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Mills, cranes, and the great divergence: the use of immovable capital goods in western Europe and the Middle East, ninth to sixteenth centuries†

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This article contributes to the ongoing debate on the causes of the great divergence by comparing the use of expensive labour-saving capital goods—water-mills, windmills, and cranes—in medieval western Europe and the Middle East. Using novel ways of measuring, we find that whereas the use of these goods increased in Europe, in the Middle East their prevalence decreased, or they were not used at all. We investigate several possible explanations and reject most of them, including religion, geography, technological knowledge, and disparities in wages and cost of capital. Our analysis shows that differences in lordship systems and the security of property rights best explain the patterns found.

One of the most productive debates of the past two decades has been that about the great divergence. Even though its exact chronology and causes are still debated,[1] there is broad agreement that the originally rather underdeveloped western European economies emerged in the modern era as the wealthiest part of the world. Recent GPD per capita estimates show that this divergence probably started earlier than previously assumed. In the high middle ages pockets of development in eastern Asia and the Middle East probably had higher wealth levels than western Europe. By the sixteenth century, however, western Europe had clearly overtaken these other areas.[2]

This suggests that in the late medieval period growth rates in western Europe were already higher than elsewhere, which implies advances in labour productivity. These advances may have been the outcome of specialization and division of labour, but even more interesting is the possibility that they were related to investments in capital goods, even before the advent of the industrial revolution. Recent research suggests that this option is very real. In the Low Countries, for example, the fourteenth to sixteenth centuries saw high investments in blast furnaces of stone,

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[1] For example, the contributions to the special issue 'Asia in the Great Divergence', *Economic History Review*, 64, S1 (2011).

[2] The Maddison-Project, http://www.ggdc.net/maddison/maddison-project/home.htm, 2013 version, using 1990 international dollars (used to make GDP per capita reconstructions).

massive breweries, brick ovens, fulling mills, and gunpowder factories.[3] In all of these sectors, it is found that western European economies, and more specifically those around the North Sea, pushed up labour productivity by making substantial investments in productivity-enhancing capital goods. Although investments of this type were also made in other parts of Eurasia, they do not seem to have been as massive or as broadly distributed as in western Europe. An examination of differences in the use medieval societies made of capital goods contributes, we argue, to the great divergence debate in two ways. First, it provides us with an indicator for the timing of divergence in economic developments for an era for which accurate measurements are scarce. In addition, while investments in capital goods were not the cause of the great divergence, they can be seen as an intermediate factor in a chain of causation. An examination of the reasons why some societies invested more in capital goods than others may point to deeper causes for differences in growth rates.

Methodologically, this article also brings progress along two lines. The first is by focusing on areas that are not often directly compared within this framework. We will not look at the divergence between western Europe and China but at that between western Europe and the Middle East, the other medieval core area of Eurasia. In the seventh and eighth centuries the Middle East clearly stood out over Europe; it was characterized by high levels of urbanization, agricultural innovation, and a flourishing market economy.[4] However, using urbanization rates as proxies for economic development, Bosker et al. have recently shown that between 800 and 1600 European growth was much more rapid: while urbanization rates in the Middle East (and North Africa) rose from 6 per cent to 9 per cent, in Europe they increased from 3 per cent to 8 per cent. The difference was especially marked after 1100.[5] When looking at GDP per capita development, differences are even more marked. At the beginning of the ninth century, labelled the Golden Age of Islam, the Middle East had a GDP per capita that was considerably higher than that in Europe.[6] By the sixteenth century, however, western Europe had clearly outpaced the Middle East and reached levels of GDP per capita of $1,000–1,500, while Middle Eastern countries such as Turkey and Egypt were at $600–700. This article concentrates on a general comparison between the two study areas: western Europe (including Italy and Iberia) and the Middle East (including Egypt and Anatolia). However, where necessary we will focus on smaller sub-areas for specific historical comparisons.

Second, we will contribute to the scholarly debate by looking systematically at the use of expensive immovable capital goods in these two areas. This investigation will thus help to open up the black box of the great divergence. We have chosen to study immovable capital goods (water-mills, windmills, and cranes) because these could not be transported elsewhere easily (unlike ships) when the local political or economic climate changed for the worse. Also, we have selected them because these capital goods were used for activities that were universally carried out, that is, milling and building higher than a man could reach, and because they were

[3] van Bavel, *Manors and markets*, pp. 353–71.
[4] Ashtor, *Social and economic history*, ch. 3.
[5] Bosker, Buringh, and van Zanden, 'From Baghdad to London', p. 1424.
[6] Pamuk and Shatzmiller, 'Plagues, wages and economic change', pp. 220–1, 223.

easily visible by their sheer size and therefore had a relatively high chance of being reported in historical sources, making them a suitable indicator. We will particularly concentrate on the most labour-saving varieties: vertical water-mills, vertical windmills, and cranes with a treadmill. These complex pieces of machinery were expensive, their construction and operation requiring quite some skill. Cranes offered a way to save labour in lifting heavy materials, for instance, on building sites and in harbours. Efficiency gains depended on the exact ratio of the sizes of the wheel and the drum and could easily amount to an advantage over manual lifting of 14:1.[7] Mechanical milling, using advanced medieval technology, was a widespread activity from the third century onwards in both study areas.[8] It saved human labour, especially in the laborious process of milling grain for bread, the staple food in pre-industrial Europe and the Middle East. One person with a hand mill would be busy during the larger part of a working day to feed eight to ten persons.[9] Later in the medieval period water-mills and windmills were often used for industrial purposes too, such as fulling, making paper, pressing oilseeds or sugar cane, sawing, and so on. These industrial mills, too, offered clear cost advantages and gains in productivity over manual labour. Mechanized fulling, as calculated for late medieval Italy and the Low Countries, offered a cost gain of some 70 per cent over fulling by foot.[10]

In the next section we will reconstruct the spatial and temporal distributions and relative prevalence of mills and cranes, based on secondary literature but supplemented by source material not used to this end before, namely Muslim geographical treatises and medieval pictorial sources. Section II aims to explain the patterns and differences observed. Religious, economic, and institutional explanations are explored and set against our findings on the spatial and chronological distribution of immovable capital goods. The last section summarizes the findings and presents some conclusions.

I: Reconstruction of use and chronology

Water-mills

Water-mills, mechanical devices driven by the flow of water and often powering mill stones, had been in general use in the Roman period.[11] Hill, the eminent historian of Islamic technology, indicates that from the third century onwards mechanical milling was a widespread activity in Europe and the Middle East.[12] Basically two types of water-mills exist: vertical and horizontal. Vertical mills, in which the wheel turns in a vertical plane, need a gearing system to operate. Simpler horizontal mills do without gearing and are cheaper and easier to use. They need less water and are often smaller in size. This study concentrates on vertical water-mills because they constitute the clearest examples of labour-saving, capital-intensive devices. Vertical mills are more powerful; their gearing makes them mechanically more complex,

[7] Matthies, 'Medieval treadwheels', p. 536.
[8] Hill, *History of engineering*, p. 161.
[9] Lucas, *Wind, water, work*, p. 20.
[10] Munro, 'Industrial energy', pp. 254–5.
[11] Wilson, 'Machines', p. 11.
[12] Hill, *History of engineering*, p. 161.

as well as more expensive to build and operate. Construction costs of water mills in thirteenth- and early fourteenth-century England have been estimated at £20 to £40 (the equivalent of 2,700 to 5,300 days' wages of an unskilled labourer), while a similar sum had to be spent on maintenance every decade or so.[13] The water driving vertical mills can flow beneath the axle or fall onto the waterwheel from above, leading to either under- or overshot mills. Overshot types have most power, as the weight of the water helps to overcome the resistance of the device they drive. A floating ship-mill on a river is always of the undershot type. Ship-mills were widely used to take advantage of stronger currents midstream and because they were unaffected by lower water levels, which could pose a problem for fixed mills during the dry season.

