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June 2015

Working paper no. 69

www.cgeh.nl/working-paper-series/

Immovable capital goods in medieval Muslim lands: why water-mills and building cranes went missing

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Abstract: Immovable capital goods such as water-mills were in widespread use in Muslim lands in the early medieval period, just as in the Latin West. In the later Middle Ages, however, vertical windmills and cranes, then widely employed in Europe, were not introduced there, while the number of water-mills dwindled. This decline was concentrated in specific parts of the Muslim world, which rules out time-invariant and generic causes like religion. We show that it was the growing insecurity of property rights and introduction of a specific system of land tenure (*ikta*) that prevented application of such labor-saving capital goods.

Keywords: capital goods, Middle East, Middle Ages, great divergence

JEL Codes: N10, N15, N30, N35, N70.

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Acknowledgements: We would like to thank Antoni Furio (Universitat de Valencia), Oscar Gelderblom (Utrecht University), Timur Kuran (Duke University) and Maya Shatzmiller (Western University) for their suggestions and comments on earlier versions of this paper, Eileen Power for the correction of the English, Iason Jongepier (University of Antwerp) for his work on the maps and Josephine van den Bent (University of Amsterdam) for her work on the database.

1. INTRODUCTION

In the Middle Ages, just as now, the main purpose of deploying capital goods in manufacturing was to save labor. These goods were costly, but the power they were able to provide allowed for a very significant reduction of labor costs; their use thus led to higher productivity at lower cost, thereby facilitating economic growth. Before the end of the eighteenth century the use of kinetic energy (other than human force) in manufacturing was restricted to the power of animals, water and wind, with water-mills and windmills dominating power-generated technology. However, the contribution made by these energy sources, and the efficiency with which they were employed, differed from one society to another. It also changed over time. Even in the pre-modern era, energy use, technological change and economic performance were related, although the exact nature of the relationship is open to discussion (Malanima, 2000; Malanima, 2009, pp. 84-94), and therefore studying these regional and temporal differences is worthwhile. It may help us understand the causes of the various developmental paths of historical economies and thus contribute to the debate on the causes of economic growth.

In this study we limit ourselves to the medieval Islamic world, concentrating on the deployment of three of the most important immovable medieval capital goods: water-mills, windmills and building cranes. Finding the deeper causes for their use or non-use is our aim. We want to go further than suggesting it is simply due to differences in religion or mentality between East and West,[1] one of the more generally mentioned explanations (Landes, 1998, and the other literature mentioned in section 5). Therefore we first reconstruct how and to what extent, between the

[1] In this article, we use 'East', 'Islamic East', 'Islamic world', and 'Muslim lands' as convenient shorthand for the region encompassing the lands between Central Asia and the Maghrib. The same applies to 'West' and 'Latin West', which we use for Europe minus the parts under Islamic rule, first the Iberian peninsula and later the Balkans.

seventh century and the seventeenth, these three capital goods were used within Muslim lands. Next, we use the observed differences in geographical and temporal patterns between various Muslim polities to obtain greater insight into the underlying causes of their prevalence. In particular, we distinguish between the core areas of the Islamic world (the Near East: Iraq, Syria and Egypt) and its periphery (the Maghrib and al-Andalus in the west, and Iran, Central Asia and Afghanistan in the east). By quantifying differences in use between areas that are all part of the Islamic world, geographically universal and time-invariant causes (religion and mentality) can be ruled out.

Likewise, lack of technological knowledge can be ruled out as a cause, as these capital goods had a long history in all regions. Water-mills and building cranes had been in use in the Roman Empire, including North Africa and the Near East, so both had a local history of centuries before the seventh-century Muslim conquest. Windmills are probably of more recent origin. The principle of using wind power was known in Antiquity, but horizontal windmills were pre-Islamic inventions of the East.

The second section of this study describes our sample of the geographical distribution of vertical water-mills within Muslim lands over time. In section 3 we discuss the use of windmills and their spread in time and space, followed in section 4 by a discussion of the use of cranes. The fifth section explores possible causes for patterns of use of these expensive, labor-saving capital goods. We will focus on three variables: the cost of labor, the cost of capital and the security offered by the institutional framework.

2. VERTICAL WATER-MILLS

Water- and wind-mills were primordial in saving human labor in milling, especially the milling of grain for making bread, which was a staple food in pre-industrial Europe and the Near East (Waines, 1987). In their absence, people had to resort to hand-mills or those driven by animals. Hand-milling took time and labor: the time needed for grinding a family's daily requirement of flour has been calculated as at least one hour (Van der Beek, 2010, p. 667, n. 16). The water-mill, as a mechanical device that is driven by the flow of water and that powers the mill stones, or a trip hammer, had been in general use in the Roman period (Wilson, 2002, p. 11).[2] Hill (1984, p. 161), the eminent historian of Islamic technology, indicates that from the third century onwards milling was a widespread activity in Europe and the Near East. The last Sasanian king, fleeing the seventh-century Muslim conquerors, was reported to have been killed near a water-mill, showing such capital goods were pre-Islamic features. 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.[3] Vertical mills are more powerful; their gearing makes them

[2] These water-mills should not be confused with water-lifting devices or waterwheels that were powered by flowing water or by animals. Such water-lifting devices are ubiquitous in the dry areas of the Near East. They are relatively uncomplicated pieces of machinery since they do not require the aquatic infrastructure needed for a water-mill. In Arabic the wheels used for lifting water were called *dawlab* or *noria*. In this study such waterwheels are not considered to be a water-mill. Furthermore the animal-driven horizontal mill that is used in the Near East for lifting water (*saqiya*) or for the milling of grain should not be confused with a water-mill. Though interesting in their own right, water technology and the various devices in use for irrigation in the Near East are not the subject of this study.

[3] In this study we mention horizontal water-mills only incidentally because they were not used in the core areas of the Islamic world and are only found in the periphery.. They have been reported in Iran (Harverson, 1993) and in

mechanically more complex, as well as more expensive to build and operate. The water driving vertical mills can flow beneath the axle or fall onto the waterwheel from above, leading to either under- or overshoot mills. Overshoot 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 undershoot type. Ship-mills were widely used to take advantage of stronger currents midstream and because they were unaffected by lower water-levels, which could be a problem for fixed mills during the dry season. Hill (1993, p. 111) reports ship-mills in Murcia and Zaragoza (Spain), and Tbilisi (Georgia). 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, including those in the Open Canal near Mosul, the caliphal mills, the big Patrikios mills in Baghdad, and the paper mills there (Robinson, 2000, p. 69, p. 79, pp. 84-85; Cutler, 2002, p. 268). 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 (Hill, 1993, p. 111).

