The Collapse of the World's Oldest Civilization: The Political Economy of Hydraulic States and the Financial Crisis of the Abbasid Caliphate

By

Robert C. Allen

Global Distinguish Professor of Economic History
Faculty of Social Science
New York University Abu Dhabi
bob.allen@nyu.edu

Leander Heldring

Post-doctoral Fellow
Department of Economics
Harvard University
lheldring@iq.harvard.edu

2016

We thank Mattia Bertazzini for outstanding research assistance and the Research Endowment Fund of New York University Abu Dhabi for financial support.

The title of the paper is not too dramatic. Mesopotamia was the birthplace of civilization. Uruk was the world's first city, and it was founded around 3500 BC. One great civilization followed another for the next four thousand years. Cities depended on a productive agriculture, and agriculture required irrigation. The irrigation system reached its peak under the Persian Sassanian empire, which lasted from 224 AD to 621 AD, when the Persians were defeated by the Arabs. The victorious invaders continued the tax and administration policies of the Sassanians and enjoyed remarkable success for two and a half centuries. Baghdad was founded and became the centre of the Golden Age of Islam in the 8th and 9th centuries. But then something went wrong. By the middle of the 10th century the irrigation system had collapsed and southern Iraq was largely depopulated. It remains like that today (Map 1). What happened?

There's no shortage of explanations, and they can be grouped under the trilogy of geography, culture, and institutions.[1]

Geography played a central role. Southern Iraq is a desert crossed by the Tigris and Euphrates rivers. When irrigated by their waters, the plain is immensely fertile. This raises two issues that are central to this paper. First, the irrigation system had to be constructed and maintained. Small scale irrigation could be organized by local groups (Mabry 1996). As perfected by the Sassanians, however, the system featured five giant transverse canals running from the Euphrates to the Tigris, a sixth running from the Euphrates into the Great Swamp, plus the Nahrawan canal which ran parallel to the Tigris on its eastern side. These canals allowed the full water flow of the two rivers to be applied to land. The system was so large that it required the state to build it and maintain it. A successful response to the geographical challenge required effective political institutions. Was there a political collapse that brought down the system? Second, the waters of the Tigris and Euphrates, while fresh, still contained small quantities of mineral salts. Modern irrigation systems have drains as well as water supply channels to remove salts from the land, but ancient Mesopotamia had no drainage system. Instead, the water supplied by fields evaporated unless it was taken up by the plants (Potts 1997, pp. 12-3). Over time the salt content of the soil increased. Farmers responded by planting barley, the more saline resistant crop, instead of wheat, but agriculture suffered none the less. Even today, after the introduction of drainage, the "Shura soils [of southern Iraq] are often [covered] with a white crust" of salt. (Quereshi and al-Falahi 2015, p. 87). The question is whether this issue came to a head in the 9th century forcing the abandonment of cultivation and settlement. The roles of irrigation maintenance and salt build up will be tested in this paper.

The cultural approach maintains that features of Islam militated against modern economic growth. Whatever truth there might be in this view, it cannot explain what happened in Iraq in the 9th century. First, this is a very long run theory, and its main concern is with the decline of the 'scientific spirit' in medieval Islam and the failure of the Islamic Golden Age to lead into the Scientific Revolution. Second, the philosopher al-Ghazali is the usual bête noire in cultural explanations, and he was born more than a century after the events discussed in this paper. Third, while the enthusiasm for philosophy among the Caliphs had its ups and downs, it was in the ascendancy at the end of the period we are

---

[1]Scholars have proposed explanations besides those considered here. Christensen (1993, pp. 81-3, 100-4) suggests the Justinian Plague (541-2AD) and subsequent outbreaks through 749 played an important role by reducing the population and labour force needed to maintain the canals. Our view of the population of Iraq is much more endogenous. Van Bavel (2016, pp. 40-94) emphasizes many of the same factors modelled in this paper but sees the decline as happening somewhat later.

concerned with. The Golden Age is said to have begun with the Caliph al-Mansur (754-75), who initiated the translation movement, and was pressed forward by Harun al-Rashid (786-809), who patronized philosophers and founded the House of Wisdom in Baghdad. This support was continued by al-Ma'mun (813-833) and al-Mu'tasim (833-842). Enlightenment lost out to religious conservatism under the reign of al-Mutawakkil (847-61), and all official support for any cultural activities disappeared in the years of anarchy (861-70) when one caliph after another was murdered, and the state barely functioned. However, stable government resumed with al-Mu'tamid (870-92). Caliph Mu'tadid (892-902) began again to support scholarship and science but at a reduced level reflecting his strained circumstances (Kennedy 2005, pp. 245-6). Unfortunately, he was the last effective caliph. Under al-Muqtadir (908-929) the caliphate was effectively bankrupt. The Golden Age ended in Baghdad not because it was overwhelmed by Islamic obscurantism, but because the Caliphs and their associates ran out of the money to pay for it. We explain why in this paper.

While the collapse of civilisation in southern Iraq is incomprehensible without attention to geographical realities, the immediate causes were failures on the institutional plane. Adam Smith (1776, Book V, Chapter 1) listed the essential functions of the state–protecting the society from foreign aggressors, maintaining internal order and a system of justice to protect the weak from the strong, and "erecting and maintaining those public...works, which though they may be in the highest degree advantageous to a great society, are, however, of such a nature, that the profit could never repay the expense to any individual, or small number of individuals" In the case of southern Iraq, the irrigation system was the pre-eminent example of such a 'public work.' The Caliphate did not succumb to foreign invasion, but it did fail spectacularly in performing the other functions. We argue that it was the failure to perform the second function that led to the failure to perform the third.[2]

Failures to maintain internal order and administer justice were manifest at the top and bottom of society. It was the failure at the top that was fundamental. Blaydes and Chaney (2013) have argued that Europe and the Islamic world diverged in the middle ages. In Europe, the sovereign raised his army from nobles, who held estates in exchange for military services. Since they had the power, the nobles could resist the sovereign, and that resistance ultimately led to parliamentary control and, with it, economic development. As the society became more stable and revolts rarer, fewer kings were deposed, and the average length of their reigns increased. In the middle east, in contrast, rulers controlled greater tax revenues and used them to acquire slave armies that rendered them independent of the landed nobility. There were no checks on the power of the sovereign, which left them more vulnerable to being deposed when they acted arbitrarily.

The Abbasidian Caliphate lay at the beginning of Blaydes' and Chaney's time period and throws some light on the dynamics of rule. The first 'slave army' in the Islamic world was purchased in this period by Caliph Ma'tasim (833-842). The length of rule was short–there were twelve caliphs in the ninth century–and 'depositions' were common–six of the caliphs were murdered.[3] Why so many? The answer has nothing to do with revolts

---

[2]Kuran (2010) offers another political approach.

[3]Blaydes and Chaney's (2015, p. 21) Figure 2 is mysterious since it shows the average duration of rule in the ninth century ranging from 12 to 18 years and the probability of deposition being on the order of at most 2% or 3%.

against the arbitrary exercise of unchecked power. Rather the explanation lies in the rule governing succession to the caliphate. Feudal Europe developed clear and rigid lines of succession to the throne–generally rule passed to the eldest son. This limited the chances of contested succession–and with that civil war–to situations where there was no son. In contrast , in the Abbasidian caliphate, brothers of the deceased caliph, as well as sons and grandsons, were possible successors. In principle, a claim succeeded if and only if it was acclaimed by the populace. This rule originated in the desert, where it was the rule used by Arab tribes to chose their Sheikhs. In a small group, where the characters of the bothers were widely known, and where popular acclaim might have had some significance, the succession rule might have produced better leaders. However, the rule was catastrophic when it was carried over to a great empire after the Arab conquest. (The Abbasidian caliph was, after all, simply a bedouin Sheikh writ large.) Popular acclaim was at first a public relations exercise and then became acclaim by the slave army. No one judged the character of the contenders, and rule went to the ruthless. The two sons of Harun al-Rashid fought a civil war in the early ninth century without great damage to the caliphate. However, when the three sons of Mutawakkil fought each other between 861 and 870, the result was anarchy that eventually did in the caliphate. The top level institutional failure was applying the succession rule of a desert band to a great empire.

The failure to maintain order in the upper reaches of society led to disorder at the bottom that also undermined the economic system. During the anarchy of the 860s, the various contending factions were in desperate need of money to pay troops. They resorted to various expedients to raise funds quickly. These included assessing the annual tax more than once at year, and tax farming where there were no limits on what the tax farmers could, in practice, take from the agricultural population. On occasion, the treasury was bypassed altogether, and the army was allowed to pay itself by pillaging the countryside. In 869 rural revolution broke out, and it lasted until 883.

Civil war at the top and revolt at the bottom meant that the state stopped maintaining the irrigation system. When caliphs were desperate to pay troops, draining canals seemed of little consequence. When peasants revolted, they stopped paying taxes, and their raids and noncompliance increased the costs and lowered the benefits of maintaining irrigation. By the end of the 9th century, the system had collapsed because the political institutions proved inadequate to the environmental challenges.

The paper proceeds as follows: The next section is a short history of the Abassidian Caliphate emphasizing fiscal, military, and agrarian issues, since these are the events that define the issues. Section II presents a model of hydraulic society in the short run that captures the key features of the Caliphate (Wittfogel 1957). In section III that model is calibrated, and in section IV its implications for a macro view of Iraq in the Golden Age are elaborated. Section V uses the model to measure the decline in output and population during the collapse of the late 9th century. Section VI extends the model of Section II to include investments, and that extension underpins section VII, which undertakes an econometric investigation of the causes of the decline. Section VIII concludes.

Section I: History of the Abbasidian Caliphate

Iraq was one of the richest provinces of the Persian Sassanian Empire, and the Persians developed it to its full potential. Southern Iraq is a desert cross by the Tigris and Euphrates rivers. The Sassanians constructed massive canals running from the Euphrates, which was slightly higher, to the Tigris in the East, as well as the giant Nahrawan canal on

the east side of the Tigrist. These canals allowed the plain between the Tigris and the Euphrates and the land on the east side of the Tigris to be cultivated to the maximum extent permitted by the available water. The state built the great canals and financed their construction and maintenance with taxes levied on the agricultural population. If ever there was a hydraulic state, this was it.

Soon after the death of the Prophet Mohammed in 632, Arab armies swept out of Arabia and conquered much of the middle east, north Africa, and Persia. Iraq fell in 636-8. The Arabs did not follow the common practice of dividing conquered land into fiefs that were parcelled out amongst the nobility. Instead the Caliph 'Umar order that new cities–Kufa, Basra and Wasit–be founded for the Arabs tribesmen to live in. The Sassanian taxation policies were continued, and most of the money that was collected was paid to the Arab settlers as military salaries. The register of those who received payments and the amounts they were entitled to was known at the time as the diwan. Only 7% of the tax revenue went to the Caliph's central treasury, 7% was spent on local administration, and the rest went to those on the diwan (Kennedy 2001, p. 71). This way of dividing up the agricultural surplus was in keeping with the egalitarianism of the nomadic bedouin who had conquered Iraq. Nevertheless, Iraq became a tribute state in which the peasantry supported the militia of invading Arabs.