In western Europe, as naked grain cultivation expanded in the seventh and eighth centuries, many mills were constructed: rye and wheat are better suited to milling than the earlier cultivated hulled grains. Ninth-century property lists, such as that of St-Bertin (northern France), indicate that most manors possessed at least one water-mill.[14] St-Bertin's 13 manors contained 14 mills, implying one mill for every 200 persons. The Domesday Book suggests that England in 1086 counted some 6,500 water-mills,[15] which would mean a density of one mill per *c.* 300 inhabitants. Grain mills were also in common use in early medieval southern Europe, for instance in the Italian countryside. Most of these mills were probably relatively simple devices of the horizontal type.[16]

In the ninth and tenth centuries, the smaller and cheaper horizontal mills were increasingly replaced by vertical mills. Most of the water-mills mentioned in the Domesday Book were probably of this type. In England, the twelfth and thirteenth centuries witnessed further expansion: while smaller water-mills made way for larger and more efficient ones, or for windmills, the total number of mills rose markedly.[17] During the prolonged economic crisis triggered by the Black Death some of the less profitable water-mills disappeared. Sample-based estimates suggest a decline of 15 to 20 per cent but also indicate an almost full recovery in the late fifteenth and early sixteenth centuries.[18]

Evidence from the continent suggests that here too investments in mills increased in the high middle ages. From the thirteenth century overshot mills increased in numbers. They were generally larger and could be used with weaker water flows, but needed a height difference between the water levels of supply and discharge of at least one wheel's diameter. Overshot mills required larger investments, which also included the construction of a mill pond, water race, and sluice gates to guarantee a regular water supply. The basin of the small river Zenne in the area around Brussels probably had some 45 water mills before 1200, which increased to more than 110 around 1450. Many were supplied with a pond and mill race, in some cases up to a kilometre long, requiring large investments but increasing the number of locations suitable for the construction of a mill.[19] In the towns, too,

[13] Langdon, *Mills*, pp. 179–80; idem, 'Mobilization of labour', pp. 42–5.
[14] Lohrmann, 'Le moulin à eau', pp. 389–92.
[15] Lucas, 'Industrial milling', p. 4.
[16] Squatriti, *Water and society*, pp. 128–39.
[17] Holt, *Mills*, pp. 112–13, 116, 118–19.
[18] Langdon, *Mills*, p. 37.
[19] Deligne, *Bruxelles et sa rivière*, pp. 19–23, 36–43, 263.

the number of mills increased dramatically, as well as their size. In the suburbs of Arras (France) from the early eleventh century 17 mills were constructed,[20] giving one mill per 450 persons. Huy (Belgium) possessed a few water-mills in the early middle ages, but around 1100 four new mills were constructed. In the fourteenth century, Huy had about 15, equivalent to one water-mill per 300 inhabitants.[21]

Industrial mills appear in the sources from the eleventh century onward. They were used for activities as diverse as fulling, tanning, crushing mineral ores, powering forges and furnaces for iron production, grinding or crushing bark or roots to obtain pigments, and sawing wood.[22] Comparative research by Lucas suggests that industrial milling was most intensive in the economically most advanced regions of France and northern Italy: it was here that industrial mills were put to the greatest variety of uses. Especially in France industrial milling experienced a strong increase in the thirteenth and fourteenth centuries.[23] In Christian Spain industrial milling was probably not as widespread, although examples from twelfth-century Catalonia exist.[24]

The summarizing conclusion is that water-mills were already numerous throughout western European in the early middle ages and further increased in complexity, size, and number during the study period. From the eleventh century onwards water-mills were also used for processes other than milling, mechanizing the production of goods.

The early middle ages also witnessed an increase of water-mill construction in the Middle East. Many local mills must have been of the horizontal type; Braemer et al. show that this was the situation in eighth-century Syria.[25] Vertical mills, however, were introduced much earlier than in western Europe, and so was the use of mills for industrial purposes. Several large mills, or series of mills, sometimes together with a dam to increase the water power, were constructed in the eighth century in Iraq; these included a number of paper mills in Baghdad.[26] The most impressive were the ship mills on the river Tigris, each of which was able to mill enough flour in one day to feed 25,000 people.[27]

By the eleventh century, however, when the numbers of vertical water-mills in Europe increased, the reverse seems to have happened in the Middle East. In Iraq and Egypt the numbers of mills actually declined. The large ship mills on the Tigris near Mosul (Iraq), for instance, up to then the granary for Baghdad, had apparently disappeared by the late tenth century.[28] Likewise, while the geographer al-Muqaddasi, who visited Egypt around the year 1000, mentions the large mills of Mashtoul (in the eastern Nile delta) that provided the holy cities in western Arabia with flour, none of the later geographical treatises reports these mills.[29] One explanation for this might be that travellers stopped recording water-mills

[20] Lohrmann, 'Entre Arras et Douai', pp. 1024–8.
[21] Joris, *La ville de Huy*, pp. 298–301.
[22] Gies and Gies, *Cathedral, forge and waterwheel*, pp. 113–17, 178, 200–1.
[23] Lucas, 'Industrial milling', pp. 13–22.
[24] Glick, *Islamic and Christian Spain*, pp. 233–4.
[25] Braemer, Genequand, Dumond Mariedat, Blanc, Deutzer, Gazagne, and Wech, 'Long-term management', pp. 43–5.
[26] Robinson, *Empire and elites*, pp. 69, 79, 84–5; Cutler, 'Gifts and gift exchange', p. 268.
[27] Hill, *Islamic science*, p. 111.
[28] Hill, *History of engineering*, p. 165.
[29] al-Muqaddasi, *Best divisions*, p. 180.

once they were no longer a novelty. For several reasons, however, this is unlikely. First, water-mills, including the vertical mills, were not new in the eighth century either: they had been in continuous use in the Middle East since the Roman era. Second, as we will shortly show, the same late medieval treatises that fail to record water-mills in Iraq and Egypt do mention them for other parts of the Islamic world, for instance in the Maghreb and Central Asia. It is difficult to understand why the authors would note the water-mills they encountered in one region but not in the other, while their journeys can be seen as random walks through the medieval Islamic world. Third, the 'argument from silence' is corroborated by the eyewitness account of a French traveller in Egypt in 1512, explicitly stating that the country had neither water-mills nor windmills.[30]

There were parts of the Middle East that did better: the twelfth-century traveller Ibn Jubayr, for instance, mentions a row of mills on the river Khabur near Ras al-Ayn in northern Syria.[31] It is, however, clear that the general, widespread growth of the number of vertical water-mills that characterized western Europe was not mirrored in the Middle East. Developments in the sugar industry, which regularly used vertical water-mills, illustrate the divergence. Sugar cane became known in Europe during the Crusades and became one of the most important medieval export products from the Middle East. However, Egypt, Palestine, and Syria, originally the three most important suppliers of sugar to high medieval Europe, were all importing European sugar by the end of the fifteenth century.[32]

To arrive at a more precise indication of the relative prevalence of water-mills in the medieval Muslim world, a computer search was done in geographical treatises by seven Muslim writers: al-Yaqubi (891), al-Muqaddasi (985), al-Idrisi (1154), Ibn Jubayr (1183), Ibn Battuta (1355), al-Wardi (1419), and al-Himyari (1461). The selection was based on a practical consideration: the availability of searchable, electronic editions of the original Arabic texts. Six of the seven works cover the entire Islamic world, while Ibn Jubayr's treatise is limited to the description of a trip from Spain to Mecca and back.[33] The various geographical descriptions of sightings of medieval water-mills certainly do not present an absolute figure of the water-mills that were operating, but they can be considered to present a relative, and largely unbiased, picture of local water-mill use as viewed by a chance passer-by at the time in question. We assume that most of the reported mills were of the vertical type, as travellers were more likely to note and record the large and conspicuous wheels of vertical water-mills. Horizontal mills are smaller; often they are housed inside a building and not easy to spot from outside. Figure 1 presents the number of water-mills reported by ninth/tenth-century and fourteenth/fifteenth-century Muslim geographers respectively.