At the end of the tenth century, however, the geographer Ibn Hawqal reports that the ship-mills on the Tigris near Mosul (Iraq), up to then the granary for Baghdad, had totally disappeared (Hill, 1984, p. 165). Likewise, the geographical treatise of al-Muqaddasi (late tenth century) does not mention any ship-mills on the Tigris, while it does note the tide mills in Basra (al-Muqaddasi, 1994, p. 113). The disappearance of ship-mills from the Tigris was apparently permanent, for Ibn Jubayr, who travelled along the Tigris at the end of the twelfth century, also

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Morocco and Spain (Barcelo, 2004). In the West such horizontal mills were in the past preferentially used in more sparsely populated areas (Ireland, Scotland, Norway) where the larger investment in a vertical water-mill probably would not have been economical. The fact that these horizontal water-mills were not found in the core areas of the Islamic world (Iraq, Syria and Egypt) and only in the periphery, makes their geographical distribution rather similar to the late medieval distribution of the vertical water-mill, see Figure 1.

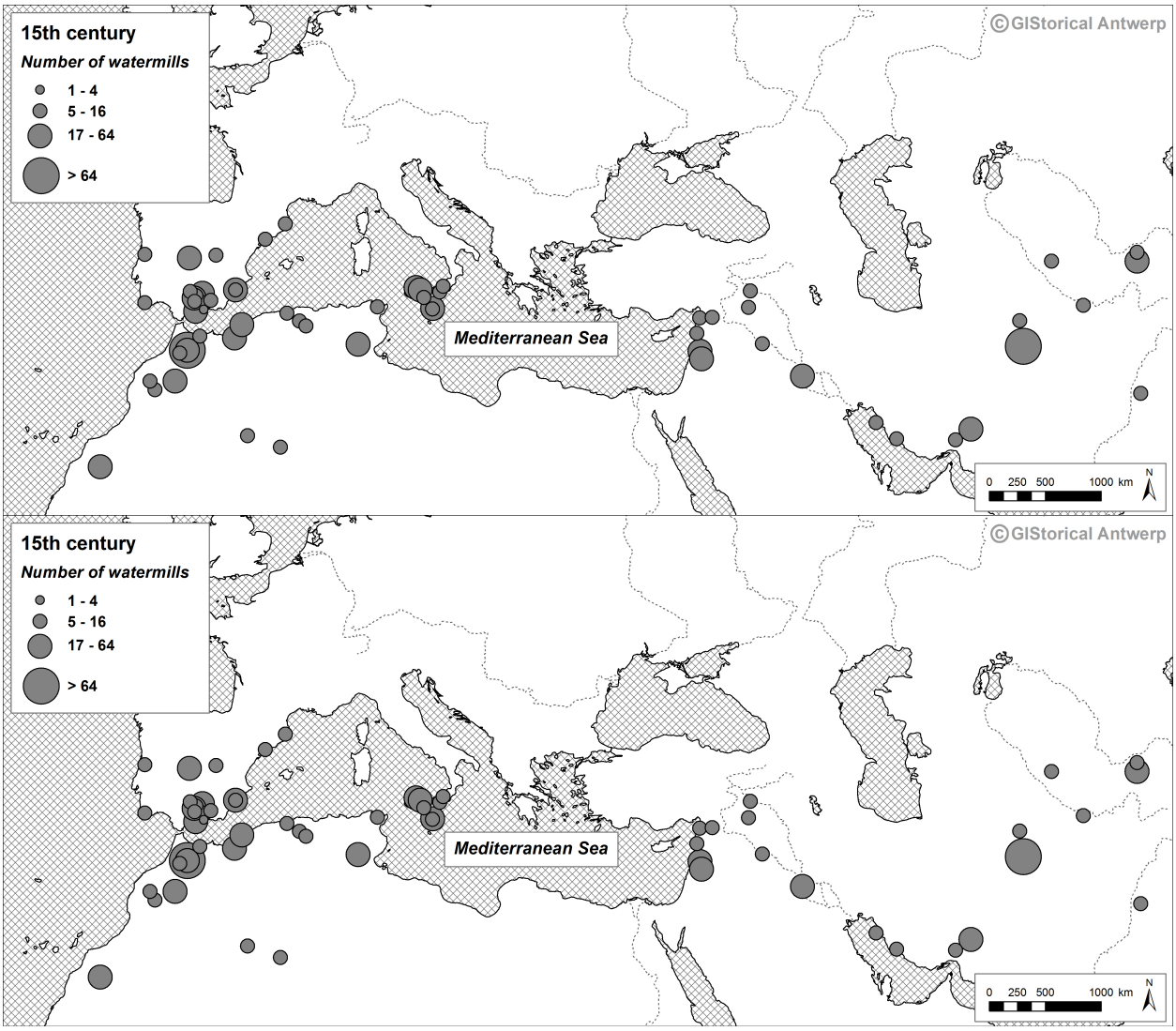
does not mention any watermills or ship-mills on the river near Mosul, although he does not fail to record various ship bridges on the Euphrates and the Tigris (Ibn Jubayr, 1952, p. 221, p. 234). Generally speaking, there is no doubt as to the progressive decrease in the number of water-driven mills in the Near East. One may quote in this context Domenico Trevisan, a Venetian ambassador and a very keen observer. Trevisan, who came to Egypt in 1512 and says bluntly that in this country "there are neither water-driven mills nor windmills". The Egyptian mills were operated by horses and by oxen, according to his travelogue. (In his conception of windmills Trevisan implicitly meant the vertical type commonly used in the West. He did not consider the horizontal windmills that existed in the Near East.) European travelers who visited the Near East in later periods noticed time and again the scarcity of mills operated by water (Ashtor, 1992, p. 278).

To arrive at an indication of the relative prevalence of water-mills, a computer search was done in Arabic geographical works.[4] Figure 1 shows the numbers of water-mills reported by ninth/tenth-century and fifteenth-century Muslim geographers. These numbers have been found by an electronic search of original Arabic texts of al-Yaqubi (891) and al-Muqaddasi (985), and those of al-Wardi (1419) and al-Himyari (1461), by counting the mills actually mentioned in various places (thereby counting 'many mills' as twenty, and a plural of 'mills' as five, see the results in the online appendix).

[4] We thank Josephine van den Bent for carrying out this part of the work (see the online appendix for the research terms used and the results obtained). The design of this computer search is such that it gives answers on the relative prevalence over time and space of water-mills in Muslim lands; it is not an absolute measure of water-mills in the East. It assumes that all sightings by Arab geographers can be seen as a sample of those that were operating at the time the observer passed the place in question. Although we do not know if geographers reported every mill seen, we can assume that together their reports form a geographically unbiased sample of the distribution of water-mills.

FIGURE 1

WATER-MILLS IN MUSLIM LANDS IN RESPECTIVELY THE NINTH/TENTH CENTURY AND THE FIFTEENTH CENTURY



Maps by I. Jongepier © GIStorical Anwerp - University of Antwerp/Hercules Foundation.

Source: see online appendix at <http://www.cgeh.nl/early-economies-hub-data>.