As the settlers grew older, they became less effective fighters, and as they died the question became whether their heirs could inherit a place on the diwan. The Caliphs resisted their claims because they wanted to hire professional soldiers. By the end of the rule of the Umayyad Caliph 'Abd al-Malik in 685, the caliphate had won and controlled the diwan, which became synonymous with its treasury.

The Umayyad Caliphate with its capital in Damascus was overthrown by the first Abbasidian Caliph al-Saffah in 750. The Umayyad Caliphate was dominated by Arabs and alienated many non-Arabs. The Abbasidan revolt bgan in Khorasan, the vast eastern province of Persia where resentment against Umayyad taxation and administration were high. On the ideological plane, the Abassids were descended from the family of the Prophet, which, they claimed, made them legitimate rulers. They constructed a regime that was more inclusive ethnically than the Umayyads had been.

The second Abbasidian Caliph al-Mansur moved the capital of the caliphate to Baghdad, which he established in 762, and began to finance the translation of Greek philosophical and scientific texts into Arabic. The Golden Age of Islam was in full bloom during the reign of Harun al-Rashid, who was certainly the most glamorous Caliph, due to his presence in *The Thousand and One Nights*. He led armies of 100 thousand against the Byzantine Empire, patronized the arts and sciences, and founded cultural institutions like the House of Wisdom in Baghdad.

Harun al-Rashid could afford all this since his income was so high. Table 1 summarizes the tax receipts of the Abbasidian Caliphate between 780 and 918. Generally these figures are based on official sources and were compiled by state officials. There is some uncertainty as to the exact years to which they apply. The list we date to 812 was compiled by Kodama, who was a high civil servant, and derives from the earliest return in the archives dating from immediately after the fire of 819. The list of 846 is from Ibn Khordadbeh's book of post roads published in that year. Ibn Khordadbeh was postmaster general and rapporteur for the province of Gabal. The return of 918 was drawn up by the

vizier Ali ibn Isa.[4] The returns may indicate target collections based on averages of earlier years (so called *'ibra*) rather than amounts actually received (El-Sammaraie 1972, pp. 140-6, 195). Nevertheless, they are the best basis we have for assessing the income of the Abbasidian state.

Nominal income was greatest in the 8th century, and so was real income. Our knowledge of wages and prices is extremely fragmentary for these years (Ashtor 1969, Beg 1972, Pamuk and Shatzmiller 2014). We have some idea of the wages of ordinary soldiers and craftsmen in Baghdad, and compensation was similar for the two (Ashtor 1969, pp. 64-72, Kennedy 2001, pp. 78-9). Higher status people had much higher incomes (Ashtor1975, p. 154). By deflating the nominal income by the wage of a craftsman/soldier we can get an idea of how many people the Caliph could employ (Table 2). In the case of Harun al-Rashid the answer is over half a million on a full time basis. This was perhaps 7% of the adult male labour force of his empire.[5] Harun could field 100,000 troops, build Baghdad, and have money to spare for poets, philosophers, and mathematicians. Later Caliphs were not so blessed.

Harun al-Rashid drew income from across the Muslim world, but the fiscal core of his realm was the old Sassanian Empire. Most of the income came from the Sawad (southern Iraq) and western and central Persia. They presented different administrative problems because of differences in geography. Irrigation was critical across the empire, but in Persia it was generally supplied by qanats. These were privately constructed, and the state played no direct role in their operation (Bulliet 2009, pp. 1-68, Lambton 1989). In contrast, southern Iraq was irrigated through a large scale system constructed and maintained by the state. Five principal transverse canals ran from the Eurphrates to the Tigris–the Isa, Sarsar, Malik, Kutha, and Grand Sarat–the Nahr Nars ran into the Great Swamp, and the Nahrawan ran parallel to the Tigris on its eastern shore (Maps 1-3). These canals, as well as many smaller ones, brought water to otherwise arid districts. The water was distributed from these giant canals to smaller canals leading to the fields. The state built the major canals, kept them clear and dredged, rebuilt the system when it was damaged by floods, and kept it in good repair. This work was managed by an irrigation ministry, the diwan al-Kharaj. It employed engineers, land surveyors, supervisors of water levels, construction labourers, reed assemblers, water carriers, and controllers to supervise the works. The diwan also sent delegations to villages to mediate disputes about water resources, and the Caliph participated in these adjudications (Cahen 1949-51, El-Samarraie 1972, pp. 105-9, 173-80).

These activities were financed out of tax receipts, and 'user charges' were also imposed on landowners when private interests were served. The Sassanians imposed fixed taxes per unit of land on the main crops. This practice was continued by the Arabs after the

---

[4]Von Kremer (1875, pp. 268-270) and von Kremer (1887). The first list we date to 780 was discovered by the famous historian Ibn Khaldun (von Kremer 1875, pp. 266-7). The list has been frequently reproduced with some variations (e.g. Levy, 1957, pp. 317-20). There are several manuscript sources for the list or perhaps for independent lists dating to the same era (Saleh 1971). The income from 893 is the income half of the state budget translated by Busse (1967).

[5]Treadgold (1988, p. 453) put the population of the Caliphate at 30 million in 780. Assuming that the adult male labour force made up one quarter of the population implies that Harun employed .5/(.25*30) = 7% of the adult males.

conquest, but the rates were substantially increased and the range of crops taxed was extended (Morony 1984, pp. 99-106). In 786 this system was replaced by one designed by the vizier Mu'awia ibn Yasar, and his system continued with some modification throughout the Abassid period. Three main taxes fell on the agricultural population (El-Sammaraie 1975, pp. 146-155). The *kharaj* was imposed on land held by non-Muslims at the time of the conquest and included much of Iraq. Under Harun al-Rashid the state took 50% of the production of the main field crops. Fruit trees were taxed as well. The rate was cut to 40% in 819 under Caliph Ma'mun and remained at that rate into the 10th century. The *jizya* was a poll tax imposed on non-Muslims. Its collection was combined with that of the *kharaj* and was of declining importance as the population converted to Islam. Finally *'ushr* (tithe) was imposed on the private property of Muslims at rates varying from 10% to 25%. This tax was of considerable importance in southeastern Iraq. In 628-9, the Tigris burst its banks and shifted its course. Much of the region was flooded and rendered uncultivable (Verkinderen 2015, pp. 50-60). Under Sharia law, anyone who brought wasteland into production acquired title to it, and that protection induced rich Muslims to reclaim land on which they were lightly taxed.

The Abbasidian Caliphate crumbled during the 9th century. The first shock was the civil war between Harun al-Rashid's sons Amin and Ma'mun. Harun devised a complicated formula to regulate the succession, but it did not resolve differences between them. Amin was in Baghdad and Ma'mun in Khorasun, where he raised an army of 50 thousand to attack his brother. Baghdad was besieged for a year, Amin was killed, and Ma'mun became Caliph. During the siege, the irrigation and agriculture in Anbar province were wrecked, and that is one reason that income derived from the Sawad was lower in 846 than it had been in 812 before the war.

The Caliphate recovered after the civil war. Ma'mun proved to be a great patron of philosophy and the movement to translate Greek texts into Arabic. Members of court also sponsored science and scholarship. Ma'mun's brother, Mu'tasim (833-842), succeeded him and continued to promote science and philosophy, although his attentions were directed to the military.

Mu'tasim decided he needed forces who were personally loyal to him, and he bought Turkish slaves as soldiers. In 835 he began to construct a new capital at Samarra to house them away from the rest of society. The Turkish soldiers numbered only about 5000, but their generals were leading figures in Ma'tasim's regime. Whether or not they were slaves, the Turkish soldiers were far from servile, and, in the long run, they proved to be a fatal mistake.

Mu'tasim was succeeded by Wathiq (842-847) and then by Mutawakkil (847-61). He was no friend of philosophy, reversing many of the enlightened policies of the Golden Age. He too spent fortunes erecting new palaces across the Tigris from Samarra. He sought to check the power of the Turkish generals by transferring administrative responsibilities to his sons through a complication succession plan. It failed even more spectacularly than Harun al-Rashid's. His sons soon conspired against each other, and the Turks were keen to make alliances to preserve their influence. In 861 Mutawakkil was murdered probably at the instigation of his son Muntasir (861-2), who was soon established as Caliph. At the behest of the Turkish military, he removed his brothers from the succession that his father had established. Muntasir died mysteriously the next year, and the Turkish generals decided together to appoint his grandson Musta'in as Caliph. He was completely dependent on the Turks and even appointed a Turk, Utamish, as vizier. Utamish did not pay the troops, and then looted the treasury, after which he was murdered. The troops mutinied and in 863 the

Caliph left Samarra for Baghdad where he broke with the Turks. The Turkish generals decided they needed a more compliant Caliph and appointed Musta'in's brother Mu'tazz to the post. The result was a war in which Mus'tazz and the Turkish army besieged Baghdad. Once again the agriculture of the region was devastated. By 866 Mu'tazz had won, and his brother was banished and later murdered.

Mu'tazz did not last long. The financial crisis continued, and the troops were not paid. They mutinied again and again the Caliph was murdered. He was succeeded by Muhtadi who was also murdered in 870.

The disastrous nine years 861-870 came to an end through a kind of joint rule between two brothers. Mu'tamid was caliph (870-892), and his brother Abu Ahmad al-Muwaffaq was governor of Iraq and Arab. Al-Muwaffaq had been a commander in Samarra and had close relations with the Turkish military, which earned him their confidence. He could broker a peace with the Turks by guaranteeing their pay and their standing in the state. In 892 his son became Caliph Mu'tadid (892-902), the last effective Caliph.

The years 861-870 witnessed the financial collapse of the Caliphate. There was some decline in revenue between Kodama's figure which we date to 812 AD and Ibn Khordadbeh's, which we assign to 846-7, the date of the first edition of his book.[6] The revenue figures for 892 show the situation as it developed in the 860s: income fell from 280 million dirhams to 38 million, and those came only from the Sawad. Even these figures may have been too optimistic. With the inflated wages of 892, the Caliph could afford less than 15 thousand craftsmen and soldiers. This was a huge decline in state capacity. Salaries had not inflated in the 860s (Kennedy 2001, p. 131), so the Caliph could hire about 70 thousand employees with his 38 million dirhams. Armies of 100,000 men were no longer an option. The largest army of the period was the one besieging Baghdad in 865, and it number 19,000. Indeed, military engagements in the 860s normally involved only a few thousand on each side (Kennedy 2001, pp. 126-7).

