estimates for the late medieval Eurasia has serious implications for research on ancient economies as well. Either the income estimates for the ancient world had to be updated and modified upwards, or, if the present numbers still turn out to be correct, we have to face the inevitable conclusion that, however unlikely it is, significant economic growth must have occurred during the early middle ages. Based on recent research on the field, however, we can safely argue that it is the estimates that need to be revised rather than it is a pre-industrial economic revolution that has to be invented.

In this paper our main objective is to give a review of the present state of the issue. We compare a set of recent estimates of medieval and ancient income levels and find that until about the 11th century, ancient economies had remarkably similar per capita income paired with strong similarities in terms of economic structure, more specifically a dominant position of agriculture. It is therefore hardly surprising that agricultural development was an important indicator of per capita income in those economies and agricultural crises played an important role in the fluctuations of per capita income. In the period of our research two crises stand out, i.e. in the 6th century (the Justinian plague) and the economic crisis of the 11th century. However, whereas all countries seem to have suffered to a more or less similar degree in the 6th century without experiencing permanent deviations in terms of the level of per capita income, this homogeneity seems to have changed in the 11th century. In the latter period, the economies of Northwestern Europe increased their per capita income growth, while the Middle East and Eastern Asia began to decline or at best remained stable, which, according to many present studies, seems to be the start of the Great Divergence.

Two factors may have contributed to this agricultural divergence in the 11th as compared to the 6th century. First, a relatively low wage to land rent ratio in China and the Middle East. This was already in existence in the first centuries AD due to the much higher land productivity compared to Europe. This would foster growth of land saving technologies. Initially, this also increased per capita output, but due to diminishing returns on land, this was about to come to a halt, which is what happened during the 10th-15th centuries. However, such stagnation was not inevitable since all regions were potentially able to substitute labour (and land) for capital. However, also in this field both the Middle East and China were at a disadvantage. First, the introduction of short term lease contracts, which took place in the whole Eurasian continent, reduced incentives to invest in capital in regions with a low wage to land rent ratio. Second, the adverse climate conditions in the Middle East and China caused an increase in the price of capital goods, most notably oxen. This mechanism worked via increased warfare and via a reduced output per hectare, causing more pasture to be converted to arable. Finally, the increase in draught animals in Europe, especially the increase in horses, caused higher output per capita.

1. Introduction

Recently there is a revived interest in national accounts for pre-industrial cultures, and especially in the late-medieval period (e.g. Walker 2008; Broadberry et al. 2011; Malanima 2011; Van Zanden and Van Leeuwen 2012). There is one conclusion that can already be drawn from this new stream of research: per capita income turns out to have been higher prior to the Industrial Revolution than what had been assumed before, most specifically by Maddison (2007).[1] In addition, the general finding seems to be that countries in Northwestern Europe started to diverge from those in the Middle East and Asia already around the 13th century.

This revision of income estimates for the late medieval Eurasia has serious implications for research on Ancient economies as well. Either the income estimates for the ancient world had to be updated and modified upwards, or, if the present numbers still turn out to be correct, we have to face the inevitable conclusion that, however unlikely it is, significant economic growth must have occurred during the early middle ages. Based on recent research on the field (e.g. Amemiya 2007; Bedford 2007; Scheidel and Friesen 2009; Pamuk and Schatzmiller 2011; Foldvari and Van Leeuwen 2011), however, we can safely argue that it is the estimates that need to be revised rather than a pre-industrial economic revolution that has to be invented. The ongoing revision of existing income level estimates has further repercussions, since income levels significantly above subsistence levels may indicate more complex economic structures than thought beforehand.[2]

At the same time, it seems undeniably, because of the large share of agriculture in these economies, that the development of per capita income was largely driven by agriculture. This finding raises the interesting question why economic divergence occurred in the crisis of the 11th century rather than in the crisis of the 6th century. Indeed, we find that up to the 10th-11th centuries per capita GDP and agricultural production were relatively stable, with the exception of some fluctuations around the Justinian plague in the 6th century. This indicates that, even though per capita GDP is well above subsistence level, still the Malthusian (Malthus 1798, repr. 1976) logic, taken in the strong sense, seems to hold. Part of the reasons of the temporary increases in per capita income after the Justinian plagues was the heavy population loss (possibly caused by adverse weather conditions, wars, as well as plagues), even though actual mortality rates differed by region, that occurred in the whole of Eurasia. This increased income declined again due to ensuing population growth. This was different in the 11th century. Even though in the 10th-11th century we witness a similar fall in agricultural output, two factors are different. First, whereas there was a decrease in average temperatures in China and the Middle East, Europe witnessed an increase (the Medieval Climatic Optimum). This was also not accompanied by a fall in population. Second, whereas after this shock China and the Middle East continued on their steady state of per capita GDP as they

[1] For a comment on Maddison see Federico (2002).

[2] The baseline Malthusian model suggests that per capita income levels should not in the long-run exceed the subsistence level, i.e., a level of income that is required for a stable population. It is possible to imagine social practices (in the form of regulations, patterns of behavior) that may result in higher income level in certain societies, but the fundamental mechanism is not changed by these. Obviously, finding income levels much above the subsistence level indicates the presence of unexplored puzzles. For a Malthusian view of pre-industrial societies, see Clark (2007).

had done in the 6th century, in Northwestern Europe slow per capita growth emerged which might be considered as the start of what is now called the Great Divergence.

In order to address these developments we start in section 2 with an overview of per capita GDP as taken from recent literature. We conclude that per capita GDP is indeed stable until the 11th century when a small divergence started to occur when Northwestern Europe took off on its path of slow per capita growth. In section 3 we move on to the explanation of this phenomenon. After concluding that agriculture is by far the largest sector in these early economies, we turn to the changes in per capita income around the Justinian plague in the 6th century. We indeed find it has all the standard Malthusian traits which, however, do not seem to be mirrored in the 11th century. In Section 4 we therefore address the question what other factors were driving the divergence in the 11th century. We find that the increased introduction of labour saving technologies (and capital saving technologies in China and the Middle East) are an important factor, which is largely driven by the high land rent to wage ratio in the latter two regions. At a given level of capital, this inevitably leads to diminishing returns on land and a stop on per capita growth. We offer some tentative reasons why this high land rent to wage ratio was not overcome by the substitution of land and/or labour with capital. We end in section5 with a brief conclusion.

2. Estimates of the income levels in early economies

Our point of departure, as for many other studies, is the magnificent work by Angus Maddison (2003; 2007) who published estimates of per capita GDP for benchmark years from 1AD until the present. Even though his post-19th century estimates have gone largely uncontested, his pre-19th century figures, and especially those for poorer countries, have been argued suffer from some degree of underestimation. Hence, several attempts have been made to revise his estimates.

The first wave, with largely European countries in focus, began in the 1990s (e.g. Blomme and Van der Wee 1994; Malanima 1994; Yun 1994; Prados de la Escosura 2000; Van Zanden 2001). These estimates, largely covering the later part of the early modern period, suggested that a gap in per capita GDP had already existed between the East and West before the Industrial Revolution. They could not tell, however, when and where the divergence had emerged. Van Zanden (2004) made an attempt to identify the very beginnings of divergence by estimating several proxies of per capita GDP. He concluded that there had been a relative dynamic development in early modern Holland and England, a decline in early modern Italy, and stagnation everywhere else until the 19th century.

Realizing that we need more data as well as data that are less dependent on assumptions, recently there has been a surge in per capita GDP estimates stretching back until the later Middle Ages. Almost without exception they resulted in upward modifications of the per capita GDP as estimated by Maddison. Furthermore, they uncovered a divergence between Holland and England at the one hand and most other countries at the other hand starting as early as the 14th century. This were not, as had been the focus in the 1990s, largely European countries but rather covered a broader set of countries in the Eurasian continent. As pointed out in the introduction, these estimates also revived interest in the ancient period, for which the existing estimates are also revised upward.