Figure 1 shows that the sparse water-mills originally located in core areas of the Islamic world (Egypt, Syria and Iraq) largely disappeared later on. Water-mills increased in number or remained important during this period in the Islamic periphery: the Maghrib and al-Andalus in the west, and in Iran, Central Asia and Afghanistan in the east.[5] A typical example in the Islamic periphery is the city of Fez (Morocco). Its industrial businesses were described in what was probably a tax list. At the beginning of the thirteenth century it reports 472 watermills and 400 paper mills (Hamilton et al. 1975, vii, 806).[6] These considerable numbers of mills testify to the large local investments in capital goods. Some decades later Fez was to become part of the efflorescent Marīnid Empire (Shatzmiller, 2014). Figure 1 generally confirms the distribution of medieval water-mills described by Hill (1984, 1993).

Although the prevalence of water-mills in Muslim lands was considerable, the Near East had fewer such capital goods per capita than Western Europe. Hill (1993, 111) indicates that according to Domesday Book, England at the end of the eleventh century had 5,624 water-mills. With a population of some two million this implies a density of approximately 320 inhabitants per water-mill. Remarkably, some eighteenth- and nineteenth-century figures concerning the numbers of water-mills and inhabitants in the Ottoman Empire resemble those in the Latin West in the medieval period. The *Encyclopédie de l' Islam* (Hamilton et al. 1975) gives for the nineteenth-century town of Safakus (Sfax in Tunisia) a number of 2,066 houses and 35 watermills, which assuming five inhabitants per house results in nearly 300 inhabitants per mill.

[5] In the modern literature the water-mills in the western periphery have received most attention (for example: Bazzana 2003, Barceló 2004).

[6] Fez was believed to have had some 80,000 inhabitants back then (Bosker *et al*., 2013), which leads to a water-mill density of 170 inhabitants per water-mill, and even less when the paper mills are taken into account too. Such a mill density is entirely comparable to those in contemporary Europe.

For eighteenth-century Kefe (Theodosia, in the Crimea) this same source presents 9,060 houses and 160 mills, or the equivalent of 280 inhabitants per mill. Durand (2003) mentions that Portugal still had 10,000 operating wind and water-mills in the 1960s, which implies similar densities of a couple of hundred persons per mill.

Unfortunately we have not been able to find reliable indications of the costs of building a water-mill or *saqiya* in the Near East, nor their daily operating costs.[7] Langdon (2004, p. 179) gives some tentative prices of historical costs of medieval English mills. Vertical water-mills cost between twenty to forty pounds, vertical windmills were ten to twenty pounds, a horse mill came to five pounds, while a hand mill cost one pound or less. As the technology was similar, we can assume that the relative costs for devices of this kind in the Near East would have been more or less comparable. Extrapolating the ranges above, we presume that in the Near East the cost of an animal-driven *saqiya* (similar to a medieval horse mill) would have been $^1/_8$ to $^1/_4$ of that of a regular water-mill.

Summarizing this section we can state that after their prior use in (late) Antiquity, vertical water-mills continued to be frequently used in the Islamic world. In the ninth/tenth century they could be found virtually everywhere. By the fifteenth century water-mills had largely disappeared from the Islamic core areas (Iraq, Syria and Egypt), and continued to be found in substantial numbers only in the Muslim periphery (the Maghrib, Iran and Sindh).

[7] The construction of the Patrikios mills in early eighth-century Baghdad allegedly required an investment of 1,000,000 dirham (Robinson, 2005, p. 85; Cutler, 2001, p. 68). However, even apart from the fact that this was not a single mill but a huge complex which reportedly powered a total of one hundred mill stones, the reliability of this sum is very doubtful.

3. WINDMILLS

Windmills come in two flavors too: vertical and horizontal. Vertical windmills are the type that is still used: their sails turn in a vertical plane and require a gearing system. Vertical windmills can be oriented into various wind directions. As more powerful machines they are mechanically more complex. Horizontal windmills are simpler, have no gears and their sails turn horizontally. Their main drawback is that they can be used with one wind direction only. An eleventh-century fortified Muslim monastery in Monastir (Tunisia) already contained a "Persian" horizontal mill.[8] Its name suggests that such mills had been invented in Iran, where strong winds often blow from one specific direction (Hills, 1994, p. 11).[9] In AD 644 the second caliph, 'Umar ibn al-Khattāb, was reportedly killed by a Persian captive who was able to construct windmills. A "Persian mill" is also spoken of in the biography of a Mamluk who lived in the fifteenth century. Xaybray al-Asrafi (d. 1482) had an estate in the Fayyum where he had planted sugar cane, established a sugar press, and built – a Persian mill. There were probably other mills of this kind in Egypt and Syria (Ashtor, 1992, p. 279).

Surprise at the absence of the vertical sailed windmill from the Islamic world has regularly been expressed before (Hill, 1984, p. 176). The existence of such vertical mills was certainly known to the inhabitants of the medieval Near East. The great thirteenth-century Crusader castle "Crac des Chevaliers" had a vertical windmill on its ramparts. Its inhabitants could grind grain, even when their castle was under siege. However, most mills in the Mamluk state were driven by animals. As an explanation for this absence of vertical windmills in Muslim lands, Hill (1984, p. 176)

[8] Hamilton et al. (1975, lemma "Monastir"). Remarkably, the *Encyclopaedia of Islam* has no lemma concerning "Persian mills". Richard Hills (2002) devotes a whole chapter to horizontal windmills in his book *Power from wind*.

[9] Hill (1991, p. 67) indicates such windmills were invented in Afghanistan in the seventh century.

suggested that most cities in the Near East were situated on rivers and therefore did not really need wind power, as they had easy access to water power. As an additional reason for the absence of vertical windmills, Hill proposed local shortage of timber. To us neither reason seems totally convincing. Most large cities in the Latin West were located along rivers too (Bosker and Buringh, forthcoming), and even in eastern cities on riverbanks waterpower was not used as widely as in the West (see previous section). Vertical windmills in Mediterranean Greece and Spain have a different construction from those in north-western parts of Europe because of local shortages of timber. We presume that such adapted and 'Mediterranean-proof' vertical windmills would have been serviceable in medieval Muslim lands too. Vertical windmills are more complex to construct and require more capital than horizontal mills without a gearing system. Both the simpler horizontal water-wheel and the horizontal windmill were often used in Persia. We find it quite remarkable that horizontal windmills have been found in the same periphery of the Muslim lands, both in the east and in the Maghrib, as medieval water-mills (see Figure 1). The more powerful vertical windmills were not found anywhere in the Islamic world. Why this device, that from the thirteenth century onwards found such a wide and fruitful application in the West, was not used in the Islamic world too, is a question that will be addressed in the fifth section.

Some indications of the cost of constructing windmills in the Latin West have been presented in the previous section on water-mills: a vertical windmill required approximately half as much capital as a vertical water-mill. We have not been able to find any indication of the historical cost of a medieval horizontal windmill in the East. However, by taking into account that this device lacks a gearing system, and by comparing average differences in cost between vertical and

horizontal water-mills, we can safely conclude that horizontal windmills would have been considerably cheaper to construct than vertical mills.