The causes of the collapse were two fold. First, as civil war broke out, troops were called to Baghdad from across the Caliphate. Regional leaders asserted their independence. The Caliphate had not provided public goods that made membership valuable–the bonds of unity were solely the ideological claim that the rulers were legitimate since they were descendants of the Prophet's family–so taxes were sent to Baghdad for no good reason. Very quickly in the 860s all outlying provinces declared their independence or were taken over by local warlords or rulers who stopped remitting funds to Baghdad. Second, a confounding factor was the large size of the military, which was said to cost 200 million dirhams per year. This was most of the budget in 846, and that is the reason that troops could not be paid once income started to fall. It was safer for the Caliphs to stopping paying troops that were far from Baghdad rather than ones that were near, but unpaid troops in the provinces became the armies of separatist rulers who continued to collect taxes but spent them locally. For instance, the inhabitants of Rayy in Persia offered to pay the commander of troops recalled to Samarra more than the troops would receive in Samarra on the condition that they would stay in Rayy and guard the city. Kennedy (2001, p. 130) suggests that deals like this were common once the Baghdad government ceased to function in the 860s.

---

[6]There is considerable variation among scholars in the date they assign to Ibn Khordadbeh's revenue figures ranging from 846-7, the date of the first edition of his book, to 885 when the second edition appeared. The political history of the 860s makes no sense if we assume the figures apply to that period. (El-Smarraie 1972, pp. 200-1).

The third result was that fiscal pressure was increased on the farmers of the Sawad. First, annual taxes were collected more than once per year. Second, tax farming became general as the need for funds became desperate. Contracts normally lasted only one lunar year, and tax farmers frequently extorted more than the taxes due. The state failed to provide justice to the peasants. (El-Sammaraie 1975, pp 171-3). Third, in the 860s when there was no money to pay troops, the Caliph allowed the army to extort pay directly from farmers in the Sawad. This greatly oppressed the peasantry, and the irrigation system went into decline as there were no resources to maintain it (El-Sammaraie 1975, p. 173). Finally, state officials and military leaders were compensated by granting them landed estates as *itqas*. The grantees were allowed to tax the peasants and keep the proceeds. The *itqas* also carried administrative responsibility for the area. As the grants were short term, however, the holders had no incentive to maintain the irrigation system (El-Sammaraie 1975, p. 173).

Revolution in the countryside was a consequence of the exploitation of the peasantry in the 860s. The center of rebellion was the Revolt of the Zanj (869-883). The Zanj were African slaves brought to Iraq to clear the land that had been flooded by the Tigris in 628-9. They were harshly treated. Ali bin Muhammad was their leader. He had previously tried his hand as a court poet in Samarra, as a revolutionary in Bahrain, and then as a prophet. When he discovered the slaves in southern Iraq, he recognized them as potential followers and proclaimed revolution in 869, preaching the egalitarian doctrines of the Kharijites. They established themselves in the Great Swamp in southern Iraq where they built a capital at al-Mukhtarah. Support for the rebellion was wide spread among the peasantry in the irrigated plain (El-Sammariaie 1975, pp. 117-8), but the marshes remained the rebellion's military strong point. The rebels successfully defeated the Caliph's troops for many years, but their capital was finally destroyed in 883. Rebellion lingered on in wide spread support for the Carmathians (Popovic 1975).

The Caliphate enjoyed a brief revival in the late 9th century under al-Mutamid (870-892), al- Mu'tadid (892-902), and al-Muktafi (902-908). They never restored the prosperity of the Sawad, but they managed to restore suzerainity over western and central Persia, northern Mesopotamia, and even Syria and Egypt. This led to an increase in revenue but a smaller increase in state capacity since wages rose sharply in the late 9th century. The budget of 918 indicates the Caliph could employ 70 thousand soldiers or craftsmen. This was far below the half million at Harun al-Rashid's command, and it did not last long either. The Sawad supplied only one fifth of the revenue. A state mainly dependent on outlying regions for its funding could not contest regional separatism. The ideology of Abbasid legitimacy was long discredited, and there were not enough troops to hold the empire together by force, so Caliphate dissolved as regional war lords and local governments ignored the Caliph's commands.

Section II: model of hydraulic society: short-run equilibrium

A narrative history like that just given explains important elements of the story and highlights relationships among them, but it is weak at elaborating all of the linkages and in gauging the importance of the various contributing factors. To address these issues, we present an economic model of a hydraulic society and apply it to Iraq. Little is know about fundamental aspects of Iraq like the size of its population in this period. One of the virtues of the model we propose is that it combines the disparate information we have about tax collections, crop yields, wages, prices, etc., to solve fundamental problems like the history of the population. It also lays bare the way in which the society worked and shows how the

riches of agriculture supported the Caliphate and the aristocracy.

The model is based on the idea that Iraq was a hydraulic state, that is, a society in which the state necessarily provided an irrigation system, which was paid for by taxing the agricultural population. Indeed, taxes exceeded the cost of irrigation, and that surplus supported the palace, the military, high culture, and urban society in general. The bigger the irrigation system, the bigger the surplus.

Figure 1 shows this equilibrium diagrammatically. The model allocates Iraq's workforce (population) AB between agriculture AL and the rest of the economy LB. The agricultural sector is assumed to consist of identical peasant farms in which one unit of labour cultivates one unit of land and produces one unit of output, which we will call grain. Since there are fixed proportions and the farms are identical, EA is the average and marginal product of labour. The size of the farm population AL is determined by the area of cultivatable land, which depends on the capacity of the irrigation system.

Labour income in agriculture, the agricultural wage w, is determined outside of the model. In the long run it is assumed to be determined by Malthusian population dynamics, so it is the subsistence income that equates births to deaths. This system is assumed to have obtained generally in the middle east. People are assumed to move into or out of southern Iraq if the agricultural income in the district deviates from the equilibrium Malthusian wage in the middle east generally.

The rectangle EDCW is the agricultural surplus, the difference between total farm production EDLA and the labour income of the farm population WCLA. We assume that the state taxes the entire agricultural surplus.[7]

The Caliph himself eats a minute fraction of the surplus: the bulk of it is used to build palaces and mosques, pay soldiers, hire craftsmen to make the luxuries of urban life, and to support poets and philosophers for amusement and enlightenment. The demand for labour outside of agriculture is the rectangular hyperbole rising from F asymptotically towards the vertical line BG: tax revenue = LB·w* where LB is employment outside agriculture and w* is the wage outside agriculture. In the simplest case, w* would equal w, but in reality nonagricultural wages were higher, and Figure 1 has been so constructed.

The model highlights how the agricultural and urban sectors are inter-related. First, if the productivity of agriculture in the sense of output per worker EA increases, then there is no change in the agricultural population, but the urban population expands since all of the extra income accrues to the Caliph as tax revenue (Watson 1974, Watson 2008). Second, if the irrigation system is expanded, so that the agricultural population AL increases, then tax receipts rise, and the urban population also expands Conversely, if the irrigation system contracts, then both the rural and urban populations fall. This is what happened in Iraq in the 860s and later.

Section III: calibrating the model

We can calculate the size of the population and the economy before and after the decline in the irrigation system, if we calibrate the model. Calibration means putting numerical values on all of the parameters in Figure 1. We add a few extra details to make the model more realistic. We begin with life in the Golden Age when population and output

---

[7]If the state failed to tax away the agricultural surplus, the farm population would expanded until total output divided by the enlarged population equalled w.

were at their greatest.

subsistence income in agriculture w

Most students of ancient societies reduce income to the grain consumption of the poor. Poor people also consumed some legumes, vegetables, cloth, and fuel, but grain was generally the largest share of their spending. Our model has only one good–grain–so we follow the usual convention and set income at 250 kg per person per year, bearing in mind that in reality some of this supported the production of the additional goods that were also consumed by the poor. In Figure 1, w = 250 kg per year.

irrigated acreage

In the hydraulic state, the agricultural population is determined by the irrigated acreage. In the early twentieth century, there was no effective, modern irrigation system in Iraq. Proposals to remedy the situation were develop by Sir William Willcocks. Willcocks was a leading Victorian engineer, who had previously worked in India and in Egypt where he surveyed the Nile (Willcocks 1899) and built the low dam at Aswan as well as other important irrigation works. Willcocks' (1917) proposals for Iraq formed the basis for that country's irrigation policy in the twentieth century. Willcocks and his team were the first to measure the flow of the Euphrates and Tigris rivers and calculate their potential.[8] The following is his conclusion:

> Assuming that the duty of water in Mesopotamia would be the same as that of the hottest and driest parts of the Nile valley near Luxor, we may say that one cubic metre per second of water will, in winter, irrigate 3,000 hectares, and in summer 400 hectares of rice, or 1,250 hectares of dry crops, such as millets, sesame, etc. Using the discharge tables of the two rivers given above, we may say that the water supply will permit of 3,000,000 hectares of winter crops, while the summer discharge will permit of 400,000 hectares of rice or 1,250,000 hectares of millet, sesame, cotton, etc. (Willcocks 1917, p. 9)

The logic behind these calculations is not entirely clear[9], but similar results can be

---

[8]Willcock's estimates are in accord with modern measurements. Thus, Willcocks's (1917, p. 9) monthly calculations of the Euphrate's discharge at Hit imply an annual flow of 34.5 billion cubic metres. This compares well with Kolars and Mitchell's 1991, p. 307-8) estimate of the 'natural flow' (ie abstracting from human interventions) at Hit of 33.69 billion cubic metres.

[9]The figures appear to derive from the survey of Egypt (Willcocks 1899, p. 142) where the ratio is given as one cubic metre per 3000 acres. This may correspond to the 1250 hectares of millet, etc watered in the summer. If the summer lasted six months, which was the usual usage of the term, Willcock's calculation assumes 1.25 cubic metres were applied to each square metre, but the details remain obscure. Jackson (1885, pp. 186-7) reports that basins in Upper Egypt were flooded to a depth of about one metre, and the water was allowed to soak into the ground. Egyptian basin irrigation involved no losses in distribution canals or

obtained by applying modern rules of thumb to Willcocks's discharge tables. The rules of thumb are (1) that a cubic metre of water is required per square metre of land by the plants for their growth under middle eastern conditions, (2) that losses from evaporation and leakage mean that 2.5 cubic metres of water must be taken from the river to supply the plants with one cubic metre per hectare, and, in addition, (3) that 35% of the water withdrawn from the river finds its way back into the river (Kolars and Mitchell 1991, pp. 124-42, especially 134-5). The upshot is that a net withdrawal of 1.625 cubic metres is required for each square metre cultivated. 3 million hectares of winter cultivation would, therefore, require 48.75 billion cubic metres of water or an average flow of 3100 cubic metres per second over the winter half of the year. This is easily accommodated by the monthly flows recorded by Willcocks (1917, p. 9) and his team: the period December - May averaged 3050 cubic metres per second and the rate increased to over 3650 cubic metres per second if the start date of the six month period is pushed back to February. The exact timing of water requirements is not known, but the land was watered in the summer before planting and again as the crop approached maturity in the spring.