Figure 1 shows that water-mills originally located in Iraq and Egypt had largely disappeared at the end of the middle ages, but also that water-mills had increased in numbers in other parts of the Islamic world, especially in the Maghreb and in Central Asia as well as in Syria and eastern Anatolia.[34] That the fourteenth- and

[30] Ashtor, *Social and economic history*, p. 312.
[31] Ibn Jubayr, *Travels of Ibn Jubayr*, p. 253.
[32] Ashtor, *Histoire des prix*, p. 384.
[33] For the method, see online app. S1.
[34] The large number of water-mills in fourteenth- and fifteenth-century Sicily and the non-Muslim parts of Spain is in keeping with the increased use of water-mills in Europe.

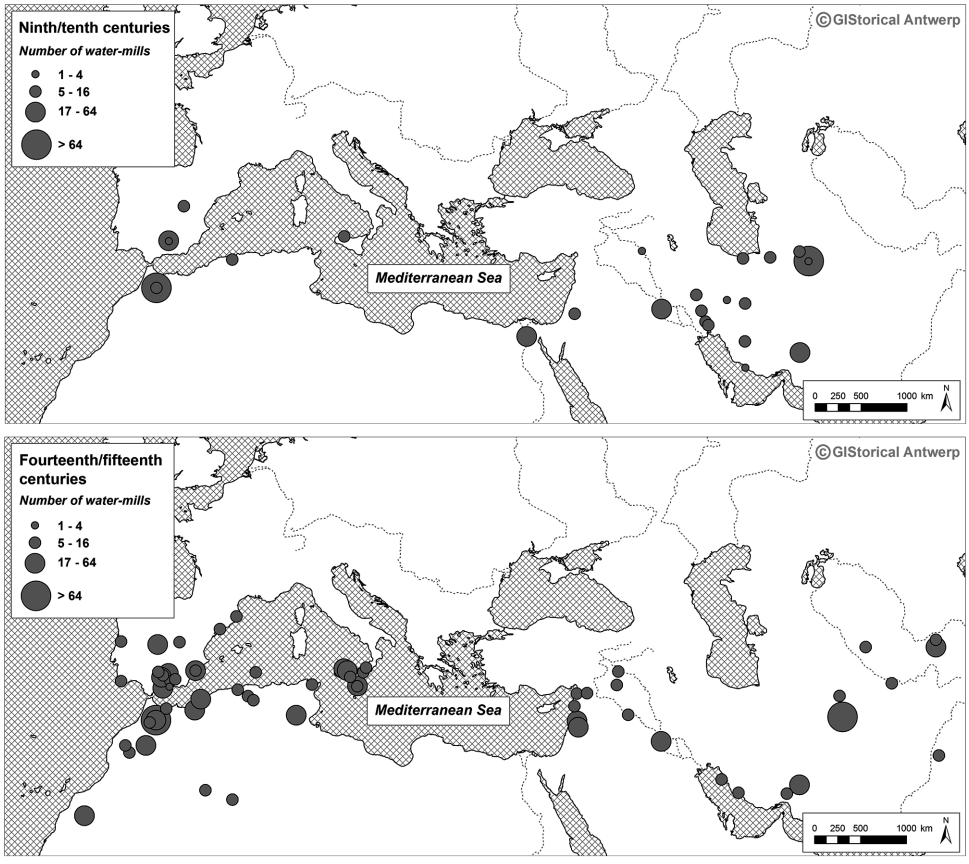

Figure 1. *Number of water-mills recorded in the selected works of Muslim geographers in the ninth/tenth centuries and in the fourteenth/fifteenth centuries*
Sources: See online app. S1.

fifteenth-century sources report no water-mills in western Anatolia is surprising, since studies of Ottoman tax and judicial registers demonstrate that in the early sixteenth century they were common here.[35] A possible explanation could be that all Anatolian water-mills were horizontal mills, as they had been in this region in the late Byzantine era.[36] The summarizing conclusion is that vertical water-mills, originally located over the whole of the Middle East, gradually decreased in numbers during the study period, most conspicuously in Iraq and Egypt.

Windmills

Windmills come in two 'flavours' too: vertical and horizontal. Vertical windmills are the type that is still used: their sails turn in a vertical plane and require a gearing

[35] Islamoğlu-Inan, *State and peasant*, p. 154; Yörük, 'Yüzyilda Konya kazasinda'; Jennings, 'Pious foundations', p. 279.
[36] Bryer, 'Means of agricultural production', pp. 110–11.

system. Vertical windmills can be oriented into various wind directions. As more powerful machines they are mechanically more complex. Horizontal windmills are simpler and have no gearing, and their sails turn horizontally. Their main drawback is that for optimizing their use they need a surrounding infrastructure, which limits their use to one main wind direction. Windmills have no Roman roots. The horizontal windmill is probably an Asian invention, and was already known in the Middle East at the beginning of the study period.[37]

In western Europe, vertical windmills have been confirmed from the twelfth century onwards. Following its introduction in the late twelfth century, the vertical windmill quickly gained ground in southern and eastern England, north-western France, and Flanders.[38] Especially in coastal plains, where water flows were too weak to power water-mills, and where winds were often strong, windmills were used in large numbers for milling grain, industrial activities, and draining water. Construction costs of wooden windmills were, at 10 to 20 pounds, about half of those of water-mills.[39] At the end of the study period, large brick windmills came into use. These could provide from 20 to 150 horsepower, considerably more than the five to seven on average provided by water-mills.[40]

In England, the thirteenth-century increase in the number of windmills was followed by a contraction in the fourteenth and fifteenth centuries.[41] On the north-western European continent, however, numbers continued to expand. In the north of France, around Lille and Douai, 96 of the 145 villages investigated contained in total 194 mills in the mid-sixteenth century, of which only 23 were water-mills. Among them were 130 grain mills, one for approximately every 500 persons, as well as 14 for processing woad, and no fewer than 44, often owned by Lille merchants, for pressing oil.[42] Likewise, in Holland, where the earliest mentioned windmills date from the thirteenth century, their later distribution was impressive. Many mills were situated in towns. Delft contained nine post mills and three large, brick tower mills on its city walls, erected in the fifteenth century. By 1500 some 215 windmills were used for drainage purposes in Holland, with about 50 new ones operating each decade.[43]

The southern parts of western Europe also saw the introduction of windmills. While the first Portuguese vertical windmills can be dated to the fourteenth century, in the sixteenth century they were widely used in the coastal areas of Portugal.[44] In neighbouring Spain late medieval windmills were concentrated in the coastal areas of Galicia, the south-east, and the coastal areas bordering Portugal in the south. There may have been some medieval windmills in northern Italy, but they were not very widely prevalent.[45]

The summarizing conclusion is that in western Europe vertical windmills have been used from the twelfth century onwards. In the flat coastal plains, they were

[37] Hill, 'Mechanical engineering', p. 67, indicates such windmills were invented in Afghanistan in the seventh century.
[38] Holt, *Mills*, pp. 20–3; Bautier, 'Les plus anciennes mentions', pp. 606–20.
[39] Langdon, *Mills*, p. 179.
[40] Davids, 'Innovations in windmill technology'.
[41] Holt, *Mills*, p. 34.
[42] Derville, 'Moulins, cultures industrielles et marchands'.
[43] van Bavel and van Zanden, 'Jump-start', pp. 520–1.
[44] Notebaart, *Windmühlen*, p. 163.
[45] Ibid., p. 117.

often more viable than water-mills. Windmills gradually increased in size and numbers during the study period, and came into general use for industrial processes as well as for milling grain.