An overview of existing estimates on early economies is presented in Table 1. Many of those estimates are still preliminary and/or unpublished, but we feel that it is now time to make a first inventory of the existing data and growth patterns. Perhaps the most important conclusion that may be drawn from this Table is that economic divergence only started to

Table 1: GDP/cap in 1990 GK dollars from the literature

	Holland	England	Spain	Italy	Byzantium /Turkey	Iraq	Egypt	India	China	Japan
300BC						670				
100BC						784			700	
1				1,400						
315							550			
720						744	750			401
930						736	725		844	429
1020					680	713	648			
1060		722				723	596			
1180					560	680	676		625	517
1300		751	849	1,630	565		635			526
1400	1,267	1,118	817	1,395	625		800		607	526
1500	1,460	1,093	832	1,405			745			
1600	2,432	1,067	852	1,346				682	616	573
1700	2,333	1,542	796	1,334				622	601	627
1750	2,486	1,682**	764	1,505				573	540	596
1800	2,691	2,045**	884	1,315	680	550	600	569	494	638
1850	2,338*	2,853**	1,079	1,350	880	600	750	556	505	679
1900	3,424*	4,492***	1,786	1,785	1,213	1,000	902	599	545	1,80
1950	5,996*	6,939***	2,189	3,502	1,623	1,364	910	619	448	1,921
2000	22,169*	20,353***	15,662	18,774	6,446	1,221	2,936	1,892	3,421	20,738

Source: Holland: Van Zanden and Van Leeuwen (2012); England: Broadberry et al. 2011); and for 1060 from Walker (2008); Spain: Alvarez-Nogal and Prados de la Escosura (2011); Italy: Malanima (2011); Lo Cascio and Malanima (2009); Byzantium/Turkey, Iraq and Egypt: Milanovic (2006), Foldvari and Van Leeuwen (2011), Pamuk and Schatzmiller (2011) ; India: Broadberry and Gupta (2012); China: Guan and Li (2010), linked with Liu (2010); Japan: Bassino et al. (2011). For the post-1850 period Maddison (2007).
Note:
*From 1850 Holland is changed in the Netherlands. Since the Netherlands as a whole is poorer in per capita terms than Holland, we find a drop in GDP per capita.
** Between 1750 and 1850 the data refer to Great Britain.
***From 1900 the data refer to the UK.

occur after the 12th century with especially England and Holland experiencing relatively high growth rates. Before that time, even though there were some differences across regions, GDP per capita estimates seem to be still remarkably similar and no significant differences in growth patterns emerge.

Nevertheless, there remain controversies regarding some of the numbers, especially for England and China. For England, there is an alternative estimate by Clark (2010) who calculated GDP based on the income based approach largely based on wages, land rents and some additional factors. Whereas the data from Broadberry et al (2011) in above table clearly show a divergence, Clark argues for a high and almost constant average per capita GDP until the late 18th century. Broadberry et al (2011), however, have shown that this difference can largely be explained by Clark's assumption of constant working days while in most of the literature the general conclusion is that days worked increased (e.g. De Vries 1994).

A similar discussion exists for China. Whereas the data used in Table 1 indicate a decline in per capita GDP over the Song period, Liu (2005) has arrived at an increase in per capita GDP, only finding a decrease between Song and Ming (which we also find in Table 1). However, he used money supply and prices in a Fisher equation, creating a problem when the share of non-market production decreases (Van Zanden 2012, 275). This seems indeed to be the case, or at the very best not increase (Foldvari, Van Leeuwen, and Van Leeuwen-Li 2012).

Yet, as Table 1 shows, there still is a large gap between the Middle Ages and the late Antiquity (roughly between the year 1 and 1200 AD). Two papers have discussed this gap quantitatively, although one needs to bear in mind that the lack of detailed data makes their outcomes tentative at best. The first method is proposed by Milanovic (2010). He calibrates the GDP of the Roman Empire to arrive at benchmark estimates of per capita GDP of these regions. Since these estimates are expressed as subsistence ratios, in order to make them comparable, we have to multiply them with the subsistence-level GDP, which Maddison estimated at 400 G-K dollars at 1990 prices. There is a reason to believe that his estimates are subject of a systematic downward bias. Milanovic basis himself on the estimates of the subsistence ratio from Allen (2007), which only refer to labourers. However, as pointed out by Scheidel and Friesen (2009) they are probably below the middling incomes. Taking the average of their optimistic and pessimistic scenario's, we arrive at the conclusion that labourers subsistence level is about representative for at best the lower 70% of the society. In order to arrive at estimates for the whole society we modified Milanovic's estimates as follows. First we assume that the poorest 70% of the population has the same income, while for the rest 30% we assume that they follow a Pareto distribution. For the total population we assume an income inequality (G=0.4). These assumptions uniquely determine a per capita income level for the society (see the appendix A.1. for the details), which, with these parameters, we find to be 45% higher than suggested by Milanovic.

As a second approach, proposed by Van Zanden at the Maddison memorial conference in Amsterdam in 2010, is to employ a model in which GDP per capita is regressed on book (manuscript) production and urbanisation in a fixed-effect panel specification, under the assumption that those represented important factors in economic development. In this paper, we follow his lead and arrive at the following regression results:

Table 2: Regression of GDP on population and book production (fixed effect panel)

explanatory variable	coefficients (t-statistics)
constant	6.089 (16.4)
log of population (t-100)	0.598 (2.12)
change in number of manuscript titles	0.014 (4.81)
rate of urbanization	1.000 (1.32)
R^2-within	0.51
N	31

We use these estimates to have estimates for GDP per capita for countries as far back in time as 800. The estimates by the two methods are reported in Table 3. Notwithstanding all data problems and simplifying assumption behind the methods, at least some picture emerges from the data. First, we find that GDP/cap was already relatively high (and relatively

Table 3: GDP/cap in 1990 GK dollars based on Milanovic and Van Zanden (see text for details)

year	Holland (Van Zanden method)	England		Italy		Spain		Egypt	Iraq
		Van Zanden method	Milanovic	Van Zanden method	Milanovic	Van Zanden method	Milanovic	Milanovic	Milanovic
14			638		1,241		696	696	835
300			708		783		783	812	748
400			696		760		760	812	760
500			603		684		684	731	812
520			603		667		667	719	824
600			603		644		644	684	783
700			621		655		655	644	748
800				611		689			
900		574		658		729			
1000		727		877		927			
1100		797		965		1,012			
1200	857	826		1,114		1,013			
1300	1,011	922		1,299		1,122			

Note: Sources and method as described in the text.

constant) before 1200. For this period per capita GDP was also relatively homogenous around the world, varying around 500-800 GK dollars. However, somewhere around the 12th century something changed: in North-western Europe countries started to show a relatively slow growth in GDP per capita. This was not true though for Southern Europe, the Middle East, or Eastern Asia. This effect was even reinforced by the Black Death when about one third of the European population died. We can see that in England and Holland this led to further increases in per capita GDP, while in the other regions there was none, or even a negative effect. Only from the 19th century we see an acceleration of GDP growth in per capita terms in North-western Europe as well as the start of what is often coined "modern economic growth" in the South. In the Middle East and East Asia, they experienced, however, first a decline in per capita GDP before economic growth (on a much more modest scale than in Europe) occurred.

3. Feeding the people: agricultural development, ca. AD. 500-1100

The conclusion from the previous section is that, according to our present knowledge, per capita GDP prior to the late middle ages seems to have been relatively stable at around 600-800 G-K dollars but still exceeding the subsistence level of ca. 400 G-K dollars (at 1990 prices) as argued by Maddison (2007). This finding is important since it suggests that these economies were way more complex than hitherto assumed.[3] This implies a more dynamic system of trade, transport, and other forms of specialisation in agriculture. This, in turn, seems to implicate a form of Smithian growth occurred in the Middle East, China, and, to a lesser extent Europe.