The calculation assumes that the full flow (at least on a seasonal basis)[10] of the Tigris and Eurphrates was being used for productive purposes. This assumption is consistent with the calculations of Adams (1981, pp. 180, 210) using archaeological survey data. Adams traversed much of plain between the Tigris and Euphrates collecting pottery shards which he dated based on ceramic style. He was thus able to reconstruct the settlement pattern of the region from the beginnings of settlement c. 4000 BC through the Islamic period. The region achieved its most complete development at the end of the Sassanian period, ie when the Arabs took over. His settlement map shows "an exceptional correspondence between the limits of this simulated zone and the limits of the surveyed area itself, indicating that virtually continuous cultivation within large parts of the latter would have been necessary. " Furthermore, "with a whole series of massive diversions upstream, it is not unlikely that in Sassanian times the Euphrates entered the swamps [at its lower end]...with very little if any residual flow." All the water was being used for agriculture. The same was true of the Tigris as well, whose waters not only irrigated the east bank but were drawn west onto the central plain. Adams (1981, p. 212) also analysed the tax data for the Sawad of Kufa, (the region around Kufa) and concluded that the tax receipts implied an area under cultivation that "was so slightly above the maximum limits of the Sawad of Kufa as calculated from Euphrates drainage patterns as to lie within an acceptable margin of error." These arguments make it reasonable to assume that Willcocks' estimates of the land that could be cultivated was actually in tillage.

Since the winter acreage is much greater than the summer acreage, we assume that the size of agriculture was determined by availability of irrigation for winter cultivation. When the system was at its peak in the days of Harun al-Rushid and Ma'mun, we assume that 3 million hectares of winter grain were cultivated. Since land was fallowed every other year, agriculture was practised over twice this area. Fixing the winter acreage at 3 million hectares pins down the size of the population and the economy.

---

flow back into the river, so water requirements would have been less than in Mesopotamia. The calculations with modern rules of thumb allow for these losses.

[10]The annual flow is available only if a dam is constructed that can contain the entire annual flow. That was not the case in ancient times.

agricultural population

How much labour was required to cultivate 3 million hectares? Peak labour demand occurred at the harvest. Experimental archaeologists have discovered that it took 20 man-days of labour to harvest a hectare of wheat using sickles with stone or early metal blades (Korobkova 1981, Russell 1988, p. 116-7). The harvest lasted two months, so one man could reap three hectares (Wilkinson 1994, p. 496). Harvesting 3 million hectares, therefore, required one million men.[11] Assuming four people per family implies an agricultural population of four million. This is line AL in Figure 1.

income of the agricultural population (peasant income)

The four million people in the countryside were each assumed to earn 250 kg of grain per year, so their total income was the product of the two numbers. This equals area wCLA in Figure 1.

gross production of field crops

We have considerable information on yields, seed, and feed regarding farming in southern Mesopotamia for earlier periods, and we use that on the assumption that conditions were similar. Wheat and barley were the main field crops, and we treat all crops as though they were wheat. There is debate about the yield of wheat (Potts 1997, pp. 80-2). We assume a yield of 900 kg per hectare. We apply this to all 4.625 million hectares that Willcocks believed could be planted in summer as well as winter. Total production of field crops was 4.1625 million tons.

agricultural costs: seed

Potts (1997, p. 82) following Halstead (1990, p. 187) put the seeding rate at 32 kg per hectare, which implies a much higher yield-seed ratio than is normally achieved when seed is broadcast. Cuneiform texts frequently mention a rate of 240 sila per bur or 37 litres (28 kg) per hectare (Powell 1990). Halstead attributed the high yield ratio to the use of a drill plough. We set the seed rate at 32 kg per hectare.

agricultural costs: feed for oxen

There is no natural pasture in southern Iraq, so all oxen had to be fed grain. Using information from ancient texts on the distance between furrows, the speed of plough teams, and the number of times fields were ploughed, Potts (1997, p. 85) deduced that a square field of 1 bur (6.48 hectares) would have required 24.98 days of labour. If the plough team consisted of the normal two oxen and if each ox ate 6 litres of grain per day, then the oxen in the plough team would have eaten 35 kg of grain per hectare. This result is consistent with Babylonian cost accounting in which it was reckoned that seed per hectare and fodder per hectare were equal (Potts 1997, p. 83, Powell 1984, Hruška, 1984, p. 154).

---

[11]Women are assumed to have been confined to domestic quarters, so all harvesting was, indeed, done by men.

agricultural costs: grain to meat

Meat was consumed in Iraq, particularly by the upper classes. Much of Baghdad's meat must have come from animals grazing on the steppe of northern Iraq, but meat was also raised in the Sawad. I assumed that 20% of the gross output of grain was fed to animals. Cattle require six kg of feed for each kilogram of meat they yield, so meat production in southern Iraq was one sixth of 20% of gross grain production.

agricultural costs: spoilage and losses

10% of gross output was assumed to have been eaten by vermin or otherwise lost or spoiled.

net agricultural output

Net output was computed as gross output of grain plus the production of meat minus grain used for seed, feeding to oxen, feeding to cattle for meat, and losses. This equals area EDLA in Figure 1.

total agricultural tax revenue

Total tax collections around 820 were 109 million dirhams (Table 1). This sum represents peak tax collections from the Sawad. Most of the taxes were in kind and converted to cash at the rate of 450 dirhams per korr of 2925 kg of grain (von Kremer 1875, p. 362-3). Some tax was also taken in money. The total is expressed in kilograms of grain by dividing the total by the price.

total aristocratic rental income

There was privately owned land in the Sawad that was leased and which supported an aristocracy. Indeed, the sum of tax revenue and peasant income is less than net agricultural output, and I take the difference to have been aristocratic income. The sum of tax revenues and aristocratic income equals area EDCW in Figure 1, and that total gives rise to the non-agricultural labour demand curve FH. (Tax and aristocratic income are not distinguished in Figure 1 since they affected labour allocation in the same way.)

We noted earlier that the typical tax rate on Kharadj land was 40% of production. Whether this was gross or net is not clear from the sources. Other land was taxed at a lower rate. Our calculation that taxes amounted to 28% of net production looks in line with these figures.

average urban wage

Urban wages were much higher than rural incomes. The average agricultural family of 4 is assigned a subsistence income of 1000 kg of grain. This would have cost 154 dirhams per year–about 13 dirhams per month–if valued at the same price as tax collections. In the early ninth century, the average wage of a soldier was 60 dirhams per month, and that agrees with scattered information about the wages of craftsmen in Baghdad (Ashtor 1969, pp. 64-5, 70-1, Kennedy 2001, pp. 78, 80-1). Ashtor (1976, p. 154) shows a broad range of earnings in the urban economy but the highest earnings only accrued to a small number of high ranking

officials. I assume the average urban wage was four times the rural wage. This is a substantial premium, but, of course, the urban population was mainly Arab, while the rural population were the descendants of the peasants under the Persians.

urban population

Under the maintained assumptions, the non-agricultural population of Iraq was 1.8 million. It might, in reality, have been larger in view of the fiscal transfer to Baghdad from other parts of the Caliphate. Russell (1958, p. 89) conjectured that Baghdad had 300,000 residents. Other cities like Kufa, Basra, and Wasit were important, and the non-agricultural population included soldiers and people in smaller settlements, too.

total population

The total population is the sum of the rural and urban components–5.8 million.

Section IV: Iraq in the Golden Age and its decline: the macro view

We have only fragmentary information about different economic, social, and geographical features of Iraq in the early Islamic period. Our model can be used to combine these into a macro picture. While one can dispute the parameters, there is at least a consistent logic that combines them into a whole. Table 3 shows some key results for the Golden Age around 812 AD.

The top panel shows total (net) agricultural production measured in kilograms of grain and its division among the principal social classes. On the assumptions made here, peasant income was 36% of the total, taxes were 26%, and rents were 38%. Irrigated farming in Mesopotamia was so remarkably productive that almost two-thirds of net production could be taken from the farmers to support the Caliph, the upper classes, and, indeed, the urban population in general. Iraq was fertile enough to support a Golden Age.

The second panel shows the implications for the size and distribution of the population. Slightly more than two-thirds of the population were in agriculture and the remainder were in the cities or in military installations, etc. The total population implied by the assumptions here amounted to 5.8 million. There is no consensus among scholars on the size of the population--McEvedy and Jones' s (1977, pp 151) put it at of 2.5 million in 800, Issawi (1981) raised the total to 5-6 million, while Russell (1958, p. 89) estimated it at 9.1 million. In view of this span, Goldsmith (1987, p. 61) settled on a 'synthetic estimate' of 4 million. All of these estimates rest on very weak foundations. Our model implies a population in accord with Issawi's estimate and in the middle of the range.

The final panel of the table shows output per worker in agriculture, income per worker in agriculture, and income per worker outside of agriculture. Income per worker in agriculture of 1000 kg per year corresponds to a family of 4 receiving 250 kg each on average–the subsistence income. The difference between output per worker and income per worker in agriculture is the agricultural surplus, which is the income received by the Caliph and the aristocracy and which supports the non-agricultural economy. Income per worker outside of agricultural is set at 4000 kg per year–four times the farm income. Had the incomes been the same, then the ratio of agricultural surplus to agricultural output would have equalled the ratio of the non-agricultural population to the total, i.e. 64%. In reality, it was much less because urban incomes were much higher.

Section V: Counterfactual calculation: How big was the economic collapse in the late 9th century?

We can use our model to simulate the effects of the economic collapse in the late 9th century. The best indicator is the decline in tax revenue from the Sawad, and numerous historians have pointed to it as a measure of decline. Between about 846 and 918 tax receipts from the Sawad dropped by 52% (Table 3). The usual interpretation is that the 52% drop in tax revenue indicates a corresponding 52% drop in production on the assumption that the state took a constant share of the harvest. This inference, however, is off the mark for two reasons. First, agricultural prices increased several fold in the late 9th century, and that means that the decline in real tax revenue was much greater than the decline in nominal revenue. Pamuk and Shatzmiller (2014, p. 202) found that the price of wheat rose by a factor of 3.55 from the mid-9th to the mid-10th centuries, in which case, the volume of the harvest in 918 was only 14% of what it had been in 846. Second, however, there was an offsetting factor that must also be taken into account, namely, the administration of the tax system shifted from direct collection by state officials to taxing farming. In 893, for instance, the entire Sawad was granted to Ahmad b. Muhammad at-Tai as a tax farm, and the 38.3 million dirhams in taxes shown in Table 1 was the sum that Ahmad remitted to the Caliph (Busse 1967). He would have collected more from the peasantry, and difference represents his costs and profit. It is the value collected from the peasants that must be compared to earlier values to calculate the decline in output, so the amount remitted to the state must be increased accordingly. It was the same situation in 918. We have no information about the premium collected by tax farmers. If we presume that they increased tax collections by one third, then real tax collections and the volume of production dropped to 18% = (.48 /3.55) * 4/3 of the 846 level. We will work with this 82% decline.