Horizontal windmills could be found in various parts of the Muslim world, as scattered evidence shows. In the year 644 the second caliph, 'Umar ibn al-Khattāb, was reportedly killed by a Persian captive who was able to construct windmills. Writings by geographers also describe windmills in Seistan (Afghanistan) and Syria, while 'Persian mills' (horizontal mills) also existed in the Fayyum and other parts of Egypt.[46]

The vertical sailed windmill was, however, not used in the medieval Middle East. The only exception appears to have been the west coast of Anatolia and the island of Rhodes, where after the Ottoman conquest vertical windmills continued to be used. These mills had been introduced there from the thirteenth to fifteenth centuries by Byzantines and Genoese.[47] Some commentators have expressed surprise at the near absence of vertical sailed windmills in the Islamic world.[48] Their existence was certainly known to the inhabitants of the medieval Middle East. In the late twelfth century, western European crusaders had built vertical sailed windmills in the Middle Eastern Crusader states.[49] Later, Anatolia was also a point of contact, but there are no signs that vertical windmills, in use on its west coast, spread to other parts of Anatolia.

None of the Muslim geographers and none of the visual representations in Islamic manuscripts show vertical windmills,[50] corroborating their absence from the secondary literature on the history of technology. The summarizing conclusion is that with the exception of the west coast of Anatolia and Crusader castles, vertical windmills were not used in the Middle East, although the cheaper horizontal mills were used.

Cranes

Building cranes were used by the Romans. Classical monuments contain representations of building cranes, which Vitruvius described in his books on architecture. An illustration of a classical crane with a treadmill can be found in the *Vergilius Vaticanus*. This Roman manuscript depicts it constructing the North African city of Carthage.[51] One of the classical books describing cranes and their working principles is *Mechanics* by Heron of Alexandria. It survived because of ninth-century Arabic translations.[52] A thirteenth-century Arabic copy shows a picture of beams, a tackle, and a pulley.[53] Together these three elements form the essential parts of a building crane. The examples above show that the basic principles of building cranes are ancient, and were known in the Arab world too. High-rise structures such as palaces, defensive walls, churches or mosques, and bell

[46] Hill, *Islamic science*, pp. 113–14.
[47] Notebaart, *Windmühlen*, pp. 232–3.
[48] Hill, *History of engineering*, p. 176.
[49] Notebaart, *Windmühlen*, p. 222.
[50] On the use of pictorial sources, see the section on cranes and online app. S2.
[51] *Vergilius Vaticanus*: Vatican Library, Rome, Vat. Lat. 3225, fo. 13.
[52] Schiefsky, 'Theory and practice', p. 16.
[53] We thank Jan Just Witkam for bringing this manuscript (Leiden, University Library, Or. 51) to our attention; the principles of cranes are illustrated on p. 61.

towers or minarets were built in the Middle East and western Europe alike. They were constructed with similar materials and similar building techniques, which did not experience any significant technological breakthroughs in the study period. Therefore building in the Middle East and in western Europe would equally have benefited from labour-saving cranes in lifting heavy materials.

We found the first representation of a crane in action for western Europe in an eleventh-century manuscript (see online appendix S2). Thirteenth-century manuscripts already depicted a more complex building crane with a treadmill.[54] This specific type of crane is the most expensive and labour-saving, and we will concentrate on cranes with treadmills. Building cranes with treadmills were only depicted in north-western Europe. It is striking that building scenes in Italian manuscripts rarely show building machines, but mainly labouring men.[55]

As a spin-off, harbour cranes were introduced in thirteenth-century western Europe. When powered by a treadmill, harbour cranes could handle heavy cargo such as large barrels of wine or millstones. The crane of Bruges (Belgium) was able to lift 1.8 tons.[56] These cranes were very efficient, as corroborated by observations of their labour-saving effect compared with hoisting by hand. Investments were heavy, not only in the crane itself but also in the required infrastructure, including stone quay walls, bridges, and roads.[57] As a result of these sunk costs, harbour cranes often remained at the same site for centuries. These cranes could be found in medieval northern Europe in large river or sea ports, especially along the shores of the North Sea, the Baltic Sea, and along the river Rhine. However, just like building cranes, harbour cranes were absent along the coasts of the Mediterranean, where ports continued to rely on the labour-intensive method of unloading cargo by ramps.[58] The summarizing conclusion is that cranes with treadmills were only found in north-western Europe and gradually increased in numbers from the thirteenth century.

In order to determine the use of cranes in the Middle East, we conducted a computer search similar to that carried out on the prevalence of water-mills in medieval Arabic geographical texts. None of these texts mention any descriptions of a crane, either in the Middle East or in any other part of the Islamic world.[59] Studies on Islamic science and technology, also covering the construction industry, are conspicuously silent on the use of building cranes in Muslim lands; for example, Nasr,[60] al-Hassan and Hill,[61] and Hill.[62] It has been suggested that a crane is mentioned in a late fourteenth-century book by Ibn Khaldun,[63] but on closer inspection this reference concerns a *mikhal* (or pulley). Indeed, the three different parts that together form a crane—the hoist, the pulley, and the rope—were each used in the Islamic world, for instance, on ships or in siege engines. However, the silence of the sources suggests that the combination of the three in the shape of a

[54] Matthies, 'Medieval treadwheels', pp. 512–24.
[55] Ibid., p. 544.
[56] Matheus, 'Mittelalterliche Hafenkräne', pp. 345–7; Degryse, 'De oudste houten kranen'. pp. 19–34.
[57] Degryse, 'De oudste houten kranen', pp. 11–13, and footnotes 13, 23, and 24 there.
[58] Matheus, 'Mittelalterliche Hafenkräne', p. 347.
[59] See online app. S1 for the design and search terms.
[60] Nasr, *Islamic science*.
[61] al-Hassan and Hill, *Islamic technology*.
[62] Hill, *Islamic science*.
[63] Lewcock, 'Architects, craftsmen and builders', pp. 140–1.

building crane was absent in the Middle East. This may seem surprising in view of the fact that many impressive buildings, including tall minarets, were constructed in the region throughout the period; even for late fifteenth-century Istanbul, which witnessed a rush of building activity, no references to building cranes were found. Indeed, high-rise construction in principle is possible without cranes: ramps and scaffolding, in combination with ropes and pulleys, and sufficient human labour provide alternatives.

As an additional check, we also searched pictorial sources depicting construction work on structures that were higher than a man could reach. We counted a mechanical device depicted in an illumination with 'high-rise' construction activities as a crane only when all three basic elements of a building crane were pictured together: a hoist, a pulley, and a rope. We took our samples of European manuscripts from the collections of medieval representations of building activities by Binding,[64] while those of Islamic manuscripts have been taken from collections amassed for a global database.[65]

Representations of building activities are not very common, and are even rarer in eastern manuscripts. Of the more than 10,000 Islamic illuminations we scanned, we found in total only 12 or 13 scenes containing 'high-rise' building activities. Not a single one of these scenes depicts building cranes (with or without a treadmill) at work.[66]

In theory it is conceivable that Muslim artists did not depict cranes despite the fact that such machines were regularly used. This, however, is unlikely. Although mechanical devices are not commonly depicted, there are manuscripts solely dedicated to the propagation of ingenious devices.[67] In fact, there are even miniatures in Muslim manuscripts in which the combination of the three units together forming a crane were used in one device; for instance, in siege engines or to fetch water from a well. Also, we did find representations of water-mills in these manuscripts.[68] These examples indicate that Islamic artists did not shy away from depicting complicated mechanical devices that they observed in everyday life. Therefore as a summarizing conclusion we believe a more plausible reason for the absence of representations of cranes during building activities in Islamic manuscripts is that they were not generally used.