Nevertheless, even though for shorter periods growth might have occurred, between ca. 1AD and 1100 no real increases in per capita GDP took shape in either region, which changed after ca. 1100AD for North-western Europe. The main argument for such a pattern in the first millennium may be Malthusian. In the strong version of a Malthusian world, an increase GDP per capita, either due to a loss of population or an invention, leads to an increase in population that erodes the initial gain in terms of per capita income due to diminishing returns on land. Likewise, any negative shocks to per capita income, like bad harvests, war damages or overpopulation will reduce population so that the equilibrium is restored again due to the decreasing marginal returns to labour. So, generally speaking, whatever happens to productivity, it should translate to changes in population but should only have a transitory effect on per capita income. Such economies are predominantly agricultural by nature with only some privileged city states as exceptions like Athens. However, even though such a Malthusian type system may have been in existence up to the 11th century,

[3] Theoretically, we could also envisage an explanation that retains classical Malthusian views on pre-industrial societies. This would require that certain social institutions and practices keep the long-run level of per capita income above what is needed for the bare survival of the population and the preservation of a state. Still the observed increase in per capita income levels would require that these rules are constantly changing shifting the equilibrium value of per capita income upwards, which is quite difficult to believe. This would be some kind of strange income growth by increasingly strict birth limitations and/or extreme mortality increasing activities. Both being limited naturally, this cannot be a feasible option to save the traditional view.

clearly something changed from that period onwards since North-western Europe started to break free from the existing per capita income equilibrium.

In order to better understand what happened after the 11th century in Northwest Europe (a topic more widely discussed in the next section), our first step is to look what determined these pre-11th century income levels. Given the predominantly agricultural nature of these economies and the (hypothetical) relationship between agricultural output and population size, we start with trying to get a handle on the share of agriculture in total output. The little data available is given Table 4 below.

Table 4 already gives us a first impression of the development of agriculture over time. We see that the share of agriculture in GDP declined strongly in Europe in the Late

Table 4: share agriculture in current price GDP

	Holland	England	Spain	Italy	Byzantium/Turkey	Iraq	Egypt	India	China	Japan
300BC						89.3%				
100BC										
1										
315										
720										71.6%
930									65.0%	72.9%
1020					85.0%					
1060		85.0%								
1180										72.9%
1300		45.1%	50.0%	48.7%						71.9%
1400	38.0%	39.8%	57.5%	42.8%						71.9%
1500	21.8%	39.6%	55.0%	47.9%					74.5%	
1600	12.0%	41.1%	52.0%	46.5%				94.3%		70.6%
1700	11.4%	28.6%	55.0%	46.5%				95.4%	56.3%	63.0%
1750	10.7%	30.0%	52.0%	47.5%				94.9%	57.3%	62.9%
1800	15.0%	27.0%	47.0%	49.5%				90.6%	60.1%	63.4%
1850	25.2%	18.0%	40.0%	50.0%				95.4%	61.0%	63.9%
1900	18.8%	28.6%	28.6%					61.9%		35.8%
1950	9.9%*	27.3%	27.3%					52.1%	62.8%**	16.9%***
2000	2.6%	1.0%	4.4%	4.6%	10.8%	2.8%	13.5%	23.2%	15.1%	1.7%

Note: subtracted 25% from China (before 1600) and Japan agriculture due to value-added output ratio
Note: values 1850-2000 data from Holland refer to the Netherlands. 1750-1850 data for England refer to Great Britain and 1900-2000 to the UK.
* 1939
**1933
***1940
Sources: Holland: Van Zanden and Van Leeuwen (2012), Smits et al. (2005); England: Broadberry et al. 2011); and for 1060 from Walker (2008); Spain: Alvarez-Nogal and Prados de la Escosura (2011); Italy: Byzantium/Turkey, Iraq: Milanovic (2006), Foldvari and Van Leeuwen (2011; India: Broadberry and Gupta (2012); China: Guan and Li (2010), linked with Liu (2010); Japan: Bassino et al. (2011). For the post-1960 period FAOSTAT (accessed 2012)

Middle Ages and especially in North-western Europe. No such decline, however, occurred in East Asia and the Middle East until well into the Early Modern Period. The only real outlier in this Table, however, is India with ca. 90% of GDP devoted to agriculture, a number which, however, can be questioned and may be a result of an underestimation of non-agricultural output in the mid-19th century.

However, as Table 4 shows, big gaps exist in the data on agriculture for the first millennium AD. Given the scarcity of data, we thus have to resort to alternative sources to obtain a picture of changes in agricultural activities. Two sources are at our disposal: historical reference works and climatologic variables such as pollen data. The results are reported in Table 5. The main conclusion seems to be that a collapse occurred in agriculture in

Table 5: Historical development of agricultural systems

	Europe	MiddleEast	China
Late Antiquity (400-600)	Prosperous, but low level of arable agriculture compared to woodland	Prosperous, complex (BOP)	Rise mixed agriculture: pasture rose but farming declined
The transitional period (600-750)	Collapse arable: increase pasture	Steppic phase and collapse	Pasture prosperous; slow rise arable
Early Middle Ages (750-900)	recovery	Slow recovery	Prosperous, complex
High Middle Ages I (950-1100)	increasing arable, prosperous pasture	Prosperous recovery: cereals and herding	Gradual collapse
High Middle Ages II (1100-1300)	mixed agriculture: strong pastoralism	Gradual collapse	Farming and pasture maintained low level
Late Middle Ages (1300-1500)	mixed agriculture: strong pastoralism (temporary drop during Black Death)	Little presence of mixed agriculture, some pastoralism	Slow recovery arable; pasture maintains low level

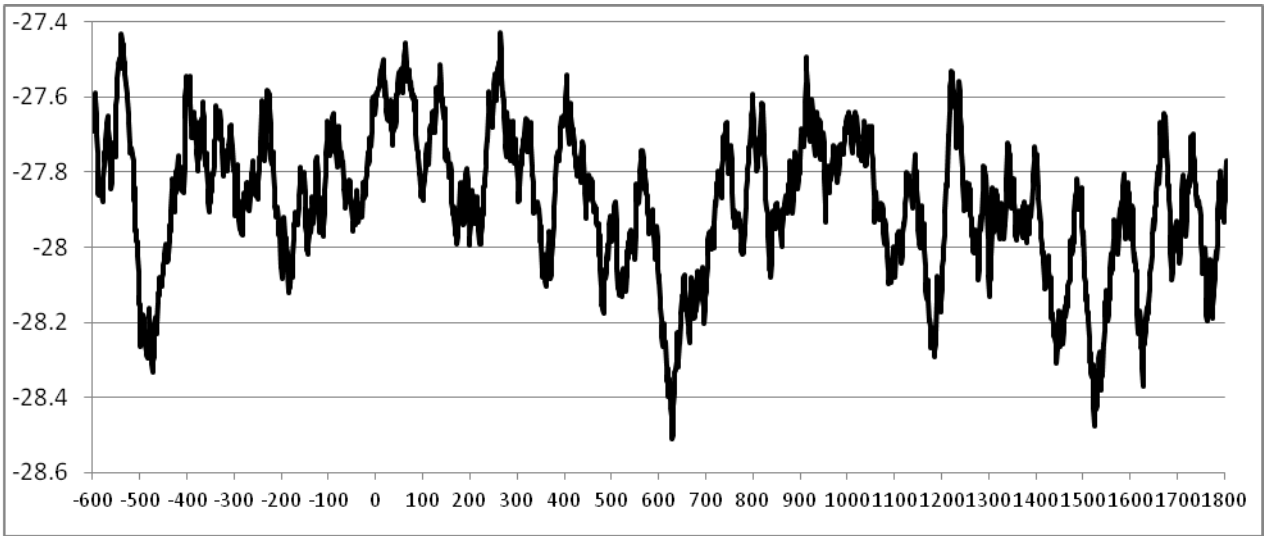
Sources: Europe: Dumayne-Peaty (1999), Mighall et al. (2006); China: Han (1993; 1999), Wu (1997), Wang (2001)

both the Middle East and Europe around the 7th century, followed by a recovery. For China, such a collapse is less prevalent. More spectacular, though is a collapse (extensification) that occurred in the Middle East and China in the 11th century, while no such development occurred in Europe, point discussed in Section 4.