In the simulation of the economy of Iraq in the early 9th century, the assumption was that its size was constrained by the discharge of the Tigris and the Euphrates rivers. In the late 9th century, the economy shrank. In the next section, we argue that the immediate cause was the collapse of state maintenance of the irrigation system. For the moment, we consider its effects. We reduce land, labour, and output by 82% since fixed proportions obtained among them. Table 3 shows some macro implications of the reduction. The population drops by 82% from 5.8 million to just over 1 million. The model implies that the agricultural and non-agricultural population drop by the same proportion reaching .7 million and .3 million respectively. This is extreme depopulation.[12] We cannot say how many people died and how many fled to other parts of the middle east. The population drop is the reason that the archaeological survey data show the central part of the Sawad to have been empty in the 10th century. This can be seen by comparing Maps 2 and 3, which show the settlements in the two portions of Iraq that Adams (1965, 1981) 'intensively surveyed.'. Settlement fell dramatically between the ninth and tenth centuries in the southern Mesopotamian plain near the Zanj stronghold in the Great Swamp and much less so in the region east of Baghdad, which was harder for the Zanj to reach. Indeed, the southern Mesopotamian plain is still

[12]An odd feature of McEvedy and Jones' (1978, p. 151) estimates is that they show only a small fall in the population between 800 and 1000 AD from 2.5 million to 2.0 million.

unpopulated today (Map 1)[13].

Section VI: model of hydraulic society: long run equilibrium

Why did Iraq collapse in the late 9th century? The key to prosperity in the Sawad was irrigation, and it depended on the actions of the aristocracy and, especially, the Caliph. He could spend his tax receipts on consumption or investment. The palace, the harem, and the army were all consumption expenditures. The irrigation system was the critical investment. The system deteriorated rapidly due to silting and flooding, so a minimum expenditure was required simply to keep it going. More expenditure led to expansion. Private individuals also invested in land reclamation, in particular, in southeastern Iraq when reclaiming land wrecked by the floods of 628-9. Our emphasis, however, is on the state, for it was responsible for the major transverse canals in the Euphrates plain as well as the Nahrawan east of the Tigris. The private land reclamation on the lower Tigris was concerned with drainage rather than irrigation.

Figure 2 analyses the investment decision of the Caliph on the theoretical plane. C_t is consumption in some year t, and C_{t+1} is consumption in the following year. It is important to appreciate that 'consumption' here means allocating labour, for the way in which the Caliph consumes the surplus is by using it to hire soldiers, poets, or, in this case, irrigation construction workers. Consuming less this year means employing more irrigation workers, which allows more consumption in future years. The straight line MQLN shows the rate of return to allocating labour to canal work. If no labour is assigned to the canals, the maximum consumption N is possible, and, in that case, consumption in the following year will be I. If JN labour is instead allocated to irrigation work, then current consumption is reduced to J but income the following year is increased to K. A horizontal line has been drawn at K for a reason. $K = C_t$. In other words, JN represents the labour that must be allocated to irrigation maintenance to keep the system in good repair. If that is done, then consumption remains the same from year to year.

How much labour is allocated to canal work depends on how future or present oriented the Caliph is. The Caliph's time preference is represented by the curved indifference curve PQR. There is a family of these curves, and the one shown is the highest that touches the rate of return line MQLN. As drawn, the Caliph would chose to consume only S in the present year. SN labour would be allocated to the irrigation system, and that would allow expansion as well as maintenance, and consumption would rise to T in the following year.

It is an important feature of the model that the rate of time preference could vary. If PQR, for instance, shifted down and to the right, then Q could fall in the segment LN. In that case, not enough would be spent on the canals to maintain them, and the system would deteriorate leading to lower future consumption. A shift like this would indicate a more present-oriented outlook.

The model highlights two types of shifts that could have influenced investment in the

---

[13]Map 1 also shows that the area around the Nahrawan canal, which had been densely settled in the middle Islamic period (Map 3), was depopulated in 2000. The canal was breached in a civil war in 937 and never effectively repaired, so agriculture was rendered impossible. This is a further example of the negative effect of the collapse of state capacity on long run economic development.

canals. One is changes in the time preference of the Caliph, as just noted. The second is changes in the rate of return to irrigation investment. A higher rate of return is indicated by sliding M up the axis to a higher value, while leaving N as it is. Sliding M down indicates a lower rate of return, for consumption tomorrow increases by a smaller amount for any given investment. Whatever the position of PQR (the rate of time preference) a higher rate of return induces a higher level of investment since the PQR indifference curves get steeper in moving left, so tangency will occur further left when the slope of MQLN increases.[14]

Section VII: Econometric analysis of the causes of the collapse of agriculture and settlement

We must now explore the reasons for the collapse in agriculture in Iraq in the 9th century. Geography posed the challenge of effective irrigation, and Iraq collapsed because the political system could not meet it. In the introduction, we claimed that state failure was manifest at both the top and the bottom of the social system. At the top, the Bedouin system of succession when a Sheikh died, which was carried over into the Abbisidian caliphate, led to civil war, as brothers fought each other to become Caliph. When they did so, their need for revenue became intense. In terms of the model just outlined, their term preference became very present oriented. The prediction is that they would sacrifice investment in irrigation in favour of hiring troops. Surely, this happened, but it is not a prediction we can verify statistically. Had we annual data on tax receipts, expenditures, and the various collection regimes, we could analyse shifts in time preference empirically, but we do not have these data.

We can, however, explore the other two explanations for the collapsed in agriculture in the Sawad–the impact of high salt content in the soil and the failure of the state at the bottom of the social structure, namely, the revolt of the Zanj.

The revolt of the Zanj affected canal maintenance by reducing the incentive to invest. In areas near the Great Swamp, there was danger that raids would disrupt agriculture and the irrigation system. In addition, the peasantry on the plain was sympathetic to the revolt and proximity to the swamp made it easier for Zanj agents to propagandize them. Successful agitprop could disrupt tax collection and lower the return from agricultural investment. This hypothesis can be expressed in terms of Figure 2 where we expect the line MQLN to be steeper, the further from the centre of the revolt a district lay. This is a cross sectional prediction that can be tested with the data showing tax collections district-by-district.

The data set consists of 29 tax districts in the central part of Mesopotamia. These are the districts serviced by the transverse canals and the Nahrawan east of the Tigris. This is the system where canal maintenance was critical. The sample does not include the reclamation districts along the lower Tigris where drainage rather than irrigation was the main issue, nor does it include some districts near the new city of Samarra where the reallocation of water in its favour looks to have overwhelmed other factors.

The dependent variable is tax revenue in 918 relative to its value in 846. This time frame includes the main decline. We hypothesize that the decline was smallest where the

---

[14]It is theoretically possible that a rise in the rate of return might increase income over the years so much that the Caliph might decide to consume more in the present than in the future. However, econometric investigations with isoelastic utility functions rule out this possibility in practice.

state maintained the irrigation system the most. Maintenance of the irrigation system can be measured by water regulators. On the transverse and Nahrawan canals there were *qantaras* (weirs)[15] that regulated the flow of water to control its discharge to smaller canals leading into the fields. The tenth century scholar Ibn Serapion (Suhrab) wrote a book about the river and canal system of Iraq and in it listed the working water regulators towards the end of the 9th century (El-Samarraie 1972, pp. 31-2). We have mapped these into tax districts according to the canals they serviced and, in some cases, the names of the *qantaras*. Adams (1981, p 216) noticed that the *qantaras* were not evenly spaced across the Sawad and remarked on the importance of this information but did nothing systematic with it. We hypothesize that the presence of a *qantara* in a district was positively related to its tax yield in 918 relative to 846.

We can also test the salt build-up hypothesis along with the social conflict hypothesis. As soil salinity increased, the yield of wheat was reduced. Barley was more saline resistant and did not suffer to the same extent. Consequently farmers cultivated more barley and less wheat in response to growing salinization. Much of the tax was collected in kind, and the returns distinguish between the wheat and barley collected. On the assumption that the tax collections reflected what was grown, we use the ratio of wheat to barley as an indicator of the severity of salinization. There was wide variation in this measure.

The most obvious test of the explanations for the decline in yield is to estimate an OLS regression of the decline in tax revenue on the presence of a *qantara* and the wheat-barley balance. This regression is number 1 in Table 4. The presence of a *qantara* in a district led to a positive and statistically significant increase in tax receipts in 918 relative to 846. In contrast, the balance of wheat to barley had a negligible impact on taxes. This regression underlines the importance of state investment in sustaining agriculture and the unimportance of environmental degradation.

There are, however, two weaknesses with this conclusion. First, it does not examine the role of rural social conflict. Second, the location of *qantara*s cannot be treated as an exogenous factor influencing tax yields. The model in Figure 2 makes clear that investment in canals was an endogenous variable reflecting a host of factors. Therefore, its effect must be estimated with instrumental variables. We hypothesize that the Zanj revolt was a factor depressing the return to investment in irrigation. We posit that its effect was greater, the closer a distract was to the Zanj stronghold in the Great Swamp, so we use distance from al-Makhtarah, the Zanj administrative capital in the Swamp near Basra, as an instrument for the presence of a *qantara* in a tax district. There is no reason to expect that the Zanj had any impact in 918 on tax collections other than through their effect on *qantara* upkeep.

Table 4, equation 2, shows the first stage regression in which the presence of a *qantara* in a district depends on distance from al-Mukhtarah. DISTANCE played a statistically significant role: the further a district was from al-Mukhtarah the more likely it was to have a *qantara* at the end of the 9th century. Furthermore, the standard test of the hypothesis that DISTANCE is a 'weak' instrument (whose use would bias the coefficients in the second stage regression) rejects that mull hypothesis since the statistic $F(1,26) = 17.998$ is greater than the customary critical value of 10. The importance of DISTANCE (and the unimportance of WHEAT) receives further support from the reduced form regression (equation 4). When DISTANCE is used as an instrument for QANTARA in the second stage of the IV estimation (equation 3) the OLS estimates are confirmed, and the importance of

---

[15]El-Samarraie (1972, p. 30) discusses the changing meaning of the word *qantara* since Abbasid times.

functioning water regulators and the unimportance of saline build-up in maintaining tax revenue is again established.

These results indicate that social revolution played an important role in explaining the decline in tax revenues in the 9th century, while ecological factors were unimportant. It is likely as well that shifts in the rate of time preference played a leading role too, but their influence cannot be measured in a cross sectional model.