II: Possible explanations

In this section we will explore why immovable capital goods such as water-mills, windmills, and cranes were increasingly used in western Europe between 800 and 1600, while they were either not used at all or gradually decreased in numbers in the Middle East over time. When seeking explanations we have to be aware that our two extensive study areas, Europe and the Middle East, certainly were not

[64] Binding, ed., *Der mittelalterliche Baubetrieb*; idem, *Der mittelalterliche Baubetrieb: Nachträge*.

[65] See online app. S2 for details on the method and sources.

[66] The only exception (Dijon, BM, MS 562) is a manuscript in French produced in one of the Crusader states and depicting a crane with a treadmill; see online app. S2 for an explanation.

[67] al-Jazarī, *Book of knowledge*; Banū (sons of) Mūsà bin Shākir, *Book of ingenious devices*.

[68] These were a visual confirmation of the distribution patterns found in the section on water-mills above. This finding also supports our use of such visual representations as an instrument to estimate the relative prevalence of the use of such capital goods.

Table 1. *Percentage of scenes with building cranes (in italics) and the absolute number of 'high-rise' construction activities in Europe and the Islamic world, depicted in a large sample of ninth- to sixteenth-century manuscripts*

Century	*9th*	*10th*	*11th*	*12th*	*13th*	*14th*	*15th*	*16th*	*Overall*
Europe									
Building scenes	1	-	6	8	18	73	125.5[a]	1.5	235
% cranes	*0*	-	*17*	*50*	*28*	*56*	*71*	*100*	*60*
Std. dev.	-	-	*c.* 15	*c.* 18	*c.* 11	*c.* 6	*c.* 4	-	*c.* 3
Islamic world									
Building scenes	-	-	-	-	-	1	6	5.5	12.5
% cranes	-	-	-	-	-	*0*	*0*	*0*	*0*
Std. dev.	-	-	-	-	-	-	-	-	-

Note: [a]The half numbers for a century concern scenes in manuscripts that are dated to two consecutive centuries.
Sources: See online app. S2.

homogeneous themselves. Economic and political differences between sub-regions and the timing of their occurrence can be used to identify possible causes for the observed spatial and temporal patterns of use of immovable capital goods.

Various authors have tried to determine why the Middle East lost its lead over Europe after the Islamic Golden Age. Lewis sees the successive destruction from the twelfth to fifteenth centuries in the Middle East by Seljuqs, Mongols, and others as a main cause of its local economic decline.[69] Lewis is right in arguing that the Mongol invasions were particularly devastating in the Islamic world. In the large sample of cities in Europe, North Africa, and the Middle East used by Bosker et al., 18 per cent of the thirteenth-century cities in the Islamic world were plundered compared to 5 per cent during the rest of their study period. Nevertheless, an econometric analysis showed there was no significant and lasting influence of this plunder on the economic success of these Muslim (or Christian) cities.[70] Moreover, the timing of the decrease in numbers of water-mills, such as ship-mills disappearing from the Tigris in the tenth century, precedes these incursions. Therefore the invasions cannot provide the explanation we are seeking.

A few other possible explanations have already been discussed in the previous pages, including the availability of technological knowledge. Vertical water-mills and building cranes had already been in use in the Roman Empire, including western Europe and the Middle East. Knowledge of the principles of these devices was moreover available in both regions throughout the middle ages. Admittedly, vertical windmills were European inventions, but Middle Eastern societies had opportunities to see them at work and could thus have learned how to construct and operate them. Geographical explanations, including the availability of water courses and the force of winds, have also proven unsatisfactory. If the Tigris was able to power large water-mills in the early middle ages, there is no reason to believe this would no longer have been possible five centuries later or that it could not have happened on the similar river Nile. Likewise, although winds are generally not as strong in the Mediterranean as in the North Sea region, this does not adequately

[69] Lewis, *Middle East*, p. 178.
[70] Bosker et al., 'From Baghdad to London', tab. A4 of app. A.

explain why vertical windmills were used on the Aegean coast but not in windy regions such as central Iran, southern Arabia, or the northern tip of the Red Sea.[71] These considerations narrow down the number of potential explanations. The remainder of this section will focus on those that are highlighted in the relevant literature: religion, the cost of production factors (labour and capital), and institutions (specifically landholding systems, property rights, and corporations).

Religion

Under this heading we do not include institutions of Islamic societies, which will be discussed below. Here, we refer to the cultural and mental aspects of religion, in particular attitudes related to technological innovations. The notion that religion and mentality were driving forces of gradual economic decline in the Middle East goes back to Weber's assessment of Islam as inherently incompatible with capitalism. Weber's influence can be traced in the oft-repeated argument that Muslims were good at collecting and copying but not at innovating because Islam saw innovation as akin to heresy.[72] A more sophisticated version of the argument states that although Islamic societies were perfectly capable of fostering scientific advances, Muslims were averse to putting innovations to practical use.[73] However, this line of reasoning does not provide a convincing explanation for the failure to copy windmill technology even though it was there to be observed, or to combine widely used pieces of equipment such as the hoist, pulley, and rope into a crane. Likewise, the continued use of watermills in Muslim parts of Northern Africa also contradicts this argument. Nor is it any help in explaining the disappearance of technology that had been used at an earlier stage, such as water-mills in Iraq and Egypt.

If a declining use of capital goods is to be explained from mental and cultural factors at all, we should look for changes in religious attitudes over time. However, no clear shift towards a more critical stance can be discerned. On the one hand, the upheavals and political fragmentation of the twelfth and thirteenth centuries reinforced the position of the *ulama*, the class of religious scholars and jurists who in this era became closely involved in administration and who tended to look upon crafts and craftsmen with distrust. On the other, scholarly writings also reflect an awareness of the importance of skills and of creativity in craftsmanship, voiced most clearly by the fourteenth-century writer Ibn Khaldun.[74] In fact, Ibn Khaldun approached science and technology from a practical perspective: he saw them as connected to the crafts and underlined their value for the enhancement of production.[75] Although it is not clear to what extent his views were shared, this suggests that there was no general aversion towards the use of mechanical devices; nor, for that matter, is there an explanation at hand as to why the Middle East would be affected to a greater extent by such an attitude than other parts of the

[71] Regions identified as having high potential for wind energy in a modern study: Nematollahi, Hoghooghi, Rasti, and Sedaghat, 'Energy demands', pp. 1179–80.
[72] Lewis, *Muslim discovery*, pp. 229–30; Mokyr, *Lever of riches*, pp. 40–4.
[73] Gibb, 'Influence'.
[74] Shatzmiller, *Labour*, pp. 385–97.
[75] Weiss, 'Ibn Khaldun', p. 31.

Islamic world, for instance, the Maghreb or Central Asia, where the use of these capital goods did not decline.

Wage levels

Local wage levels might provide an explanation for the deployment of capital goods. If the wages of unskilled workers were lower in the Middle East than in western Europe, investment in labour-saving building cranes might not have been profitable. Likewise, declining wage levels in the Middle East between the tenth and fifteenth centuries might explain why vertical water-mills that were present in the early period disappeared afterwards.