There was thus a clear difference between the agricultural crises of the 6th and the 11th centuries: whereas the fist crisis was virtually universal in the Eurasian continent, the second mainly hit in regions outside Europe. Also, as we have seen in section 2, per capita income did not divergence during the first crisis while a divergence did take place during the second. In order to understand this difference, it is therefore important to address the factors affecting income in the 6th century in this section, and compare with the differences in the 11th century in the next section.

An important explanation for the crisis of the 6th and 11th century is climate. Indeed, as can be seen in Figure 1, the Greenland ice core data show a clear downward peak in the 7th century, suggesting a decline in temperature. Also a decline in the 13th century may be

Figure 1: Delta^{18}O in Greenland Ice Core



Source: Langway et al. (1985).

witnessed. In Figure 1 one may see the delta ^{18}O isotopes. This is the ratio between oxgen-18 and oxygen-16 molecules in water. Since in fresh water the ratio is lower, the more negative the value is, the lower the temperature was when the sample was frozen. As a rule of thumb, a decline by 0.2 refers to about a decline of 1 degree Celsius in temperature. This suggests that in the 6th century there was a massive decline in temperature with about 2.5 degree on average. However, the Greenland ice core data are really only representative for Northwestern Europe and North-eastern America. Nevertheless, separate data for such an cold period around the 4th-6th century are also provided by Man (2009) and Ge and Wu (2011) for China.

These climatic events may affect agricultural output in several ways. Zhang et al (2007, p. 19214) put it very succinctly, arguing that, the following lack of food may, besides the standard Malthusian reaction of plague, also induce several social reactions which, "[b]esides migration, […] include warfare, economic change, innovation, trade, and peaceful resource redistribution". They argue that neither of the peaceful options is very likely, which leaves us, besides increased mortality, with migration and war.

The mortality issue is the one that captures most people's imagination. The most famous is perhaps the Justinian plague of the 6th century. For Europe Russell (1958, p. 148) estimated that the Justinian plague killed 40% of the population while in some Middle Eastern and North African countries (Syria, Egypt, Arabia) mortality was much lower with just 10%. For other parts of the Middle East both Issawi (1981) and Treadgold (1997, 278) estimate high losses due to the Justinian plague (35-40%) which was followed by the Arab invasions and a small recovery. As outlined by Findlay and Lundahl (2006), the Arab tribes were largely spared from the disease while the Byzantine and Sassanid Empires did suffer, paving the way for the Arabs to establish their empire. Likewise, we find that in China in the 6th century only witnessed a small decline in population numbers from roughly 50 to 46 million (Lin 1995, 272; Ge 2002; Dong 2002).

It would be wrong, however, to argue that the lack of mortality during the Justinian plague meant there was no, or only little, effect of mortality on agriculture in the heartlands of the Middle East and in China. Rather, it would be more correct to view the Justinian plague as the culmination of plagues that ravaged the lands for centuries, possibly already since the start of the cold period in the 2nd century AD. For example, Ge (2002) argues for a big plague around 217 in China giving as an example that in a family consisting of 200 persons two thirds had died because of it. Something similar is observed by Wan (2003) who finds that in a plague in 253AD two thirds of the soldiers died. This corresponds with similar observations of the Antonine plague (165-168AD) and the Cyprian plague (ca. 250AD) in Europe as well as in the Middle East (Russell 1958, p. 80). Hence, it may be more accurate to speak of a period of 400 years of almost continuous plagues. This means also that, even though there are no clear "jumps" in agricultural productivity, total agricultural production must have suffered. For example, we clearly see that in all three regions the first 500 years of the first millennium AD were characterised by regressing arable and an increase in pasture; a common phenomenon in cases of large scale population decline as the evidence of the Black Death shows (e.g. Broadberry et al. 2011). Indeed, this is clearly portrayed in Table 5. Another example of this move towards pasture can be found in the number of horses grazed on state-owned farms. Their numbers in the Northern Wei in the 4th century were close to 20,000, a number that increased to 400,000 in the 7th century and even to 430,000 in the 8th century.

Of course, as pointed out by Zhang et al. (2007), declining per capita output can not only lead to mortality, but also to migration and warfare. One way, to distinguish their effect is to look at regional developments in agriculture. For example, In China the mortality was probably heaviest in Shanxi and Jiangsu. This caused migration from the North to the more productive areas of especially the lower Yangtze area. Also for the Middle East a similar pattern may be observed. However, contrary to Europe and China, for the Middle East it is possible at this time to make a more detailed agricultural chronology based on palynological research even though we have to bear in mind that the entire region is unevenly covered by palynological research.[4] Also, when a Dutch team from Groningen attempted a research in the

[4] Some countries – like Israel or Turkey – can be considered quite well studied, whereas others – e.g., Iraq or Lebanon –yield no pollen cores useful for an historian whatsoever. For Iran and Georgia, one has only one or two interesting sites for each country (i.e. Djamali et al. (2009); Connor, et al. (2007); De Klerk et al. (2009); Connior and Kvavadze (2005))

early decades of the radiocarbon dating, the costs of obtaining a ^{14}C date was too large to aim at more than one or two dates for each core. Since then little research has been done on late antique or medieval period. That being said, we can still make some inferences of agricultural development in the Middle East. The pollen record – as well as the archaeological evidence – leaves no doubt that Late Antiquity was a period of strong agricultural expansion in the

Table 6: A comparison of plausible scenarios of agricultural histories of selected Middle Eastern regions.

	SW Asia Minor	E Asia Minor	N Asia Minor	Palestine: Galilee and the Dead Sea region (modern Israel)	Palestine: the Dekapolis (modern N Jordan)	NE Iran (Lake Almalou)
Late Antiquity (400-600)	Prosperous, complex (BOP)	Prosperous, complex (BOP)	Prosperous, complex (BOP)	Prosperous, complex (BOP)	Prosperous, complex (BOP)	Prosperous, complex (BOP)
The transitional period (600-750)	**Steppic phase, notable decrease in the spatial extent**	**Steppic phase and collapse**	**Steppic phase**	**Steppic phase and collapse**	**Prosperous + complex**	**Short-term collapse**
Early Middle Ages (750-900)	Slow recovery	Abandonment	Slow recovery	Simple, generally pastoral	Prosperous + complex	Prosperous, complex (BOP)
High Middle Ages I (950-1100)	Stable, cereals and herding	Prosperous recovery: cereals and herding	Stable, cereals and herding	Simple, largely pastoral	Prosperous + complex, than collapse	Prosperous, complex (BOP)
High Middle Ages II (1100-1300)	**Gradual collapse**	**Collapse**	**Collapse**	**Simple, largely pastoral**	**Abandonment, small-scale pastoralism**	**Collapse**
Late Middle Ages (1300-1500)	Little presence of mixed agriculture, some pastoralism	Domination of pastoralism	Prosperous recovery, cereals, herding, nuts	Simple, largely pastoral	Abandonment, small-scale pastoralism	Small-scale agriculture

Note: The chronological categories are mere approximations.

Note: BOP - Beyşehir Occupation Phase, cereal cultivation and herding combined with fruiticulture.