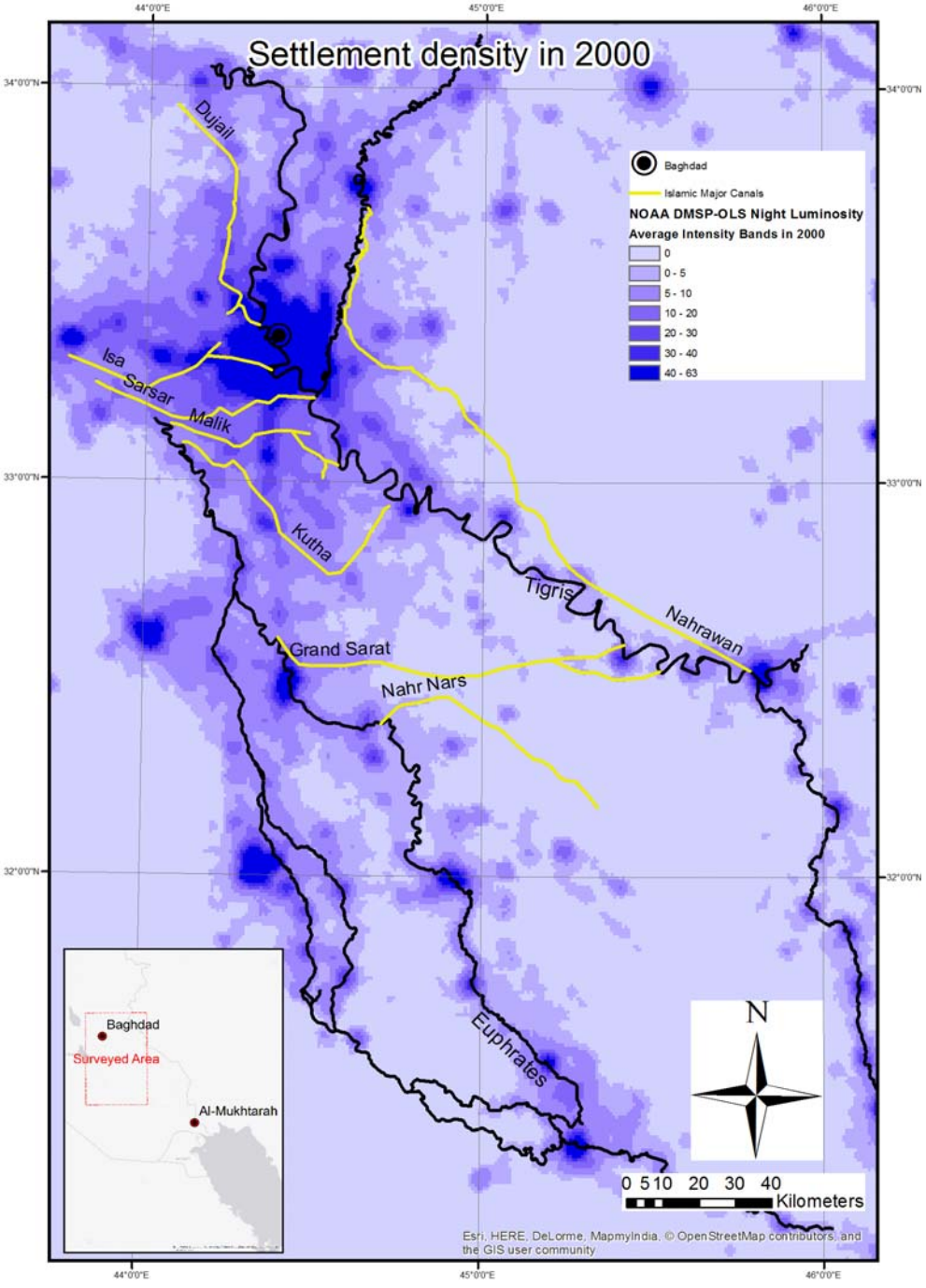
Section VIII: Conclusion

The Arab armies that overwhelmed the Sassanian and Byzantine empires in the 7th century conquered some very rich territories. The Sawad of southern Iraq was the keystone of their empire. Our calibrated model of a hydraulic society shows why: Even with Stone Age tools, Mesopotamian agriculture was so productive that the support of the farming population only required 36% of the net output of food produced. The rest was available to support great cities, extensive commerce, and a vibrant culture. This prosperity underpinned the Golden Age of Islam.

But this success required irrigation and the geography of the Sawad meant that state support was vital. Unlike Persia where irrigation with qanats was small scale and could be organized locally by private entrepreneurs, the Mesopotamian plain required giant long distance canals to realize its full potential. These canals required public investment for their construction and maintenance. When Caliphs were rich and far sighted, the system worked. When money became tight and immediate needs dominated, maintenance of the canal system was threatened.

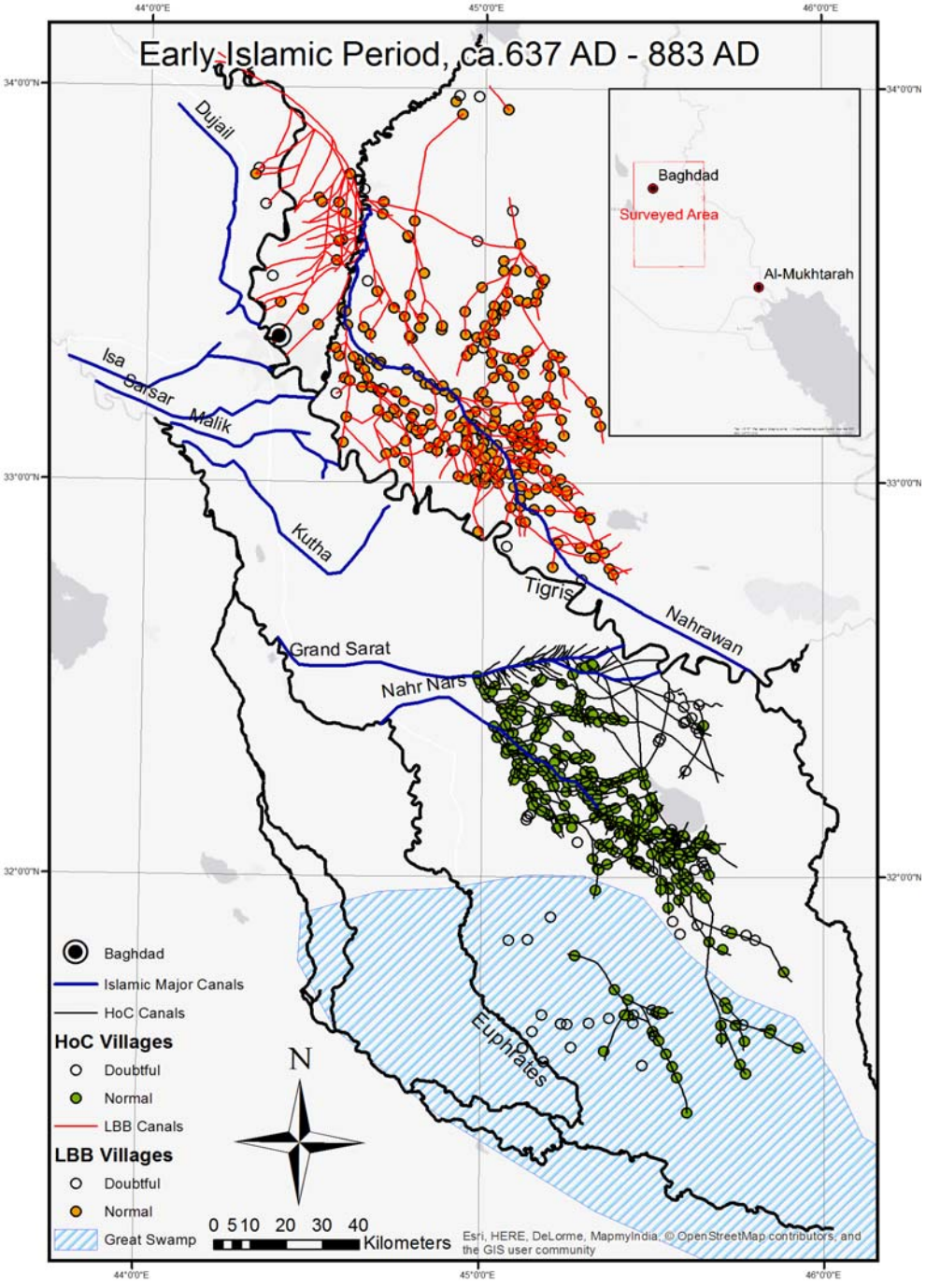
The political organization of the Caliphate contained an imperfection that led to its downfall–namely the Bedouin rule of succession. Unlike Europe, where the crown descended to the eldest son, the brothers, sons, and grandsons of a deceased Sheikh or Caliph could claim the throne. Maybe this rule worked for a desert band, but it led to civil war when it was followed in a great empire. Civil war meant that the contenders for the Caliphate became extremely present oriented and sacrificed the irrigation system for victory in battle. In addition, it led to the exploitation of the peasantry and rural revolt. The Revolt of the Zanj contributed to the collapsed of agriculture in Iraq by making investment in the irrigated plains of Iraq closest to the rebel held marshlands riskier than otherwise. Investment suffered and by the end of the 9th century most of the Sawad was desolate and abandoned, and it remains like that now.