There is evidence for only the second of these two hypotheses: wages in the Middle-Eastern regions indeed appear to have fallen, although opinions diverge on the pace of their decline. In the moderate interpretation of Pamuk and Shatzmiller, real wages for unskilled labour in Iraq (Baghdad) and Egypt (Cairo), expressed as the number of 'bare-bones baskets' that unskilled labourers were able to purchase, declined after the eighth/ninth century.[76] Although Middle Eastern levels remained well above subsistence, wages for unskilled labour were much lower in the tenth to thirteenth centuries than they had been in the early Islamic period. Pamuk and Shatzmiller attribute the decline to the recovery of population numbers after the demographic low of the sixth to eighth centuries caused by the Justinian plague. The rise of extractive institutions in Iraq and the resulting growth of inequality provide an alternative explanation.[77] Specifically for Egypt in the late Mamluk era, Borsch arrives at much less favourable figures.[78] For the early fourteenth century he calculates wheat wages that were on a par with the figures computed with the data provided by Pamuk and Shatzmiller. However, Borsch concludes that a very sharp drop took place afterwards: he argues that in the late fifteenth century the wages of Egyptian labourers, expressed in quantities of wheat, were only about 20 per cent of what they had been in the early fourteenth century.[79]

Early wage comparisons between the Middle East and western Europe are impossible because of the absence of European data, but from the fourteenth century onwards Egyptian real wages can be compared with those in western Europe. Table 2 suggests that before the fifteenth century unskilled labour was considerably cheaper in Italy and England than in Egypt. Only after 1400 was the gap closed. Again, the figures for Egypt may be too optimistic.

As discussions on Middle Eastern wage levels continue, it is difficult to draw firm conclusions, but it seems safe to say that before the fifteenth century wage levels in the Middle East were not lower than in western Europe, and may have been higher. Nevertheless, as early as the eleventh to fourteenth centuries the number of European water-mills increased remarkably. Building cranes, moreover, were not observed at all in Muslim lands. Wage differentials cannot explain these phenomena.

[76] Pamuk and Shatzmiller, 'Plagues, wages and economic change', pp. 206–7.

[77] Ben Abdallah, *De l'iqta étatique*, pp. 90–120; van Bavel, Campopiano, and Dijkman, 'Factor markets', pp. 283–4.

[78] The difference is probably partly due to the application of another method—wheat wages instead of subsistence baskets—and partly to the use of a wider set of wage data.

[79] Borsch, *Black Death*, pp. 108–10.

Table 2. *Real daily wages for unskilled labour expressed as the number of subsistence baskets*

	Unskilled wages in subsistence baskets		
	Egypt (Cairo)	*Italy (Florence)*	*England (London)*
1250–1300	1.46		
1301–50	1.75	0.60	0.77
1351–1400	2.09	1.18	1.03
1401–50	1.56	1.44	1.47
1451–1500	1.74	1.25	1.53

Sources: Egypt: Pamuk and Shatzmiller, 'Plagues, wages and economic change', p. 202; Italy and England: Allen, 'Labourers'.

Cost of capital

Another reason for a lower application of these expensive capital goods may have been the high cost of capital and the associated opportunity costs of investing in them. Possessors of surplus capital may have been better off lending out their money than investing it in labour-saving machines. Also, investors requiring a loan faced higher costs. Even though investments in mills and cranes were often made without resorting to the market, interest rates in the capital market can be used as a proxy for the cost of capital. In the Middle East, financial markets boomed in the ninth and tenth centuries, most notably in Basra (Iraq).[80] Money changers and merchant bankers (*jahbadh*) were collecting payments and offering credit facilities, to entrepreneurs and to the government and its officials.[81] Information on interest rates in the Middle East is scarce, however. A couple of large tenth-century loans to viziers bore interest rates between 8 and 20 per cent. A document from eleventh-century Egypt listing loans to a total of 38 persons mentions rates between 4 and 11 per cent, but the particulars of these loans are unknown. Documents from the late twelfth and early thirteenth century relating to a very limited number of private loans (four in total), contracted under what appear to be normal conditions, suggest slightly higher but still modest interest rates, ranging between 10 and 17 per cent per year.[82]

Interest rates at any given time and place varied greatly, depending on the purpose and terms of the loan and risks involved. Especially when capital markets were not fully developed, personal relations and the social status of lender and borrower probably also played a part. A comparison of modal interest rates, based on data relating to long-term private loans assembled in previous in-depth studies, nevertheless allows for some tentative conclusions. Table 3 suggests that before the Black Death the range of interest rates in western Europe was similar to those in the Middle East. They mostly hovered around 10 to 11 per cent, or even higher in economically less developed areas. This suggests that the cost of capital was not a decisive factor in the use of expensive capital goods before the Black Death.

After the plague, interest rates in Europe declined considerably. The few figures in table 3 suggest a very different development in the Middle East. Egypt presents

[80] van Bavel et al., 'Factor markets', pp. 278–81.
[81] Fischel, 'Origin of banking'; Sabari, *Mouvements populaires*, pp. 29–30.
[82] Ashtor, 'Le taux d'intérêt', pp. 198–200; Goitein, *Mediterranean society*, vol. I, pp. 254–6.

Table 3. *Modal interest rates on long-term private loans in per cent per year in western Europe and the Middle East*

Period	*England*	*France*	*Germany*	*Italy*[a]	*Netherlands*	*Egypt/Syria*	*Anatolia*
1151–1200	20				20	10–13	
1201–50	10.3	10.8	11	12.5	11.2	10–17	
1251–1300	10.2	11.1	10.8	12.5	10		
1301–BD[b]	11.2		10.1	12	11.2		
BD–1400	4.5	10	9.7	10	9.2		
1401–50		10	8.5	8	7.9	18–24	
1451–1500	4	9.2	6.5	6	5.5	18–24	
1501–50	4.6	8.2	5	6.5	6.1		10–20
1551–1600	5.5	8.3	5	6.5	6.3		10–20

Notes: [a] Central and north Italy; [b] Black Death.
Sources: England, France, Germany, and Italy: Pezzolo, '*Via Italiana* to capitalism', p. 302; Netherlands: Zuijderduijn, *Medieval capital markets*, pp. 283–5; Gelderblom and Jonker, 'Public finance and economic growth', p. 7; Egypt/Syria: Goitein, *Mediterranean society*, vol. I, pp. 254–6, 384; Ashtor, 'Le taux d'intérêt', pp. 198–204; Anatolia: Pamuk, *Monetary history*, pp. 78–9.

an extreme case. Notably, the later Mamluk state, especially from the early fifteenth century on, was beset by growing extortion of wealth by semi-public 'protectors' and confiscation of wealth.[83] Because of the climate of uncertainty, inhabitants of the Mamluk state hoarded their money instead of investing it or lending it. In combination with the outflow of specie caused by a negative trade balance, this led to a deficit of local capital after the Black Death. Interest rates rose dramatically.

In other parts of the Middle East rates were more moderate. In sixteenth-century Anatolia, for instance, 10 to 20 per cent appears to have been typical.[84] At the low end of this range were the interest rates charged by 'cash *waqf*s'. *Waqf*s were trusts established by an individual in order to supply a function, usually a charitable one, considered legitimate under Islamic law. In the case of cash *waqf*s this function was to supply credit; cash *waqf*s were endowed by the founder with a sum of money designated for this purpose. Cash *waqf*s first emerged in the fifteenth century and gradually gained in popularity. Because they were seen as legitimate institutions, they could charge relatively low interest rates. In fact, the foundation deed usually prescribed a fixed rate.[85]

This suggests that interest rates in Anatolia did not rise after the Black Death, as they did in Egypt. However, an interest rate of 10 per cent is still substantially above what was typical in sixteenth-century Europe. Moreover, the assets of cash *waqf*s were usually modest and the loans granted were small.[86] In other words, cash *waqf*s were useful as providers of limited loans, but had little value when large investments were needed. This might, at least in part, explain why no large vertical water-mills were established in Anatolia.

In western Europe, on the other hand, the cost of capital substantially declined in the fifteenth and sixteenth centuries. Moreover, open capital markets developed there, allowing potential investors to get access to capital at ever-lower interest rates. These investors included the town communities that sold annuities, sometimes

[83] Meloy, 'Privatization of protection', pp. 201–2.
[84] Pamuk, *Monetary history*, pp. 78–9.
[85] Kuran, *Long divergence*, pp. 158–60; Çizakça, 'Cash *waqf*s', pp. 331–2.
[86] Jennings, 'Loans and credit', pp. 178–9.

even on a massive scale, in order to finance urban infrastructure, including military works but also roads, quays, and harbour cranes.[87] For this period, therefore, this factor can help explain why in western Europe more expensive capital goods were used than in the Middle East. However, for the period before the Black Death, when the divergence first became visible, we must look for other explanations.