Middle East, both in the Eastern Roman Empire and within the Sassanian world.[5] What one observes almost everywhere – perhaps with the exception of Northern Asia Minor and the Transcaucasia – is the flourishing of mixed agriculture, consisting of intensive cereal cultivation and arboriculture (olive, walnut and fruit trees) co-existent with significant pastoral activities. This type of environment exploitation visible on pollen diagrams is called the Beyşehir Occupation Phase (BOP) (called after the first site at whose pollen diagram it was identified)[6], of which Late Antiquity seems to have been in most areas the final, often most developed, phase.[7] This phase of mixed agriculture came to an end somewhere between 600 and 750 AD as we discussed before. Even though we lack detailed pollen data, the available evidence suggest the decline was regionally uneven.[8] Especially in the Middle East proper (Iraq, Iran, Palestine) we cannot find a strong decline of mixed agriculture while in Asia Minor (and possibly Western Mediterranean), such a decline occurred on quite a massive scale (see Table 6). One might try to identify key factors in these changes and similarities between local variations. First, it seems that in general it were the calamities of the 6th/7th century which set off the process: the Justinian plague leading to a drastic reduction in the availability of agricultural labour which, as we have seen, was especially pronounced in those regions which had the strongest decline in agriculture; the prolonging and gradually damaging Roman-Persian wars; the increasing dryness of the climate which made it more difficult and less rewarding to cultivate environmentally marginal areas such as the non-irrigated regions of Asia Minor and the Western Roman Empire. Second, we find that the end of the BOP (mixed agricultural phase) in the pollen record is usually marked by the same changes: a pronounced increase in pine pollen (in Asia Minor through to Iran) and a rise in steppic (pastoral?) indicators occurring almost everywhere, which either preceded, coincided with or followed the expansion of pine. This shift in the pollen record means that a relatively sudden change towards more pastoral agriculture must have taken place, however, without a complete collapse of cereal cultivation and arboriculture. This transition period came to an end around the 9th and 10th century. For the Middle Eastern countries, not much change was recorded. Since the collapse in the 7th and 8th century was small, the 9th and 10th century only recorded a small recovery to a more or less mixed agricultural type of land use once more.[9] The recovery was much more spectacular in the Western Mediterranean and Asia Minor to a stable and even prosperous mix of herding and cereals.

Hence, it is clear that climate, plagues, and warfare (no matter their causal relations) all contributed to a decline in arable output and a possible increase in pasture in all regions of Eurasia in the 6th-8th centuries. However, societies clearly recovered afterwards as can be seen from the previous Tables showing a virtual constant per capita GDP in the long run. This suggests that some Malthusian-type mechanism, in which increased per capita GDP due to

[5] See for instance Decker (2009).

[6] The original paper introducing the notion of the BOP was Bottema et al. (1986). Further reinterpretation and spacial extension was done by Eastwood et al. (1998).

[7] See a more detailed analysis Izdebski (2011, 291-312).

[8] Cf. for instance the sites in Cappadocia (England et al. 2008), and in Pisidia, south-western Asia Minor (Bakker al. 2011), and in northern Anatolia (Izdebski, (submitted)).

[9] Djamali et al., pp. 1364-1375. Even though the agriculture did not fully recover In Palestine, it still remained at a rather prosperous and complex level (i.e. Baruch, 1986; Leroy, 2010; Leroy et. al. 2010; Neumann et al., 2007).

warfare and plagues lead to higher population growth and declining per capita GDP, was at work.

This mechanism of the crisis of the 6th century was changed in the 11th century. Whereas the agricultural crisis hit the entirety of the Eurasian continent in the 6th century, in the 11th century only the Middle East and China fell victim to it. This set in motion a train of developments that led to small but significant per capita growth in Europe which, consequently, cannot be explained by a mere Malthusian-type development as in the 6th century. This will be the topic of the next section.

4. Divergence, development, and the crisis of the 11th century: some hypotheses

In the 7th century, a decline in agricultural output, mortality and wars, possibly driven by a decline in average temperature caused fluctuations in per capita GDP. Yet, in the long-run GDP per capita returned to its equilibrium of around 600-800 GK dollars. This was completely different in the 11th century which witnessed two changes with opposite directions: a decline in over-all agricultural output in the Middle East and China (while no such decline occurred in Northwestern Europe [a small decline seems to have occurred in Southern Europe]), while at the same time an increase in terms of per capita GDP in North-western Europe took place as opposed to the Middle East and China. The observed changes were paired by an increase in population and changes in the factor markets as well. In order to better understand what may have happened, we first review how agricultural productivity changed in the 11th century and compare developments in China, the Middle East, and Europe.

As for the yields per hectare, it seems that the medieval Chinese agriculture was much more productive, approximately by a factor of two, than that of the Roman Empire. Erdkamp (2005, pp. 43-44) argues that during Roman times the yields per hectare in Italy were about 1,400 litre for fertile soils and around 875 litre for medium soils. For China, it was closer to 300 jin/mu, i.e., about 2,500 litre per hectare. Even if we were to assume this is an upper bound estimate, the agricultural productivity in terms of land was clearly much higher in

Table 7: Estimate of Food Grain Production during 711-1840 years in China

Year	Per acre yield (*jin/mu*)	Per capita yield (*jin/*person)
711-755	334	1257
806-851	334	1257
1040-1085	275	1100
1142-1187	275	1100
1236-1301	338	1352
1368-1413	343	1235
1570-1620	346	1246
1795-1840	367	716

Source: Wuhui (1985), Han (1993; 1999), Wu (1997), Wu (2000).

China than in Europe. This is, in fact, similar in many ancient cultures of the Middle East. As pointed out by Van der Spek (2006) and Jursa (2010, p. 49), agricultural productivity per unit of land was very high in Babylonian times (second half of the 1st Millennium BC), largely caused by the introduction of the seeder plough which deposited the grain seeds in the furrows, the distance being carefully measured and the use of irrigation agriculture. The seed to yield ratio is estimated at 1:24 and even though technological development in this area seems to have stopped, the remarkable fertility of the land was preserved for a long time. For the Near East in the early medieval period, Ashtor (1976, p. 50) reports seed to yield ratios of the magnitude 1:10, whereas in Carolingian times the Western European agriculture could not surpass 1:2.5 in the long-run. The coming changes favoured Europe, however: the Near East experienced a significant deterioration while China was confronted with stagnation of the yield per unit of land (see Table 7). At the same time, Slicher van Bath (1963) showed that the wheat yield ratio's in the 9th century Western Europe were close to 3 in the 9th century, increasing to ca. 4.3 by the first half of the 14th century. Around 1500 this had increased to 6.3-7, eventually increasing in some regions above 10 after 1750. It is difficult to determine what this means for the yield/acre since we do need to know the seeding rate. However, for England in the 13th century, the seeding rate of wheat was about 2.5 bushels/acre, a number that did not change much until well into the early modern period (Broadberry et al. 2011). Hence, we may assume that the amount of bushels (bu) per hectare increased from 7.5 bu/acre (675 l/ha) to about 11-12 (990-1080 l/ha) in the 13th century, possibly partly because of the move from a two to a three field rotation system that took place around the 10th-12th century. This implied that, contrary to China and the Middle East, Europe saved much more land until the 12th century.

Indeed, this low starting level of yield per hectare in Europe also implies lower levels of persons per cultivated area compared to China and the Middle East. The fast rise of yield per hectare in Europe even widened this gap since both regions had to face an increase in population with strong limitations on the extension of arable land areas. This can probably best be illustrated by an example from Slicher van Bath (1963). He argued that the increasing yield per hectare in Europe caused the share of seed to contract: a yield/seed ratio of 3 means that 1/3 of the total harvest must be set aside for next year's harvest, while a ratio of 10 means that only 1/10th needs to be set aside. Something similar applies to the land required to seed. In the standard two course rotation, with a yield to seed ratio of 3, this means that from a certain plot of land only 2/3*1/2=1/3 of the maximum output can be obtained. When the three course rotation started in the late medieval period, combined with the yield/seed of 4, this means that ¾*2/3=1/2 of the maximum output is utilized.[10] Given a stagnation or decline of output/hectare in China (see Table 7) and the Middle East, this increase of close to 50% meant that the population pressure in Europe was easier to deal with.

Indeed, in China the number of persons per hectare increased considerably: Perkins (1969, p. 16) calculated that the number of persons per cultivated hectare increased between 1400 and 1770 from 3 to 4.3. In Europe, the number of people per cultivated area increased at a

[10] Of course this maximum output would be unsustainable.

much lower pace. Based on Broadberry et al. we can calculate that the number of persons per cultivated hectare (including fallow) changed from 0.9 in 1300 to 0.6 in 1420 and 1.9 in 1800.