Map 1



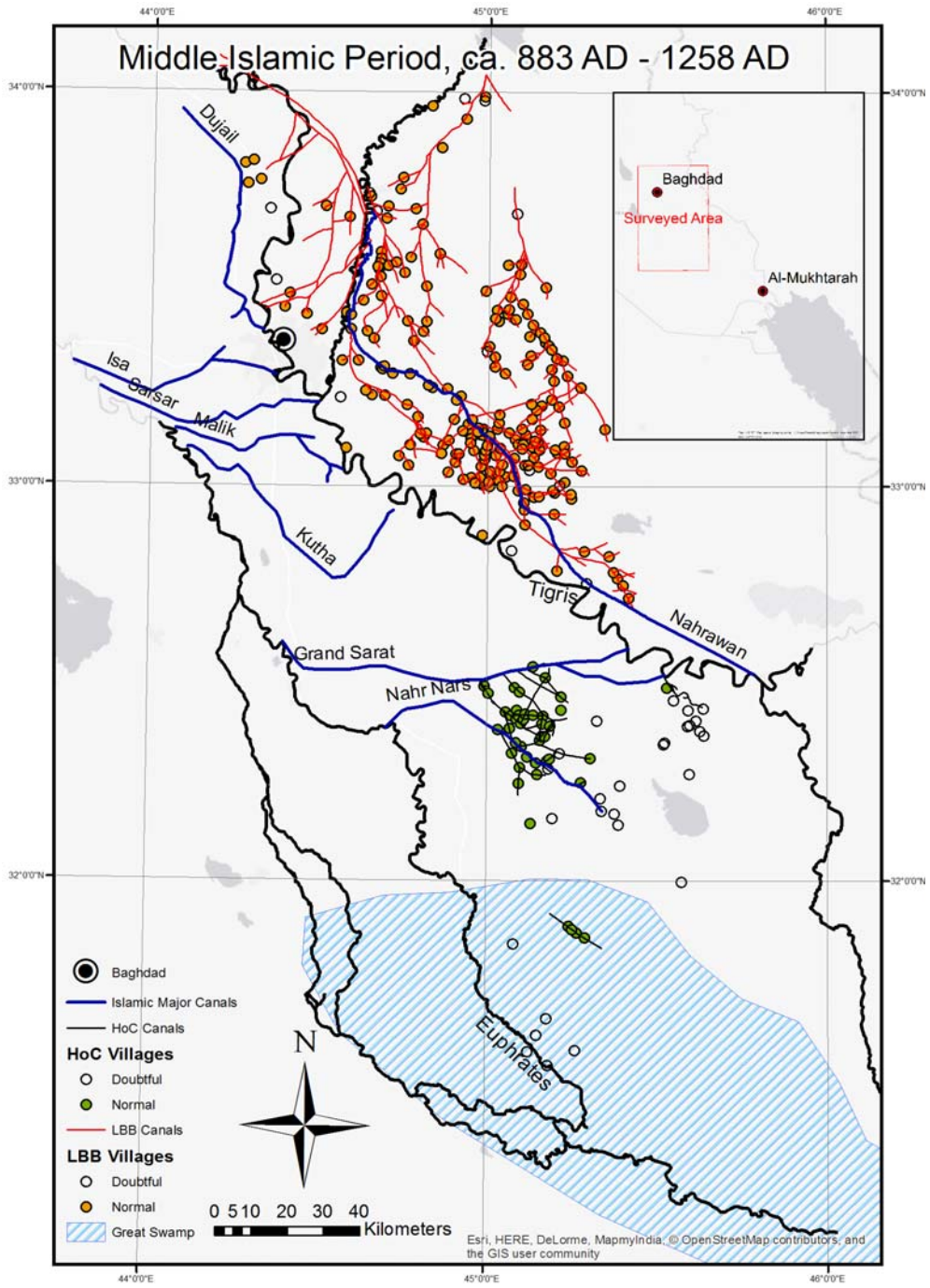
Note: The canals shown in yellow were the principal canals of the Islamic period.. Many are now abandoned. The area around the former Grand Sarat Canal and the Nahr Nars is virtually deserted today, but it was densely settled in the ninth century. Compare the area around the Nahr Nars here with the corresponding area in Maps 2 and 3.

Map 2



Note: The red dots denote villages occupied in the early Islamic period according to Adam's *The Land Behind Baghdad*, while the green dots denote early Islamic settlements listed in Adam's *Heartland of Cities*. These villages lie in his two 'intensively surveyed' regions of Mesopotamia.

Map 3



Note: Compare this map to Map 2 and observe that settlement dropped sharply in the area between the Grand Sarat canal and the Great Swamp, which was the stronghold of the Zanj rebels The map inset in the upper right shows the location of al-Mukhtarah, the Zanj capital. It lay south east of the region mapped here. Settlement decline was much less extreme east of the Tigris and further from al-Mukhtarah.

Table 1
Income of the Caliphate (millions of dirhams)

year AD	Sawad	northern Mesopotamia west/central Persia	Peripheral Persia	Armenia	Syria	Egypt	Arabia	total
780	90.5	165.1	67.2	13.0	18.7	57.8	10.1	422.3
812	109.5	144.3	45.2	5.0	13.5	37.5	22.8	377.7
846	80.1	115.4	28.2	0.0	29.9	32.7	9.0	295.3
892	37.5	0.0	0.0	0.0	0.0	0.0	0.0	37.5
918	38.3	129.5	0.0	0.0	0.0	20.6	1.2	189.5

Source:
von Kremer (1875, pp. 356-9, 360-9, 370-9), Busse (1967, p. 15), von Kremer (1887, pp. 32-8).

Table 2

Potential employment of soldiers or craftsmen by the Caliphate

year AD	monthly wage	man-years
780	60	586556
812	60	524602
846	60	410077
893	225	13889
918	225	70188

source: Tax revenues from Table 1 have been divided by the annual wage (taken to be twelve times the monthly wage shown here) to obtain man-years of employment. Monthly wages from (Ashtor 1969, pp. 64-72, Kennedy 2001, pp. 78-9, 160)

Table 3

The Social & Economic Structure of Iraq in 846 and 918

	846	918	
agricultural production (net)	2757	495	millions kg
state tax revenue	711	96	millions kg
tax farmers' income	0	32	millions kg
rent to upper class	1046	188	millions kg
peasant subsistence	1000	180	millions kg
farm population	4000000	718351	people
non-farm population	1757450	315616	people
total population	5757450	1033967	people
farm workforce	1000000	179588	people
urban workforce	439363	78904	people
output/worker in agriculture	2757	2757	kg
income /worker in agriculture	1000	1000	kg
income/worker nonagricultural	4000	4000	kg

soure: see text.

Table 4

Decline in Tax Revenue

regression	1	2	3	4
dependent variable	DECLINE	QANTARA	DECLINE	DECLINE
estimator	OLS	OLS	IV	OLS
constant	.171	-1.201	.159	-.521
	(3.43)	(-4.00)	(2.73)	(-2.08)
QANTARA	.526		.566	
	(5.69)		(5.53)	
WHEAT	.003	.046	-.004	.022
	(.06)	(.35)	(-.10)	(.24)
DISTANCE		.004		.002
		(4.24)		(3.27)
R^2	.638	.243	.63	.182

variables:

DECLINE equals the ratio of a taxes in 916 to taxes in 846.

QANTARA is dummy variable equalling one if there was a qantara in the tax district at the end of the 9th century.

DISTANCE is the distance in kilometers from al-Makhtrara, the Zanj capital, to the tax district.

WHEAT is wheat collected in tax divided by barley collected in tax in 846.

Figure 1

The hydraulic state: short-run equilibrium

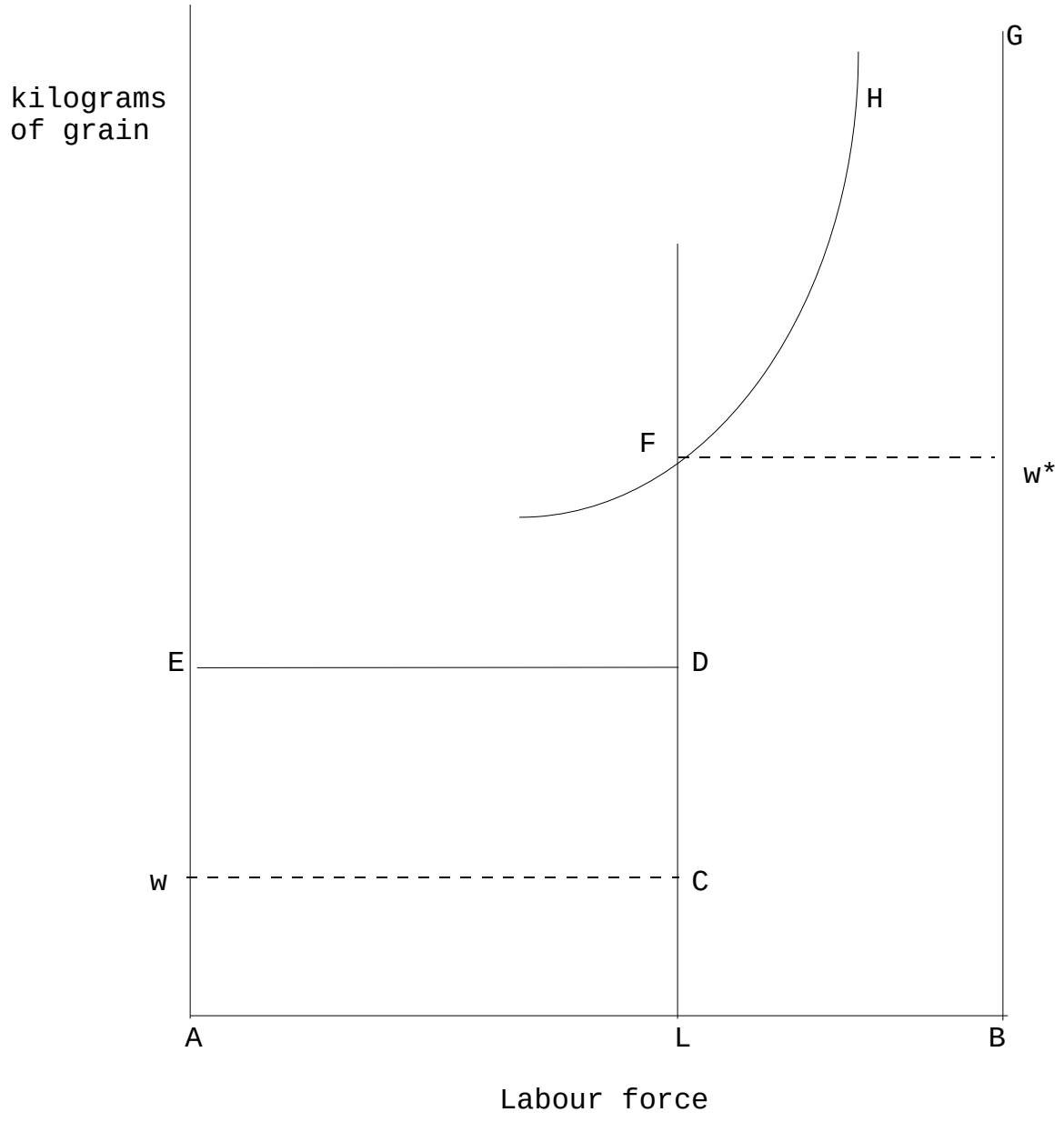
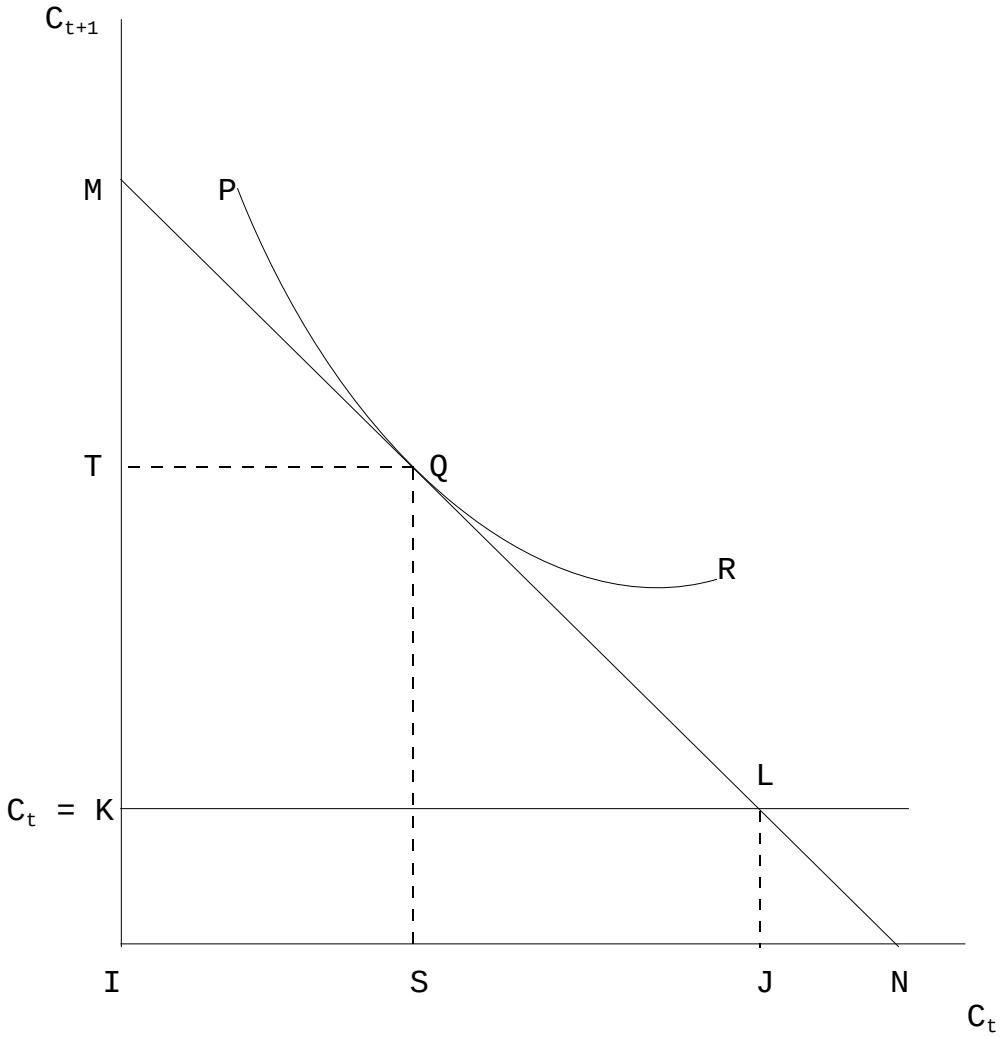