Institutions

We investigate three institutional factors that can be expected to have contributed to the divergence in the use of capital goods between western Europe and the Middle East: systems of lordship and surplus-extraction, property rights, and corporations and foundations. Starting with the first of these three: the relation between the increasing use of vertical water-mills and windmills in early and high medieval Europe and the prevalence of the manorial system is well established in the literature.[88] Manorial lords not only were able to muster the capital required to build a mill, but also stood to profit from the investment directly through the dues paid for its use, and also indirectly, since the mill freed labour that could be used elsewhere. They also invested in ovens and breweries, as mills produced their feedstocks. From the ninth century, breweries and malt mills were sometimes mentioned together, and this combination became widespread in the high middle ages.[89] One explanation for the readiness of manorial lords to invest in mills is the fact that they were in a position to enforce the use of the manorial mill and the payment of milling fees upon their villein (unfree) tenants. Compulsory use and high rates gave rise to many conflicts between lords and peasants, but also bolstered the profitability of mills and thus contributed to an increase in their numbers.[90] In France this was reinforced by the rise of banal lordship from the tenth century.[91] While this interpretation indicates a highly uneven distribution of the benefits of mills, it also suggests that in the restricted context of the high medieval period, and compared to other options open at that time, the manorial system was conducive to investments in these costly capital goods. Moreover, a more optimistic interpretation is possible. For England, research has shown that it was not unusual for free tenants to make use of the lord's mill, even if they were under no obligation to do so. The fees they paid were usually lower than for villeins and probably reflected market conditions. In those situations the labour-saving effect of mechanical milling apparently outweighed the costs.[92]

In both interpretations, one clear difference with the Middle East stands out. Lords in western Europe, because of the hereditary nature of their position, were certain to benefit not just in the short term but also in the long run, increasing their propensity to make the necessary investments. This element was absent from the system of the military *ikta* that developed in the Middle East. The *ikta* was a specific type of tenure limited to the revenues of the land. Partly building on pre-existing forms of tax farming, in Buwayhid and Seljuqid Iraq state land was given

[87] Boone and van der Heijden, 'Urban finances', pp. 345–51.
[88] A seminal contribution was made by Bloch, 'Avènement', pp. 552–60; Holt, *Mills*, pp. 36–53.
[89] Bautier, 'Les plus anciennes mentions', pp. 601–3.
[90] Holt, *Mills*, pp. 36–44.
[91] Bloch, 'Avènement', pp. 554–5.
[92] Holt, *Mills*, pp. 48–53.

out to military commanders and soldiers as payment for their services instead of a salary in cash. This military *ikta* system became the dominant system of lordship in Iraq.[93] In marked contrast to the manorial and banal lordships of western Europe, *ikta*s were usually not hereditary. Changes of tenure, taking place every few years, discouraged investments in maintenance and repair, the benefits of which would accrue to an unknown and unrelated successor.

The military *ikta* system was not dictated by Islam. The Fatimid regime that ruled Egypt from the late tenth to the late twelfth century did not grant *ikta*s in return for military services on a large scale. However, when Saladin came to power in 1169, he ensured the loyalty of his Syrian troops by assigning *ikta*s to them. The *ikta* system subsequently became a dominant factor in Egyptian society.[94] In the early Mamluk era investments in the upkeep and extension of Egypt's dykes and irrigation systems, enforced by an intricate civilian bureaucracy and a powerful military apparatus, were nevertheless substantial. However, after the Black Death, when intra-elite cohesion broke down and investments came to depend on the efforts of individual landlords, the short time-horizon of the *ikta* system led to neglect and ultimately decay of vital water distribution systems.[95]

The brevity of individual tenure imposed by the *ikta* system offers a plausible explanation for the apparent reluctance of Middle Eastern lords to install expensive water-mills at a time when their western European counterparts were keen to do so. Notably, the *timar* system of landholding that dominated in the Ottoman Empire between the fourteenth and sixteenth centuries in many respects resembled the *ikta* system. *Timar*s were non-hereditary grants of tax revenues from state land for the purpose of sustaining the army and the administration. In Anatolia *timar*s coexisted with private landowning. *Timar*-holders were responsible for the management of the estates; the revenues (including milling dues) were divided between them and the owners.[96] These arrangements can hardly have been an encouragement to landowners to invest in costly vertical water-mills, which indeed seem to have been rare in late medieval Anatolia.

The second institutional factor to be examined regards property rights. In late medieval western Europe, rural lords had largely been replaced as investors in expensive capital goods by urban communities and market-driven investors, mainly but not exclusively from the towns.[97] This process was associated with the dissolution of manorialism and banal lordship and the growing commercialization of the economy. This new type of market-driven investor was much more exceptional in the late medieval Middle East. Although in medieval Muslim lands property rights were in principle well-defined, secure, and protected by law, in late Abbasid Iraq a deterioration seems to have occurred which affected urban elites in particular. Confiscations of private property had occurred in the eighth and ninth centuries, but only as a punishment for misbehaviour or fraud. In the tenth century, however, arbitrary confiscations became common, caused by the state's growing lack of cash, declining tax revenues, and the increase of private wealth.[98]

[93] Sato, *State and rural society*, pp. 18–24.
[94] Ibid., pp. 42–5.
[95] Borsch, *Black Death*, pp. 40–2.
[96] Islamoğlu-Inan, *State and peasant*, pp. 62–8.
[97] For instance, Goldthwaite, *Economy*, pp. 301–2, 308–9; Carus-Wilson, 'Evidences', pp. 193–6, 199–202.
[98] Kabir, *Buwayhid dynasty*, pp. 158–60; Mez, *Die Renaissance des Islāms*, pp. 108–11.

Total tax revenue in 918 had been some 14.5 million dinars, while in 924 the imposition of arbitrary fines produced almost half of this sum.[99] This shows that such arbitrary appropriations from the rich then formed a considerable fraction of total tax revenue and it also indicates that even senior dignitaries were unable to protect their property. Likewise, the Seljuq rulers of the eleventh and twelfth centuries repeatedly imposed arbitrary fines on high officials. The sums were lower than before, but this seems to have been a reflection of Iraq's general economic and demographic decline rather than of a greater respect for property rights.[100]

A similar development took place in Egypt in the late middle ages. Ashtor indicates that rich Egyptian merchants no longer invested their capital in textile factories that could easily be confiscated.[101] In the later Mamluk period, mills were among the properties from which 'protection money' was usually requested, while millers and waterwheel operators are explicitly mentioned as being embedded in the system of protection and extortion.[102] These examples suggest that the resulting insecurity of property rights could have downright negative economic consequences through underinvestment. Protection of property rights did not deteriorate everywhere in the late medieval Islamic world, however. There were also regions where it improved, for instance, in Marinid Morocco.[103] Notably, Morocco was one of the regions that witnessed a strong increase in the number of water-mills in the late middle ages.