The summarizing conclusion is that vertical windmills were not used in Muslim lands, while the simpler and cheaper horizontal windmills were restricted to the eastern and western peripheries.

4. BUILDING CRANES

Building cranes were used already by the Romans. Classical monuments contain representations of contemporary building cranes, which Vitruvius described in his books on architecture. An illustration of a classical building crane with a tread mill can be found in a Roman manuscript from around AD 400, the *Vergilius Vaticanus*, (Rome, Vatican library, Vat lat. 3225, f 13). It depicts a crane constructing the North-African city Carthage. One of the classical works describing cranes and their working principles is *Mechanics* by Heron of Alexandria. This work survives only because of Arabic translations from the ninth century (Schliefsky, p. 2007). A thirteenth-century Arabic copy (Leiden, University Library, or 51, p. 61) shows a picture of three beams, a tackle and a pulley. [10] Together these elements are essential for a building crane. The above examples show that the basic principles of building cranes are ancient, and were known in the Arabic world.

In the Islamic East as well as in the Latin West large and tall structures, whether palaces, defensive walls, churches and mosques, or bell towers and minarets were built in the Middle Ages. Such high rise structures were built with similar materials and techniques in East and West, and would more or less equally have benefitted from cranes to save labor in lifting heavy

[10] We thank Jan Just Witkam for bringing this manuscript to our attention.

materials. In order to survey to what extent building cranes were used, we searched not only literary sources but also pictorial sources. Though images in medieval manuscripts certainly give no absolute numbers of the prevalence of the local use of cranes, finding actual medieval representations confirms their use, while a complete absence of such pictures suggests that they were hardly used or not at all.

We used manuscripts that picture construction work on structures that were higher than a man could reach (which we have called 'high-rise'), on which builders were often depicted using some kind of scaffolding or ladders.[11] We counted a mechanical device rendered 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.[12] We took our samples of western manuscripts from medieval representations of building activities by Binding (1987, 1992), while those of Islamic manuscripts have been taken from collections amassed for a global database (Buringh, 2011). Representations of building activities are unfortunately not very common, even less so in eastern manuscripts than in western.[13] Medieval books portrayed

[11] This means that work on for example the construction of a grave (see for example: New York, Metropolitan Museum of Art, 63.210.35) or on a stone road (for example: Brussels, Koninklijke Bibliotheek, ms 9242, f 48v) was not considered to be a 'high-rise' structure, and these illustrations were omitted from Table 1. However, we classified work on the protective wall built as a safeguard against the mythical and Biblical figures Gog and Magog, which according to popular stories was constructed at the command of Alexander the Great, to be a 'high-rise' structure by its very nature.

[12] This means that a person hauling building material with the aid of only a rope is not considered to be operating a crane (see e.g. London, British Library, or 6810, f 154v for the East; similar hauling of building material with only a rope in the West has also not been counted as operating a building crane).

[13] The absence of such representations has sometimes been ascribed to an Islamic prohibition on the portrayal of living beings. However, only part of the *hadith* – sayings validly or invalidly ascribed to the Prophet – is more

religious and epic battle scenes much more often than mundane themes such as workers constructing a building. In the East the construction of the wall against Gog and Magog was depicted a number of times, in the West the construction of the tower of Babel was a popular subject. Per century we counted the numbers of times that building cranes were pictured in any illumination of 'high-rise' construction activities in East or West, leading to a relative prevalence of cranes. As a proxy for the date we used that of the manuscript in question.

TABLE 1

THE PERCENTAGE OF SCENES WITH BUILDING CRANES (IN BOLD FACE) AND THE ABSOLUTE NUMBERS OF 'HIGH-RISE' CONSTRUCTION ACTIVITIES IN THE ISLAMIC EAST AND LATIN WEST, DEPICTED IN A LARGE SAMPLE OF NINTH- TO SEVENTEENTH-CENTURY MANUSCRIPTS

Century	9th	10th	11th	12th	13th	14th	15th	16th	17th	Overall
West										
Building scenes	1	-	6	8	18	75	125.5	1.5	-	235
Percentage cranes	**0**	**-**	**17**	**50**	**28**	**57**	**67**	**100**	**-**	**60**
St dev.	-	-	± 15	± 18	± 11	± 6	± 4	-	-	± 3

explicit in its prohibition of illustrating people or animals, though it is not formally prohibited in the Koran itself. These sayings have never led to a complete absence of the depiction of human beings in Islamic manuscripts, however. The Byzantine Empire has known periods of iconoclasm in which figurative illuminations largely faded away from manuscripts, and in the West there have been certain religious sects that did not use figurative illumination either.

East										
Building scenes	-	-	-	-	-	1	6	2.5	1.5	11
Percentage cranes	**-**	**-**	**-**	**-**	**-**	**0**	**0**	**0**	**0**	**0**
St dev.	-	-	-	-	-	-	-	-	-	-

note: The half numbers for a century concern scenes in manuscripts that are dated to two adjacent centuries.
sources: see online appendix: <http://www.cgeh.nl/early-economies-hub-data>

Western manuscripts became less common after the introduction of printing presses half-way through the fifteenth century.[14] In the Islamic world printing arrived later and manuscripts continued to be written by hand for several centuries, which is why Table 1 continues into the seventeenth century for the Islamic East. It shows that in the East scenes with building activities are scarce. We found in total only eleven scenes containing 'high-rise' building activities, while considerably more than 10,000 Islamic illuminations have been scanned. However, not one of the scenes with 'high-rise' building activities in the East depicted building cranes at work. If—as a thought experiment—we assume that in the fifteenth century the percentage of building crane use in the East would have been similar to that in the Latin West (the overall fraction of 60% in Table 1), we would have had only a 0.4% chance of finding a result of zero cranes within a sample size of six. Table 1 thus shows that the use of building cranes differs significantly between East and West. In the East cranes were conspicuous by their absence.

[14] The sharp cut-off of the sample in the West is also influenced by the fact that Binding stopped collecting manuscripts dating from circa 1500.

This conclusion has been corroborated by a similar computer search similar to that carried out on the prevalence of water-mills in medieval Arabic geographical texts. Electronically available works of the same geographers have been searched for descriptions of cranes in their original Arabic texts.[15] None of these texts mention any description of a crane, while the texts describe economically important geographical features in the Islamic world as a whole (see results in online appendix). In the literature it is at times suggested that a crane is mentioned in Arabic text (Lewcock, 1984: pp. 140-41), but on closer inspection this reference, in the late-fourteenth century work by Ibn Khaldun, concerns a *mikhal* (or pulley). In combination with the fact that the work of Heron, who does mention a crane, was translated into Arabic, this is taken as an indication that cranes were actually still used in the time of Ibn Khaldun, but no proof is offered. In our opinion this negative result from written sources confirms the absence of cranes in manuscripts.