The higher yields/hectare as well as the consequently higher number persons per cultivated area resulted in relatively high price of land (i.e. a low wage to land rent ratio) in the Middle East and China. Unfortunately, this is difficult to quantify. However, the scattered data as reported in Table 8 seems to suggest that already around 1AD the wage

Table 8: land rent to wage ratio in China, the Middle East and England

	land rents grammes silver/ha	Wages grammes silver/day	ratio wage/land rent percentage
		ca. 100BC-200AD	
China	1,084	2.1	0.19%
Middle East	538.8	5.0	0.93%
		ca. 1000-1200AD	
China	707	3.0	0.42%
England	25	1.4	5.62%
Middle East	467	3.2	0.68%

Source: Needham and Bray (1984); Borsch (2005, Table 5.7) Clark (1998); Scheidel (2010b); Pamuk and Schatzmiller (2011).

to land rent ratio was much lower in China and the Middle East. This is not surprising given the high population per hectare and the high output per hectare. However, this apparently remained this way until the 10th-13th centuries. In Europe, however, wages were relatively high compared to land rents. (For a more technical discussion of factor price ratios see Appendix A.2.)

Following Allen (2009) as well as Rosenthal and Bin Wong (2011) we might use this as an indication that in China and the Middle East it was more profitable to create land saving technologies, while in Europe labour saving technologies were more profitable. However, this creates a problem: why did economic divergence only start in the 10th-12th century rather than in the 6th century, during which China and the Middle East apparently also were dominated by a relatively low wage to land rent ratio? Two reasons may be found.[11] First, as already observed, the higher wage to land rent ratio in the West shows us, that by increasing labour by one unit, you can have more income than in a country with low wage to rent ratio. This is simply, because the wage is assumed to reflect marginal product if labour. Of course, land cannot be increased above a certain limit, so unless you can invest in capital, you can have more output only by employing more labour: this puts a limit on feasible maximum population and income. Land saving techniques (such as irrigation, rotation, and the

[11] This argument is similar to that of Van Bavel (2010) who basically argues for the importance of climate, geography etc, but gives pride of place to socio-economic institutions and social balance. However, we claim that this socio-economic balance might, in turn, be determined in part by climate and geography.

introduction of new crops), made attractive by the low wage to land rent ratio, eventually will run out of steam, which is what happened in the 11th century (Needham and Bray 1984; Lin 1995).[12]

One possible way out of this trap could have been a substitution of land and labour by capital, but this was dependent on the state of capital markets and especially on the motivations and availability of possible investors. This leads us to a fundamentally very Ricardian question: who received the income from land?[13] For China and the Middle East it seems that mostly either the government or the landowners did, with the peasants or tenants getting just enough for bare subsistence as we will see later. Obviously landowners, or the government, were not interested in investments in lands which they were renting out, while peasant could simply not do it. China and the Middle East got into what development economics would label a financing gap, or poverty gap. In Europe, on the other hand, the lower labour intensity allowed for an accumulation by the tenants. But this is not the complete story, just a component of it.

The situation in China and the Middle East became even worse due to some institutional changes and the nature of agricultural system. First, the rise of short term land lease contracts caused even less interest from landowners in agricultural investments, second, some unfavourable climatic changes caused an unstable situation, finally preventing more capital intensive developments, and the need to feed a large population kept the share of pasture (producing not only food but also capital goods i.e. farm animals) limited.

To start with the first factor: in China, the Middle East and Europe there was a transition towards short term lease contracts. This was partly due to increasing population pressure, which increased the value of the land especially in China and the Middle East, where the output per hectare was already much higher than in Europe to begin with and which had much less possibilities to further increase output by increasing labour intensity. This movement towards short term leases started in China during Han times and was caused by increasingly intensive use of land combined with increasing population (Needham and Bray 1984, pp. 591-592). This also led to the establishment of large estates where many small peasants leased their land against high land rents of up to 50% of the produce. This was not much different in the Middle East during the Sassanid period where farmers leased land for 1/4 to 1/3 of the crop (Morony 1996). Both in China and the Middle East this inevitably led to accumulation of land in the hands of big landholders in combination with short-term lease contracts for

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[12] Without more effective melioration techniques, the limitation of land saving technologies in a pre-industrial society can quickly be approached. With mainly rice cultivation one cannot introduce new crop rotations, and without the necessary knowledge on genetics and chemical further improvement of the plants or introduction of artificial fertilizers was also not possible.

[13] David Ricardo (1817) believed that lad rents that are paid to the landlords are not favorable for the long-run development of a country as those incomes are spent on luxury rather than used for capital accumulation. Since Ricardo saw capital accumulation as the key of long-run economic development his concerns were in accordance with his economic views. He also correctly saw that if the wealth of a country increases (and more agricultural products are demanded) land rents should increase. In the framework of the model that we have in Appendix 2, we could simply say, by employing more labor with the total land area fixed, the marginal product of labor will decrease, while that of land increases. If the share of factors within total income can change, that depends on the technology: in a Cobb-Douglas world they cannot, with CES technologies they can and most likely will.

peasants. However, there was one main difference between the two Asian regions: whereas in China most income originating from land was paid out as land rents (up to 50%) and probably not more than 10-20% as taxes, the proportions in the Middle East were exactly the opposite (Van Bavel, p. 15, Needham and Bray 1984).

A similar development of lease contracts took place much later in Europe, starting in Flanders, Holland, and the Eastern part of England during the 13th and 14th centuries (Van Bavel 2008, p. 188). However, even though also in Europe large landowners emerged, land rents were not as high as in China and the Middle East. In Europe, land rents were only 1/10 of the land price (Clark 1998, p.273), or about 30% of the produce, while taxes were roughly 10%. Hence, the burden for the small farmers was much lower which made it possible for them to invest in capital. Likewise, landowners will be pushed to increase the productivity of their tenants since land is relatively cheap compared to labour. If the reverse is true, as was the case in the Middle East and China, the rise in short term lease was less pronounced and led to labour intensification of land use (for an example of such a process in inland Flanders see Soens and Thoen 2008, p. 33). After all, if labour is cheap and capital (such as oxen) expensive, both the tenant and landowner will be tempted to increase labour rather than buy buffalo's or oxen. Obviously, this increased the output per hectare in China and the Middle East, without substantially increasing per capita output.

The second reason for the lack of substitution of land with labour or capital in China and the Middle East may be found in adverse climatic factors. We already pointed out that in the 10th-12th century Europe was characterised by the so-called Medieval Climatic Optimum, i.e. a period with higher average temperatures in North-western Europe and Northern America while the remainder of the Eurasian continent is thought to have experienced remarkable coolness (Mann et al. 2009). This is also shown separately by work on historical documents for the Middle East by Domínguez-Castro et al. (2011) and for China by Ge and Wu (2011) who showed, for the Middle East and China respectively, that there was a remarkable set of cold anomalies between 900 and 1100, even though China experienced a one-off peak in temperature somewhere around 1250. This suggests that a cooling episode occurred during 10th-11th century which Europe somehow managed to avoid. Two centuries later however the little Ice Age had its effect felt in Europe as well.

According to Zhang et al (1997), this cooling down in China and the Middle East might lead via a reduced supply of food, to increased mortality as well as warfare and migration. Even though it is difficult to estimate the exact effects on agricultural output but Campbell, Kelly and O'Grada (2007) have calculated that an increase of 1 degree Celsius in temperature may have increased wheat output by 5%. Given that the temperature went up with ca. 1 degree (see Figure 1), this means an increase in output per hectare of close to 5% in Western Europe and a similar decline in the Middle East and China. However, it is difficult to determine its effect on population and mortality. It seems fairly sure however, that whereas Europe witnessed a strong increase in population (Broadberry, Campbell, and Van Leeuwen 2011) while both in China and the Middle East population stagnated, or even declined (Russell 1958; Lin 1995). At the same time we witness regional strife. Indeed, Zhang et al. (2007) find that the number of wars in China increased considerably during the cold period which lasted between 1200 and 1300. The most famous political event was the overthrow of the Song dynasty by the Northern (Mongol) Yuan dynasty as well as invasions of the Mongols in the Middle East (where they decimated Baghdad, for example). Especially in China, this had clear implications for migrations from the Northern regions to the lower reaches of the Yangtze delta, which may be one explanation why the middle and lower reaches of the Yellow River underwent an extensification and the Southeast (where many people migrated to) agricultural intensification. Likewise, in both the Middle East and China it increased the price of capital goods. As argued by Qi (2009), the price of a buffalo in China increased spectacular in this period. A similar argument we may make for the Middle East where the ruling Muslim dynasties suffered at the hands of the Mongol invasions.