In medieval Europe wealthy merchants and entrepreneurs were not always safe from harassment by the authorities either. However, most examples of confiscation of property concerned foreign merchants or targeted specific groups: Jews expelled from England in the late thirteenth century, for instance, or Knights Templar in France upon the dissolution of that order in the early fourteenth century. On the whole, however, in western Europe rights to private property were increasingly secure from predatory rulers, not just in law but also in practice, as part of the rise of market exchange and the growing limitations on the rulers' arbitrary power. The rise of self-governing cities dominated by the interests of merchants and entrepreneurs and, from the late twelfth century onward, of parliaments, was an important component in this.[104]

The third and last institutional factor under investigation is concerned with the role of corporations and foundations. The idea that the absence of collective, self-governing bodies with legal status held back the development of the Islamic world has a long history. Following Weber, one line of thought focused on the absence of urban self-administration and resulted in the claim that because pre-modern Islamic cities did not possess European-style charters, they must have lacked governance and coherence. Opponents have claimed that the reality was far more complex than a simple dichotomy between European and Islamic towns suggests: in Ottoman cities, for instance, local *qadi*s (judges) had an important role in administration, and cohesion was provided by religious and ethnic communities,

[99] Ashtor, *Social and economic history*, p. 141.
[100] Ibid., pp. 215–16.
[101] Ashtor, 'Levantine sugar industry', p. 266.
[102] Meloy, 'Privatization of protection', pp. 205–6.
[103] Shatzmiller, 'Islam and the "great divergence"', pp. 33–4.
[104] Ogilvie, *Institutions*, pp. 243–5; van Zanden, Buringh, and Bosker, 'Rise and decline'.

neighbourhoods, and guilds.[105] More recently attention has focused on the role of business corporations which emerged in early modern Europe but were absent in the Middle East.[106]

Here we discuss a related aspect: the role of corporations and foundations as a third category of investors in expensive capital goods, besides rural lords and urban entrepreneurs. In the Middle East many mills were owned by *waqf*s. The cash *waqf* has already been discussed; more common were *waqf*s established to support community services such as mosques, schools, or fountains. *Waqf*s first appeared in the mid-eighth century but gained importance in the late ninth century. They were increasingly used by the rich to shield wealth from confiscation and arbitrary levies. Once the founder had determined the aim of the *waqf* in the founding deed, it could not, or only with great difficulty, be changed. The *waqf* was expected to continue to deliver the designated function in perpetuity. Its founder benefited not just because of the status and gratitude that establishing a *waqf* provided, but also because in the founding deed he could appoint himself, or a family member, as a salaried caretaker.[107]

Mills were frequently included in the asset-bearing revenues of a *waqf*, in the Ottoman era but also in earlier periods.[108] Based on the situation in early modern Bursa (Anatolia) it appears, however, that although *waqf*s saw to the maintenance and repairs of their possessions, they usually did not construct new mills: an investment like that was seen as a withdrawal of funds from the designated purpose of the *waqf*.[109] More generally, the fact that revenues could not be spent freely implied that investors who established a *waqf* to ensure protection for their property also had to deal with the inflexibility of the system and the restraints this imposed. Swapping one asset for another, for instance, required the permission of a judge,[110] and corruption among caretakers was rife.[111] Therefore, although the *waqf* helped to lower barriers against investments, it could not fully remove them. It should be added that the characteristics of the *waqf* cannot explain why investments in capital goods declined in the Middle East but not in some other parts of the Islamic world, especially since the Hanafi law school that prevailed in most of the Middle East was not quite as strict about making changes in the assets or purpose of a *waqf* as, for instance, the Maliki school that dominated in Morocco.[112] This suggests that differences in other institutions, such as the time-horizon of local lordship systems within the Muslim world, probably form a more adequate explanation for the differences in prevalence of immovable capital goods between Morocco and the Middle East than Islamic foundations as such.

In Europe many mills were financed and constructed by lords, and in the later middle ages by urban entrepreneurs, but also by non-natural legal entities, including towns, abbeys, and chapters. Like *waqf*s, these entities had a long time-horizon; but unlike *waqf*s, they were free to employ their money as they saw fit.

[105] For example, Raymond, 'Islamic city', p. 10.
[106] Kuran, *Long divergence*, pp. 97–142.
[107] Ibid., pp. 110–15.
[108] For example, van Leeuwen, *Waqfs and urban structures*, pp. 81, 144–5, 156, 164; Jennings, 'Pious foundations', pp. 276–9, 290–1, 301–2, 319, 323.
[109] Gerber, *Bursa*, pp. 71–2.
[110] Kuran, *Long divergence*, p. 128.
[111] Kuran, 'Provision of public goods', pp. 883–7.
[112] Shatzmiller, 'Islamic institutions', pp. 67–9.

This facilitated substantial investments in the construction of labour-saving capital goods. We have already encountered the examples of Huy and Arras, where local abbeys were the major investors in mills. Windmills in Holland were often built and owned by cities or, when used for drainage purposes, by water management associations. The grain mills were mostly leased out to a miller, who paid a lease sum to the owner and a yearly fee to the princely or territorial lord, for the use of the wind, the so-called right of the wind. Harbour cranes with treadmills, which were very costly, were often financed and owned by urban governments, which rented or leased them out.[113] Cities, water management associations, and monastic communities had in common that they were corporations: collective bodies with a considerable degree of autonomy. Just like the Middle Eastern *waqf*s, European corporations were able to safeguard investments and the revenues they rendered from predatory rulers. However, their autonomy enabled these corporations easily to adapt their investments to changing economic opportunities.

III: Capital goods and their consequences

Around the year 800 the Middle East had acquired a higher level of wealth than Europe. The Middle East probably also used more labour-saving immovable capital goods per person. Around 1600 the situation was reversed. The Middle East on average then had a lower GDP per capita and in the region there operated considerably fewer vertical water-mills per person than in western Europe. The two other categories of labour-saving and expensive capital goods (vertical windmills and cranes) were not used at all in the East. If they mechanized at all, people in the Middle East turned to cheaper but also less labour-saving alternatives such as horizontal water-mills and horizontal windmills or animal mills. In western Europe all three categories of expensive capital goods were used extensively around 1600. In fact, Europe's advance had started much earlier: from the eleventh or twelfth century onward the use of labour-saving capital goods expanded rapidly.

The observed differences in the use of capital goods within the Middle East show that its main drivers cannot be seen as mainly religious or cultural. Economic reasons explain some of the patterns we find, particularly for the fifteenth and sixteenth centuries. At that time wages in the Middle East fell below European levels, while the costs of capital were higher than in western Europe. Such factors, however, do not hold for the period before the Black Death. We have therefore included institutional causes in our explanation, in particular lordship systems, the attitude of the state regarding private property, and the role of collective bodies.

The manorial system in western Europe, with its hereditary landholdings, created landlords with a time-horizon of generations. It made these lords willing to invest in capital goods, even if that only paid off in the long term. While compulsory use of the lord's mill in the short run mainly benefited the lord and not his peasants, the increases in mill density did lead to saving of labour. A non-hereditary *ikta* system in the Middle East made large investments with a time-horizon longer than a few years quite unattractive for the lords. This system also often made investments in maintenance and repair economically unviable, as its later benefits

[113] van Bavel, *Manors and markets*, p. 227; Degryse, 'De oudste houten kranen', pp. 8, 13–14.

would not be accrued by the lord or his descendants. This effect was reinforced by the growing insecurity of property rights in most parts of the Middle East. The *waqf* could only remedy this in part, because of the difficulty of changing the predetermined purpose of the foundation. Meanwhile, the development of markets and more secure property rights in western Europe stimulated investments in expensive capital goods by entrepreneurs and corporations.

Even when average wage levels and costs of capital would have been such that an investment in labour-saving capital goods would have been profitable, such investments will generally not have been made unless institutions were supportive too. When institutions fail in a society and property rights, investments, or profits are insecure, a cheaper alternative (a horizontal or animal mill) is likely to be chosen instead of the most labour-saving (and expensive) vertical mill. In the long run, the consequences of such gradual suboptimal choices for investments in capital goods will work out negatively. Thus, investments in immovable capital goods not only form a good indicator of the timing and speed of the reversal of fortunes between Europe and the Middle East, but also point to the underlying institutional causes for this reversal.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. Water-mills in Arabic literature
Appendix S2. Mentions of cranes in manuscripts