Adequate samples prior to the eleventh century are missing in Table 1. Nevertheless we assume that cranes were known throughout the whole period. For instance, the ninth-century Byzantine Khludov Psalter (Moscow, Histor. Mus. Ms 129 Д, f 96) depicts a construction scene with a building crane. Byzantine workers were hired to help with the construction of the eighth-century Umayyad mosque (Damascus) and the 'Dome of the Rock' (Jerusalem). Such workers might have provided a channel through which knowledge of building cranes could have flowed into Muslim lands. Also, inhabitants of Muslim lands were aware of the principles of building cranes. Basically, it was a well-known technology and the three different parts that together form a crane, the hoist, the pulley and the rope, were each used in the Islamic East too, for instance on

[15] See the online appendix for the design and search terms of the literature search by Josephine van den Bent.

board ships and in siege engines. Still, the silence of the sources suggests that before the fourteenth century building cranes were not used in the East.

A theoretical explanation for the absence of representations of building cranes in Islamic manuscripts might be that Muslim artists did not depict cranes despite the fact that such machines were regularly used in daily life. However, we think this explanation is unlikely. For instance, local water-mills were rendered on paper in Muslim manuscripts. One can find a water-mill in a thirteenth-century Maghribi manuscript from Spain or Morocco (Rome, Vatican library, Vat ar. 368, f 19), and a seventeenth-century Mughal miniature also portrays a water-mill (London, British Museum, 1920-9-17-0297).[16] There were even miniatures in Muslim manuscripts in which the combination of the three units together forming a crane, a hoist, pulley and a rope, were used in one device — however, not to haul building materials but to fetch water from a well in a bathhouse (Dublin, Chester Beatty Library, ms 195). Siege engines that were wonders of mechanical construction such as trebuchets, also containing the same basic three units that define a crane, were regularly depicted in Islamic battle scenes. Although mechanical devises are not commonly depicted in books there are a number of specific Arabic manuscripts solely dedicated to the propagation of ingenious devises (Hill, 1974, 1979). A mechanical grab to extract jewels from the sea, or things that had fallen into a well or recover objects that had become submerged in a river—and essentially very similar to those used currently in cranes to grab sludge or sand—was already illustrated and described around the ninth century in *The book of ingenious devices* by the sons of Musa bin Shakir (Hill, 1979, 243). These examples indicate

[16] Remarkably, this independent visual evidence of contemporary depictions of water-mills in Islamic manuscripts points to their more widespread use in the western and eastern periphery of the Islamic world than in the core areas. We believe this anecdotic evidence supports our conclusion from Section 2.

that Islamic artists did not shy away from depicting complicated mechanical devices that they saw in everyday life. Therefore we think a more plausible reason for the absence of representations of building cranes in Muslim manuscripts is that they actually were not generally used. Studies on Islamic science and technology, extensively covering the construction industry, are also conspicuously silent on the use of building cranes in Muslim lands, for example Nasr (1976), Hassan and Hill (1986) and Hill (1993).

The cost of medieval cranes could be considerable. Harbor cranes were introduced in the West in the thirteenth century, and when powered by a treadmill could load or unload heavy cargo. A famous example is a harbor crane in Bruges (Munich, Bayrische Staatsbibliothek, clm 23638, f 11v). This capital good was so costly that it was often financed by urban governments (Van Bavel, 2010, p. 227). Building cranes used for constructing cathedrals and equipped with a treadmill would also have been expensive, and probably cost a few times the price of a medieval water-mill. A much cheaper device consisting solely of a hoist, a pulley and a rope could of course be constructed by building workers on site. Because building cranes were absent in the Muslim lands we have no indication of what their local cost would have been.

Summarizing this section we can say that despite preserving and passing on the classical Greek knowledge of Heron on the principles of cranes, these devices were not used generally in the Islamic world. Nevertheless the peoples of the region knew and separately used each of the three parts that together define a building crane.

5. POSSIBLE CAUSES OF DEPLOYMENT OF CAPITAL GOODS IN MUSLIM LANDS

Why did water-mills disappear from the core areas of the Islamic world? Why did vertical windmills find no application? And why are building cranes missing from medieval Muslim lands? Their geographical distribution and the timing of their deployment and disappearance provide clues as to the underlying causes of their prevalence.

Some scholars have ascribed the long decline of medieval Muslim economies—one of the great puzzles in economic history—to religion and mentality. Ashtor (1992, p. 412), eminent economic historian of the Near East, asked: "Should we believe, then, that the technological decline of the old oriental civilizations was the consequence of their religious fatalism?"[17] This question was answered by Landes (1998, 394-395), attributing Islamic decline to despotism and exploitation of the masses by a wealthy and powerful elite. However, the question is whether such generic and time-invariant explanations can adequately describe the causes of the observed time-specific and geographical differences in the use of various medieval capital goods within the Islamic world.

The timing of water-mill deployment shows that the use of these mills was general in the Near East in the first centuries after the Islamic conquest and only later began to disappear selectively from these core areas, while in the periphery water-mills continued to be used. Such differences in timing and location within Muslim lands suggest that there was no single generic and time-invariant cause for this phenomenon and therefore we think culture, religion or laws are less likely as explanations. For the same reasons other generic and time-invariant alternative explanations such as lack of knowledge, climate change, geography or hydrology may be ruled

[17] Our translation (*« Devons-nous donc croire que le recul technologique des vieilles civilisations orientales était la conséquence de leur fatalisme réligieux?»).*

out too. A much more advanced thesis is propagated by Kuran (2011), who shows that specific aspects of Islamic law, such as *waqfs*, inheritance laws and absence of legal corporations were well suited to the demands of the early Middle Ages, but failed to adapt to the changing conditions of the late medieval and early modern era. But while this line of reasoning may well contribute to an explanation for changes in the use of capital goods over time, it cannot account for the significant geographical variations within the Islamic world which we have found. We should investigate additional causes: factors that differentiate between the core areas of the Islamic world (the Near East) and the periphery. This leaves a number of interesting avenues to explore: whether in the Near East wages were so low that it was not economical to employ labor saving capital goods; or whether the cost of capital was so high here that capital goods were not an option; finally local institutions might have hampered the use of capital goods in the Near East.

Cost of labor

Local wage levels might provide an explanation for the deployment of capital goods. If wages of unskilled workers were lower in the East than in the West, investment in labor-saving building cranes might not have been economical. Likewise, declining wage levels in the core regions of the Islamic world between the tenth and fifteenth centuries might explain why water-mills, present in the early period, disappeared afterwards.