Besides the increased price of capital goods in China and the Middle East, this asymmetric climatic effect had as a consequence that the pressure on the land in China and the Middle East increased even further (since output per hectare declined) while it relaxed in Europe. This left the way open for capital intensification in Western Europe, which had preserved a large pastoral sector compared to China and the Middle East. Besides that draught animals are more difficult to use in wet-land agriculture such as the irrigated fields in China and the Middle East, they also required a lot of food and pasture to be raised. Given the large population pressure, both land and food grains were not easily available, which made draught animals expensive. For example, Huang (2002, p. 507) argues that in the North of China in the 1930s the wage of a man was as high as the cost of a donkey and only one-half of that of a horse or mule. This caused pasture to decline more or less in tandem with the rise in population and the price of arable land (see Table 9). Something similar seems to have

Table 9: The trend of pasture in the Chinese history

Period	Pasture change	Result of pasture change
B.C. 220~A.D.220	declining slowly	1)scale of raising: from large to small: 2) Main meat consumption: pork
A.D.220~A.D.900	Recovery and prosperous slowly	1)scale of raising: from small return to large 2) Main meat consumption: sheep and goat
A.D.950~A.D.1850	declining again	1)scale of raising: from large back to small 2)Main meat consumption: pork

Source: Perkins (1969), Han (1993; 1999), Wu (1997), Wang (2001), Zhang (2010).

happened in the Middle East. Even though there pasture seems to have survived, their share must have been small in the more densely occupied, irrigation dominated areas. Indirect evidence is that in contemporary agricultural treatises on Egypt limited time is devoted to draught animals (Wilfong 1999, p. 223). This seems to be comparable with the finding of 2009) who argued that pasture (largely consisting of sheep) did not make up more than 10% of GDP in the first centuries BC. Nevertheless, it seems plausible that in the irrigated areas, which also exhibited the fastest increase in population, pastoralism was reduced to a great extent. Obviously, this applies only for the fertile areas of Iraq, Iran, and Egypt, but many poorer regions became dominated by small scale pastoralism.[14]

The direction of changes was just the opposite in Europe where labour was less abundant than in China (especially after Black Death). Here we observe a substitution for labour by the increasing use of farm animals and the increasing use of lower quality lands for pasture (Broadberry and Campbell 2009; Campbell 1997). A large (and hence relatively cheap) pastoral sector, combined with a rather labour extensive arable sector suggests that it

Table 10: Relative price of draught animals in China and England

	Relative price of draught animals			
	China, buffalo		England, ox	
	kg of rice	ha. Of land	kg. Of wheat	ha. Of land
1	487		520	
994	6,838	7.7		
1110	1,140	1.1	451	0.9
1123	1,302	1.0		
1127-1150	15,195	10.7		
1150-1200	12,156	7.6	679	1.0
1250			740	0.9
1300			491	0.7
1350			473	1.0
1400			707	1.5

Source: Farmer (unpublished archive); Scheidel (2010); Tang (2008).

[14] In the core regions, however, new rice and cotton crops were introduced and, as shown by Liu (forthcoming), also irrigation and land intensity increased spectacularly, especially in the lower reaches of the Yangtze. Clearly, population densities increased, irrigation works increased, and new varieties of rice were introduced while it also spread to the North, hence replacing less labour intensive crops like millet and sorghum. A similar trend for the Middle East is more difficult to discern given the controversy over the question if there is something like a "golden age of Islam". However, it seems clear that several new crops were introduced on a larger scale (their introduction not necessarily originating from the 8^{th}-12^{th} century) such as rice, cotton, and hard wheat. This has led some to argue that an agricultural revolution took place in the period 700-1100 in the Middle East (e.g. Watson 1974). Even though the existence of such a "revolution" has been criticized, many agree that these crops started to spread on a much larger scale around this period (Decker 2009).

became profitable to use draught animals to substitute for labour. For England, Campbell (1997) found that capital and labour intensive agriculture was only significant near cities where a supply of relatively cheap labour and the demand for more pricy products were present at the same time. The lower labour intensity in European agriculture, paired by more investment in animals, contributed to higher marginal product of labour and higher real wages. A larger livestock also allowed for a higher protein and dairy content in European diet, but this also meant a larger proportion of expensive food in the consumption basket. This led to consumer prices above the Chinese level, but not enough to totally erode the wage increasing effect of higher labour productivity.

In sum, the reason of the divergence in terms of per capita income between on the one hand Europe and on the other China and the Middle East during the 12th century can be traced back to difference in agriculture. The fertile (and often irrigated) lands in Asia resulted in a high level of land productivity (output per area unit) but only at the price of high labour intensity (high labour content per output unit). This led to a relatively low wage to land rent ratio, which in the long-run stimulated the introduction of land saving techniques which, being subject to strong limitations in a pre-industrial world, could not offset the effect of decreasing marginal product of labour and land. However, this does not mean that a halt of agricultural output growth was inevitable since it remained possible to substitute for labour (and land) by capital. However, whether this happened depended on whether tenants (and to a lesser extent landlords) had enough wealth to invest. Yet, while this could happen in Europe, China and the Middle East lagged behind in this respect as well, because of adverse effects of the introduction of short term leases, of adverse climatic circumstances, and the high price of capital, more specifically draught animals, which all made investments in capital goods difficult for small tenants.

5. Conclusion

In this paper our aim was to look at the long run patterns of per capita GDP. Setting available (tentative) estimate side by side, we found remarkable stability until the 11th century, followed by a divergence. The fluctuations until the 11th century were largely Malthusian in nature. The main crisis of the 6th century was a climatic and mortality crisis that hit every region in roughly similar fashion. The population decline together with colder weather which, together with accompanying political upheaval, meant a reduction in complexity of agriculture in all regions. This led to decreases in per capita GDP, which only started to recover by the 10th century.

In the 11th century we witness similar fluctuations in GDP/cap. However, whereas in the 6th century in the long-run stability had prevailed in all regions, this time a first cautious divergence emerged when Western Europe started to show a slow per capita economic growth. Two factors may have contributed to this agricultural divergence. First, a relatively low wage to land rent ratio in China and the Middle East. This was already inexistence in the first centuries after Christ in both the Middle East and China due to the much higher land productivity compared to Europe. This would foster growth of land saving technologies. Initially, this also increased per capita output, but due to diminishing returns on land, this was about to come to a halt, which is what happened during the 10th-15th centuries. However, such a stagnation was not inevitable since all regions were potentially able to substitute labour (and land) for capital. However, in this field both the Middle East and China were at a disadvantage. First, the introduction of short term lease contracts led to diminishing incentives to invest in capital in regions with a low wage to land rent ratio. Second, the adverse climate conditions caused an increase in the price of capital goods, most notably oxen, via warfare and via a reduced output per hectare, causing an even bigger population pressure on the land. Finally, the increase in draught animals in Europe, especially the increase in horses, caused higher output per capita.

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Appendices

A.1. Derivation of GDP/cap from a partial distribution

Let us denote the share of the poor with equal subsistence income level by z (their group Gini is zero, their Lorenz curve is a straight line). From our assumptions it is straightforward that only the remaining 1-z share of the population will have an internal income inequality. Their income is assumed to follow a Pareto distribution. We have two reasons to prefer this type of distribution: first it is reported of coming reasonably close to the income distribution of wealthier groups (Soltow and van Zanden, 1998), secondly it is quite convenient as the Lorenz curve for the Pareto distribution can be expressed as follows:

$$L(F) = 1-(1-F)^{1-1/\alpha}$$

where 0<F<1 is the cumulative share of people from the poorest to the wealthiest and α is a key parameter of the distribution. Be aware that only α>1 is acceptable for our purposes as otherwise the Lorenz curve would have zero or negative values.