There is evidence for only the second of these two hypotheses: wages in the core regions indeed appear to have fallen, although opinions diverge on the pace of the decline. In the moderate interpretation of Pamuk and Shatzmiller (2014), real wages for unskilled labor in Iraq (Baghdad)

and Egypt (Cairo), expressed as the number of 'bare-bones baskets' that unskilled laborers were able to purchase, declined after the eighth/ninth century. Although levels remained well above subsistence, wages for unskilled labor were much lower in the tenth to thirteenth century than they had been in the early Islamic period. Pamuk and Shatzmiller attribute the decline to the recovery of population numbers after the Justinian plague of the sixth to eighth centuries. The rise of extractive institutions in Iraq and the resulting growth of inequality provide an alternative explanation for declining wage levels in this Islamic core region (Ben Abdallah, 1986; Van Bavel *et al.,* 2014). Specifically for Egypt in the late Mamluk era, Stuart Borsch arrives at much less favorable figures.[18] For the early fourteenth century he calculates wheat wages that are on a par with (or even somewhat higher than) the figures a similar computation based on the data used by Pamuk and Shatzmiller would render: 3142 liters of wheat per year versus 2734 liters. However, Borsch concludes that a very sharp drop took place afterwards: he argues that in the late fifteenth century the purchasing power of the wages of Egyptian laborers was, at 627 liters of wheat per year, only about 20% of what it had been in the early fourteenth century (Borsch 2005, pp. 108-10).

There is reason to believe that in the Islamic periphery—or at least in al-Andalus and the Maghrib—no similar decline occurred. The scarce wage and price data for Umayyad Spain is insufficient for a reliable calculation of subsistence baskets, but enough to suggest that in tenth/eleventh-century al-Andalus standards of living were above those in the East. Nominal

[18] 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. After the Black Death wheat became more expensive in Egypt, and the local population largely replaced it as a staple by sorghum or millet. This, however, still leaves a considerable gap that for the moment remains unexplained.

wages appear to have been about 30% higher than in Egypt, while wheat prices were at a similar level; wage differences with Iraq must have been even greater.[19] The high standards of living in the western periphery are in keeping with the general impression of economic prosperity given by medieval Muslim geographers. Although even less quantitative data is available for the era after the collapse of the Umayyads, qualitative information suggests that later successor states in al-Andalus were able to maintain previous economic levels, up to the *taifa* princedoms (Lévi-Provençal, 1931, p. 306; Glick, 1979, pp. 125-26). Morocco actually experienced a period of efflorescence under its Marīnid rulers in the fourteenth/fifteenth centuries. The fact that this region attracted large numbers of mercenaries from neighbouring regions suggests that their remuneration was competitive (Shatzmiller, 2014, pp. 30-31). In short, although no hard data on wage levels in the western periphery is available, wages appear to have been higher than in Islamic core areas. This is in line with the use of capital goods—particularly water-mills—in the periphery.

However, another result of Pamuk and Shatzmiller's investigation of real wages in the Near East poses greater problems in this respect: the comparison of unskilled wages in the Islamic East and the Latin West. Early comparisons are impossible (because of the absence of European data), but from the fourteenth century onwards Egyptian real wages can be compared with those in Europe.

[19] Based on the lowest wage of 1.5 dirham per day for labourers involved in the construction of the new capital under Abd al-Rahmān III in the middle of the tenth century and—following Pamuk and Shatzmiller—of 25 working days per month plus one fifth extra for additional payments in kind; and on a 'normal' grain price of 0.0152 dinar per kg in the early eleventh century (Ashtor, 1965, 665, 675-676; Pamuk and Shatzmiller, 2014, 201).

TABLE 2

REAL DAILY WAGES FOR UNSKILLED LABOR EXPRESSED AS THE NUMBER OF SUBSISTENCE BASKETS

Unskilled wages in subsistence baskets			
	Egypt (Cairo)	Italy (Florence)	England (London)
1250-1300	1.46		
1301-1350	1.75	0.60	0.77
1351-1400	2.09	1.18	1.03
1401-1450	1.56	1.44	1.47
1451-1500	1.74	1.25	1.53

Sources: Egypt: Pamuk and Shatzmiller (2014 p. 202). Italy and England: Allen, 'Labourers', retrieved from http://www.nuffield.ox.ac.uk/People/sites/Allen/SitePages/Biography.aspx

Table 2 suggests that in Italy and England before the fifteenth century unskilled labor was considerably cheaper than in Egypt. Only after 1400 was the gap closed. Again, the figures for Egypt may be too optimistic. If the wheat wages calculated by Borsch are taken as the point of departure, before the Black Death the purchasing power of unskilled labourers in England was no less than in Egypt.

Conflicting figures make it difficult to draw firm conclusions, but it seems safe to say that before the fifteenth century wage levels in the East were certainly not lower than in the West, and

possibly even considerably higher. Nevertheless, already in the eleventh to fourteenth centuries the number of European water-mills increased remarkably and mill densities became much higher there than in the East. Building cranes, moreover, were not observed at all in Muslim lands. Wage differentials cannot explain these phenomena; if anything, they should have given rise to a greater reliance on such capital goods in the Near East than in Europe. The conclusion is that we should look for additional explanatory factors, as wage levels and costs of labor are certainly not the conclusive explanation of patterns of deployment of capital goods in Muslim lands.

Cost of capital

Another reason for a lower application of capital goods could be that the cost of capital was so high that it scared Muslim investors away from investing in them. It is hard to assess the cost of capital in Muslim lands. Financial markets did exist, however. The ninth and tenth centuries were a period of booming financial markets and new financial instruments, most notably in Iraq, with Basra as one of the main centers (van Bavel *et al.*, 2014). Money changers and merchant-bankers (*jahbadh*) were changing coins, verifying the value of coins, collecting payments, and offering banking facilities, including to the government and its officials. These exchanger-bankers are first mentioned in the second half of the eighth century, but they proliferated in the tenth century (Fischel, 1933; Sabari, 1981, p. 29-30). Information on interest rates is scarce. A couple of large tenth-century loans to viziers bore interest rates between 8 and 20%. Local loan sharks could make big profits by extending loans to ruined former members of the elite, with interest rates of up to 1,000 % (Ray, 1997, pp. 68-71). For the eleventh, twelfth and thirteenth centuries, some Egyptian interest rates for commercial loans are available.

Although a gradual increase appears to have taken place, these rates were mostly modest, ranging between 10 and 17% per year (Ashtor, 1978, pp. 198-200).[20]

Table 3 shows that before the Black Death the range of average interest rates in the West was similar to those in Muslim lands. They mostly hovered around 10 to 11%, or even higher in economically less developed areas. This suggests that the cost of capital was not a decisive factor in the absence of building cranes before the Black Death in the East. If, before the fourteenth century, someone would have wanted to make an investment in one of such capital goods, it probably would have been as economical in the East as in the West, or even more so when in the East wages of unskilled workers were indeed higher.

TABLE 3

AVERAGE INTEREST RATES IN PERCENT PER YEAR IN EAST AND WEST

Period	England	France	Flanders	Italy	Netherlands	Egypt/Syria	Ottoman Empire
1151-1200	9.5				20	10-13	
1201-1250	8.8	10.8		8.6	11.2	10-17	
1251-1300	10.3	11.1	10.0	10.6	10		
1301- BD	10.7			12.9	11.2		
BD -1400	7.0			8.1	9.2		
1401-1450	5.6			9.6	7.9	18-24	
1451-1500	4.5	9.2	6.4	7.6	5.5	18-24	
1501-1550	5.1	8.2		4-10	6.1		10-20

[20] Asthor (1978) also mentions an interest rate of 4% for this period, but we doubt whether this is a reliable figure and, if so, it is certainly an outlier and representative of then prevailing rates.

1551-1600	5.9	8.3	4.3	4-10	6.3	10-20
1601-1650	5.7	6.6	3.9		5.3-8.3	
1651-1700	5.4		4.4		2.4-3.9	
1701-1750	4.3	4.2	3.8			

Note: BD = Black Death
Sources: Egypt/Syria: Goitein (1987, pp. 254-56, p. 384) and Ashtor (1978, pp. 198-204), Ottoman Empire: Kuran (2011, p. 148), England-Italy: Clark, (1988), Epstein (2002, p. 62), 16th c. Italy: Homer (1963, p. 138) and The Netherlands: Zuijderduijn, (2009, appendix), Gelderblom and Jonker (2011, p. 7)).

After the plague, interest rates in the Latin West declined considerably. Information on interest rates in the East is sparse. However, the few figures in Table 3 suggest a very different development. The fact that the later Mamluk state, especially from the early fifteenth century on, was beset with growing extortion of wealth by semi-public "protectors" and confiscation of wealth (Meloy, 2004) likely played a role in this. 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. The resulting high interest rates in the East are diametrically opposed to the patterns seen in the West. However, once again the divergence does not give an adequate explanation for the patterns and timing of the use of capital goods in Muslim lands, since their non-use, or decline, had already occurred in a period of relatively low interest rates.

Institutions in the Near East

In order to explore whether local variations in spread and timing of institutions within Muslim lands can provide indications for the prevalence of capital goods in the Near East, we will take a

closer look at what we regard as two essential institutions: systems of surplus extraction and property rights.

Systems of surplus extraction

After the seventh-century conquest by the Arabs, most inhabitants of the Near East and North Africa were still Christians. This changed only gradually in the next couple of centuries. The Umayyads, the first Muslim dynasty, ruling an empire stretching from al-Andalus in the west to Sindh in the east, basically continued the pre-existing systems of taxation. In addition, they imposed a special land tax on non-Muslims: the *kharadj*, varying from 25 to 40% of agrarian output. The Umayyads paid their Arab warriors in garrison cities with the taxes collected. A prosperous and market-based urban society emerged (Kennedy, 2002). A common Islamic law and the Arab language of the elite facilitated long-distance commerce. The Umayyads introduced new crops and irrigation systems in some of the conquered territories, enlarging agrarian output. In pre-industrial societies a greater agrarian surplus was the way to obtain economic growth, leading to what has been described as an Arab 'golden age'.

At first the system of taxation of the Abbasids (eighth/tenth century) did not differ markedly from that of the Umayyads. However, a first change was the introduction of tax-farming in the late-ninth century. Tax-farmers were made responsible for the investments in large-scale irrigation works and other infrastructure, but were mainly interested in short-term gains, again to the detriment of investments. Moreover, tax-farming was often combined with coercion and violence in the levying of taxes, sometimes linked to coercive dealings in land and credit markets. Illustrative is the story from the tenth century of an honourable man who was tortured

by the tax-collectors, who forced him to sell them a piece of land and lent him the remaining money at an interest rate of 1,000 % (Mez, 1922, pp. 126-27). However, Katbi (2010, p. 253) indicates that in the Abbasid period more land grants were given out in *ikta,* a specific system of land tenure limited to the right to the revenue of the land. From the middle of the tenth century onward, under the Buwayhid and Seljuqid regimes, *iktas* were also given out to military commanders and soldiers, as payment for their services instead of a salary in cash (Sato, 1997, pp. 18-24). This military *ikta* system now became the dominant system of land holding in Iraq.

One major cause of a gradually lower surplus production in the core region of the Islamic world is that the *iktas* generally were not hereditary (in marked contrast to the medieval feudal estates in the Latin West). As indicated, the *iktas* were used to finance the pay for the officers of mercenary troops. The Muslim authorities felt that regular changes of tenure every few years were necessary to prevent their holders from becoming too securely established in a region and to stop them from creating their own regional power base, possibly threatening the ruler's position. In the medieval Near East *ikta* was seen as a right to an income. The rapid turnover of tenures meant that over-taxation would benefit the current feudal lord, while the longer-term consequences of this too heavy tax burden or the fruits of any investments in maintenance and repair would be passed on to his unknown and unrelated successors. The twelfth-century Crusader states, which can be considered a natural social experiment in the Near East —locally implanting quite different hereditary feudal institutions—show how eighty years of hereditary feudalism under lords from the Latin West had made the local Muslim peasants much more prosperous than their brothers in faith, living at a few miles distance in the same climate and environment, under Muslim lords who were exploiting *iktas* that changed hands rapidly (see Ibn Jubayr's contemporary report: Ibn Jubayr, 1952).

In its turn, the resulting decline of agricultural output in the Near East led to an erosion of the tax-base and to declining fiscal revenues, as can be observed in Iraq in the ninth and tenth centuries (Campopiano, 2012). Rulers responded to this by trying to tax other resources, including trade and capital goods, that up to then were taxed only mildly. Especially in the tenth century, these taxes were introduced or increased, and they explicitly also targeted mills and flour (Cahen, 1952, paragraph 25 and 67; Kabir, 1964, pp. 153-55). These taxes must have reduced the attractiveness of investing in capital goods like mills.

The military *ikta* system was not dictated by Islam, but was the result of specific policies pursued by the powers that be. Notably, the Fatimid regime that ruled Egypt from the late tenth to the late twelfth century did not grant land in *ikta* 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 them lands in *ikta.* The *ikta* system subsequently became a dominant factor in Egyptian society (Sato, 1997, pp. 42-45). The thirteenth- to fifteenth-century Marīnids, on the other hand, actually reclaimed *iktas* that had been granted by their predecessors (Shatzmiller, 2014, p. 34).

In the Muslim core areas the situation under the Mamluks (thirteenth/sixteenth century), with arbitrary tax regimes, was rather similar to that during the Abbasid caliphate. Borsch has shown that agrarian production in Egypt during the Mamluk Empire diminished considerably. He analysed its agrarian output, and found a decrease in agrarian GDP between 1315 and 1517 of 55%.[21] Because of the feudal system in the Mamluk Empire that was based on the *ikta,* there was no incentive for the powerful Mamluk landlords to invest in the upkeep of dykes and irrigation systems essential in Egypt to make adequate use of the water and silt from the yearly Nile floods. After the demographic shock of the Black Death these vital water distribution systems largely

[21] Borsch (2005, 88) indicates that in England GDP between 1300 and 1526 also declined, but only by about 17%.

and gradually fell into a state of disrepair, with devastating consequences for the average agrarian output in Egypt (Borsch, 2005, p. 87). It was only after the Ottoman conquest that the situation improved. Ottoman taxation was less oppressive in Syria and Egypt than the preceding situation of insecurity, extortion and confiscation under the rulers of the later Mamluk period, as can also be deduced from the fact that in both places the first century of Ottoman rule brought relative stability and prosperity with a massive commercial expansion (Kuran, 2011, p. 272).