As of the poorest z share of the population we know up to F=z the Lorenz curve for the whole society is not a 45 degree line, because this z*100% share of the population owns less than z*100% of total income. Obviously they own just an L(z) share of the total income, where L(z)<z. Since the Lorenz curve is a composite of the Lorenz curves of the two groups and the Lorenz curve is continuous, the Lorenz curve of the poor should connect the origin to the start of the Lorenz curve of at F=z or $L(z) = 1-(1-z)^{1-1/\alpha}$. The composite Lorenz curve for the whole society is a function of z, alpha and, of course, F:

$$L(F) = \begin{cases} F\left(\dfrac{1-(1-z)^{1-1/\alpha}}{z}\right) \text{ if } 0 < F \le z \\ 1-(1-F)^{1-1/\alpha} \text{ if } F > z \end{cases}$$

The Gini coefficient is calculated as one minus twice the definite integral of the Lorenz curve:

$$G = 1-2\int_0^1 L(F)dF$$

Since

$$\int F\left(\frac{1-(1-z)^{1-1/\alpha}}{z}\right)dF = \frac{1-(1-z)^{1-1/\alpha}}{2z}F^2 + C_1$$

and

$$\int 1-(1-F)^{1-1/\alpha}dF = F + \frac{(1-F)^{2-1/\alpha}}{2-1/\alpha} + C_2$$

where C_1 and C_2 are arbitrary constants. The definite integrals are:

$$\int_0^z F\left(1-(1-z)^{1-1/\alpha}\right)dF = \frac{\left(1-(1-z)^{1-1/\alpha}\right)}{2}z$$

and

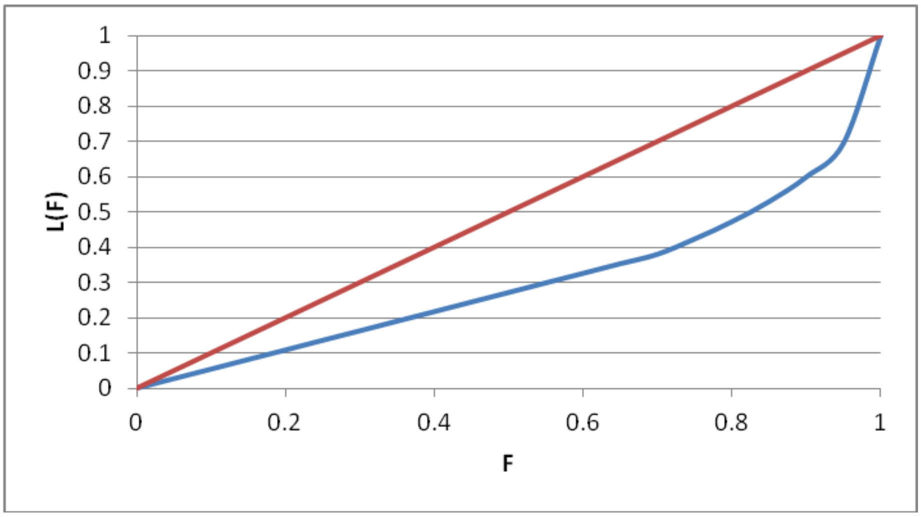
$$\int_z^1 1-(1-F)^{1-1/\alpha}\,dF = 1-z-\frac{(1-z)^{2-1/\alpha}}{2-1/\alpha}$$

Hence the income Gini coefficient for the whole society is expressed as:

$$G = 1-\left(1-(1-z)^{1-1/\alpha}\right)z-2\left(1-z-\frac{(1-z)^{2-1/\alpha}}{2-1/\alpha}\right)$$

From this expression we can estimate the alpha parameter for any assumed Gini coefficents which, if G=0.4, and z=0.7 yields approximately 1.659. One needs to be aware that not any values for z are permissible if we wish to stick to the Pareto distribution for the higher income group and a reasonable assumption regarding income inequality. With values of z much higher than 0.7, the estimated alpha quickly went under 1. Using above assumptions we arrive at the following Lorenz-curve:

Figure 1: Lorenz curve, with Gini=0.4, Z=0.7 and further assumptions as in the text



We would like to have an estimate of the GDP per capita of the total population. The mean income of lower 70% equals the subsistence level (assumed to be 400 G-K dollar at 1990 prices). For the mean income of the upper 30% we can use the formula for the expected value of the Pareto distribution:

$E(x) = \frac{\alpha x_m}{\alpha - 1}$, where x denotes the random variable and x_m is the lower limit. In this case this is the subsistence level of 400 dollar. The mean income (E(y)) for the whole society is hence:

$E(y) = \left(z + \frac{(1-z)\alpha}{\alpha-1}\right) y_{\min}$, which is 1.45 times the subsistence level, that is, 582 G-K dollar at 1990 prices.

A.2. A formal model of changes in the wage to land rent ratio In the following we offer a simple formalized explanation for the observed changes in wages to rent ratios.

For our purposes we assume a constant elasticity of substitution (CES) production function. We cannot rely on a Cobb-Douglas production function simply because that involves some strong assumptions regarding the relationship among the production factors and does not leave any space for biased (or unbalanced) productivity changes.

A simple two factors CES that suits our needs is:

$Q=\left[\alpha\left(A_T T\right)^{\gamma}+(1-\alpha)\left(A_L L\right)^{\gamma}\right]^{\frac{1}{\gamma}}$ where Q is the total agricultural output, α is a technical parameter that affect the factor income shares within total income (but does not necessarily equal it) A_T and A_L denote productivity indices (similar to TFP but this are factor specific) and T and L are land and labour respectively. Introducing further factors would not add anything to the model and would be dropped during derivations so we will not make our model more complex than needed. γ is also a technical parameter of importance as it is a function of the elasticity of substitution among the production factors. Without going into details, the elasticity of substitution will basically determine what happens to the factor prices if the ratio of factors employed changes. In the Cobb-Douglas case, γ=0, and the elasticity of substitution equals unity. In this case if the ratio of labour to land goes up by 1 %, the wage to land rent ratio will decrease by 1%, which is clearly a sign of substitution between the two factors, and also assures that the share of factor incomes to total income remains the same, whatever happens. Also, as we will see, if this is the case productivity changes can only be neutral in the sense that a change in A_T / A_L ratio will not affect any of the factor prices, which may sound counterintuitive, but is the case anyway. It is safer to assume rather a different value for γ, preferably a negative one as this assures that the factors of production are substitutes.

We need to assume that the factor prices (w –real wage, l – land rents) equal their respective marginal product which yields:

$$w=(1-\alpha)\left(A_L\right)^{\gamma}(L)^{\gamma-1}(Q)^{1-\gamma}$$

$$l=\alpha\left(A_T\right)^{\gamma}(T)^{\gamma-1}(Q)^{1-\gamma}$$

The wage to land rent ratio is hence:

$\frac{w}{l}=\frac{1-\alpha}{\alpha}\left(\frac{A_L}{A_T}\right)^{\gamma}\left(\frac{L}{T}\right)^{\gamma-1}$ and indeed for the Cobb-Douglas case with γ=0 we find that the factor price ratios are unaffected by the relative change of productivity indices (the bias of technology).

We observed an increase of this wage to rent ratio in China (Table 8) from 0.19% to 0.42% over about thousand years. Assuming that alpha and gamma did not change over time, we can find out the possible reasons behind this. By taking relative changes, we arrive at the following expression:

$$\frac{dw}{w}-\frac{dl}{l}=\gamma\left(\frac{dA_L}{A_L}-\frac{dA_T}{A_T}\right)+\left(\gamma-1\right)\left(\frac{dL}{L}-\frac{dT}{T}\right)$$

That is, with $\gamma<0$, either the land to labour ratio increased, which is not supported by the available data, or China experienced a more land biased technological development (A_T grew faster than A_L). This is clear empirical evidence that agricultural technology in China was land saving during this period.