Property rights

Although in principle property rights were well-defined, secure and protected by law in medieval Muslim lands, a deterioration seems to have occurred in the Abbasid and later periods. This deterioration was found especially in the core Islamic areas. Parts of the periphery actually saw an improvement of legal security. In Morocco, for instance, state formation and the building-up of legal institutions had started later and accelerated in the thirteenth century, with the law being made more uniform, the legal personnel better trained and the courts working more efficiently and their decisions acquiring more weight (Shatzmiller, 2014, pp. 11-13). In the core areas of Islam, however, the situation was different. Here, arbitrary confiscations of private property (the imposition of 'contributions' from rich bourgeois, senior officials or merchants) became a striking feature of social life (Ashtor, 1976, p. 114). By squeezing the rich, the Abbasid government tried to obtain the money necessary to pay off the uncomfortably powerful army of permanent mercenaries of non-Arabic tribes. Total tax revenue in 918 had been some 14.5 million dinars, while in 924 the imposition of arbitrary fines—*al musadara*—produced seven million dinars (Ashtor, 1976, p. 141). This shows that such arbitrary appropriations from the rich then formed a considerable fraction of total tax revenue, indicating that in spite of their great

wealth and power even senior dignitaries never lived in security. This practice did exist in the eighth and ninth centuries, but only as a punishment for misbehaviour or fraud. However, in the course of the tenth century it became common, caused by the state's growing lack of cash, declining tax revenues and the increase of private wealth of the period (Kabir, 1964, pp. 158-60; Mez, 1922, pp. 108-11). The victims were bankers, officials, notaries and merchants, and especially those who lacked or had lost the protection of the ruling elite.

In tenth-century Iraq various passages in the writings of Arabic authors show that local peasants, because of the heavy taxes, only cultivated the area necessary for the upkeep of their family (Ashtor, 1976, p. 156). In the countryside, access to land became more dependent on political favor and relationships than on clear property rights. As a result, landowners were focused on short-term gains and not geared to long-run investments (Campopiano, 2012). Gradually, between the end of the eighth century and the end of the thirteenth, revenues of taxes and agricultural surplus production declined considerably; tax revenues declined as much as fourfold.

Investments in capital goods must also have suffered. Ashtor (1992, p. 266) indicates that rich Egyptian merchants in the later Middle Ages no longer invested their capital in textile factories that could easily be confiscated. Also, 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 (Meloy, 2004, pp. 205-06). These examples suggest that the insecurity of property rights resulting from this could have downright negative economic consequences through under-investment.

To shield wealth from confiscation and arbitrary levies, wealthy families increasingly used the waqf. Waqfs first appeared in the mid-eighth century but gained importance in the late ninth

century. They were trusts established by an individual in order to supply a function considered legitimate under Islamic law: usually a social service that required substantial investments, such as a mosque, school, fountain, bath-house or karavanserai. 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. The 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 of the waqf.

In the Ottoman era mills were frequently included in the asset-bearing revenues of a waqf, but examples from earlier periods also exist (for example Van Leeuwen, 1999, p. 81, pp. 144-45, p. 156, p. 164). However, while this meant that investors were able to profit from the protective function of the waqf, there was also a downside. Kuran has argued that the waqf was never intended as a profit-maximizing entity. As a consequence of the designated purpose of the waqf the revenues from its assets could not be spent freely. Also, swapping one asset for another required the permission of a judge (Kuran, 2011, p. 128) and corruption among caretakers was rife (Kuran, 2001, pp. 883-87). Therefore, the waqf could not provide a full alternative for security of property rights. Although it helped to lower barriers against investment, it could not fully remove them.

6. CONCLUSIONS: EXPLANATIONS FOR PATTERNS OF USES AND NON USES OF CAPITAL GOODS

Generic and time-invariant causes cannot explain the patterns of application of capital goods that we found within Muslim lands. This leaves us with explanations that take differences between regions and change over time into account. Although wage levels in the Islamic East decreased after the eighth/ninth century, and did so to a greater extent in the core areas than in the western periphery, wage levels are not a convincing explanation. Before the Black Death wage levels were certainly not lower in the Near East than in the Latin West. Economically then, wage levels should have fostered local use of labor-saving capital goods in the East as well as in the West. Likewise, before the Black Death the cost of capital was no higher in the East than in the West, which also should have helped investment in capital goods. This is not observed, which also rules out the cost of capital as the main causal factor.

The explanation that best matches patterns of use and non-use of capital goods in the Islamic world is institutional. The gradual disappearance after the tenth century of water-mills from Islamic core areas coincides with heavy local surplus extraction and non-hereditary feudal systems, curbing investment in capital goods. Both timing and geographical distribution are right. The western periphery, where the feudal system was not based on *ikta* rapidly changing hands, witnessed a period of prosperity under the Marīnids, and a level of deployment of capital goods (water-mills in Fez) which was similar to that in the Latin West. Deficient property rights in Muslim core areas did not stimulate investments in immovable capital goods. Because of their long-term fiefs landlords in the Latin West often built water-mills on their estates, thereby forcing their peasants to grind grain at the mill, producing extra income for themselves. Van der Beek (2010) has shown how regional political fragmentation and competition influenced

landlords in France in their investment decisions concerning water-mills. However, in the East, with its non-hereditary tenure system (*ikta*) with high turn-over rates, erecting a water-mill was not profitable for a landlord.

The fact that the more expensive vertical windmills were not used in Muslim lands while the simpler and cheaper horizontal mills were employed in the periphery during the whole of the period under study, probably has to do with both deficient property rights and the changing cost of capital. Vertical windmills were only slowly introduced in the Latin West from the thirteenth century onward. After the plague, capital became considerably more expensive in the East than in the West, which prevented investment in more expensive capital goods. When people from the East wanted to invest in an immovable labor-saving device for milling, they often opted for the cheaper animal mill or the horizontal windmill.

It is somewhat puzzling to find that building cranes were not used in the East, as they would have saved considerably on the costs of the relatively expensive construction workers. A convincing economic explanation for the absence of cranes is problematic, but we hypothesize it may have been related to the very large capital cost of a building crane with a treadmill: the investment was probably several times higher than the sum required for a water-mill. Such high capital demands may have discouraged Muslim investors from a risky gamble in a polity where property rights were not secure.

Deficient property rights, a climate of uncertainty, arbitrary taxation and high capital cost—all of which were common in the core areas of the Islamic world after the fourteenth century—form the main reasons for less local investment in capital goods in the late medieval period. While we do not want to suggest that this provides a full explanation for the failure to keep up with

European competition, it must have made it more difficult to enhance labor productivity to the levels that in the transition to the early modern era were to become customary in the West.

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Design and search terms of literature search by Josephine van den Bent

Results of literature search by Josephine van den Bent

Mentions of 'high rise' building activities in western and eastern medieval manuscripts