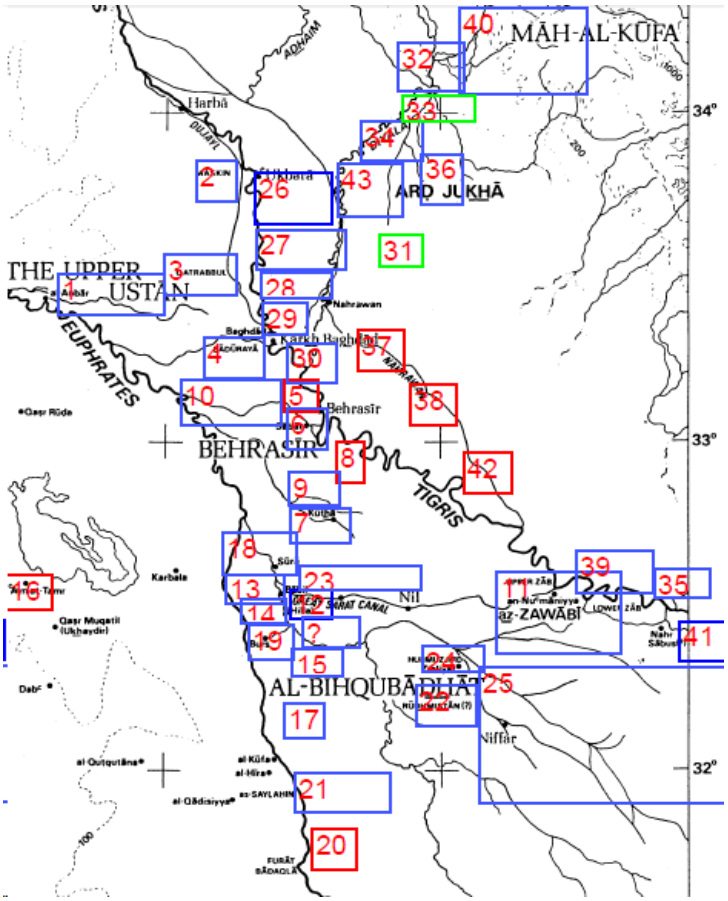
Figure 2

The hydraulic state: long run equilibrium



Appendix
the location of the Sawad tax districts

number	district
1	Anbar & canal Isa
2	Maskan
3	Katrabbol
4	Baduraja
5	Canal Nahr Shur Bahorasyr
6	Rumakan
7	Kuta
8	Canal Darkyt
9	Canal Gaubar
10	Barusama und Nahr Malik
11	Three Zab district
12	Babel und Chatarijja
13	Over Falluga
14	Under Falluga
15	Nahrain
16	Ain al-Tamr
17	Ganna
18	Sura & Barbisma
19	Over & Under Bors
20	Forat Badakla
21	Sailahyn
22	Rumistan und Hormozgird
23	Jasyr/Nistar
24	Yghar Jaktyn
25	Kaskar District
26	Bozork Sabur
27	Radanain
28	Nahr Buk
29	Kalwada & Nahr Byn
30	Gazir & Madynat al'atyka
31	Rostakabad
32	Galula & Halula
33	Zabanain/Dasyn
34	Daskara
35	Bandanygain
36	Baraz al-rud
37	Upper Nahrawan
38	Middle Nahrawan
39	Badaraja und Baksaja
40	Hulwan
41	Canal Sila
42	Lower Nahrawan



References

Adams, Robert McC. (1965). *Land Behind Baghdad: A History of Settlement on the Siyala Plains*, Chicago, University of Chicago Press.

Adams, Robert McC. (1981). *Heartland of Cities: Surveys of Ancient Settlement and Land Use on the Central Floodplain of the Euphrates*, Chicago, University of Chicago Press.

Ashtor, Eliyahu (1969). *Histoire des prix et des salaires dans l'orient médiéval*, Paris, S.E.V.P.E.N.

Ashtor, Eliyahu (1976). *A Social and Economic History of the Near East in the Middle Ages*, London, Collins.

Beg, Muhammad Abdul Jabbar (1972). "A Contribution to the Economic History of the Caliphate: A Study of the Cost of Living and the Economic Status of Artisans in Abbasid Iraq," *Islamic Quarterly*, Vol. 16, pp. 140-167.

Bulliet, Richard W. (2009). *Cotton, Climate, and Camels in Early Islamic History*, New York, Columbia University Press.

Busse, Heribert (1967). "Das Hofbudget des Califen al-Mu'tadid billāh (279/892 - 289/902)," *Der Islam: Zeitschrift für Geschichte und Kultur des Islamischen Orients*, Vol. 43, pp. 11-36.

Cahen, Cl. (1949-51). "Le service de l'irrigation en Iraq au début de XIe siècle," *Bulletin d'Etudes orientales*, pp. 117-134.

Campopiano, Michele (2012). "State, Land Tax and Agriculture in Iraq from the Arab Conquest to the Crisis of the Abbasid Caliphate (Seventh-Tenth Centuries)," *Studia Islamica*, Vol. 107, pp. 1-37.

Christensen, Peter (1993). *The Decline of Iranshahr: Irrigation and Environments in the History of the Middle East, 500 B.C. to A.D. 1500*, Copenhagen, Museum Tusculanum Press.

El-Samarraie, Husam Qawam (1972). *Agriculture in Iraq during the 3rd. Century A.H.*, Beirut, Librairie du Liban.

Goldsmith, Raymond W. (1987). *Premodern Financial Systems: A Historical Comparative Study*, Cambridge, Cambridge University Press.

Halstead, P. (1990). "Quantifying Sumerian Agriculture–some seeds of doubt and hope," *Bulletin on Sumerian Agriculture*, Vol. 5, pp. 187-95.

Hruška, B. (1984). "Die Bodenberarbeitung und Feldbestellung im Altsumerischen Lagaš," *Archiv Orientálni*, Vol. 52, pp. 150-7.

Jackson, Lowis dA. (1885). *Statistics of Hydraulic Works and Hydrology of England, Canada, Egypt, and India*, London, W. Thacker & Co.

Kennedy, Hugh N. (2001). *The armies of the caliphs : military and society in the early Islamic state*, London, Routledge.

Kennedy, Hugh N. (2005). *When Baghdad ruled the Muslim world : the rise and fall of Islam's greatest dynasty*, Cambridge, MA, Da Capo Press.

Kollars, John F., and Mitchell, William A. (1991). *The Euphrates River and the Southeast Anatolia Development Project*, Carbondale, Illinois, Southern Illinois University Press.

Korobkova, G.F. (1981). "Ancient Reaping Tools and their Productivity in the Light of Experimental Tracewear Analysis," in *The Bronze Age Civilization of Central Asia: Recent Soviet Discoveries*, ed. By Philp L. Kohl, Armonk, NY, M.E. Sharpe, Inc., pp. 325-49.

Kuran, Timur (2010). *The Long Divergence: How Islamic Law Held Back the Middle East*, Princeton, Princeton University Press.

Lambton, A.K.S. (1989). "The Qanats of Qum," in *Qanat, Kariz, and Khattara*, ed. by Peter Beaumont, Michael Bonine, and Keith MacLachlan, Wisbech, Middle East & North African Studies Press Ltd.

Levy, Reuben (1957). *The Social Structure of Islam*, Cambridge, Cambridge University Press.

Mabry, Jonathan (1996). *Canals and Communities: Small-Scale Irrigation Systems*, Tucson, University of Arizona Press.

McEvedy, Colin, and Jones, Richard (1977). *Atlas of World Population History*, Penguin Books.

Morony, Michael G. (1984). *Iraq after the Muslim Conquest*, Piscataway, NJ, Gorgias Press, facsimile edition, 2005.

Pamuk, Sevket, and Shatzmiller, Maya (2014). "Plagues, Wages, and Economic Change in the Islamic Middle East, 700–1500," *The Journal of Economic History*, Vol. 74, pp. 196-229.

Popovic, Alexandre (1975). *La Révolte des esclaves en Iraq au IIIe/IXe siècle*, Paris, Librarie Orientaliste Paul Geuthner, S.A.

Potts, D.T. (1997). *Mesopotamian Civilization: The Material Foundations*, Ithaca, Cornell University Press.

Powell, M.A. (1984). "Late Babylonian Surface Mensuration," *Archiv für Orientforschung*, Vol. 31, pp. 32-66.

Powell, M.A. (1990). "Masse und Gewichte," *Reallexikon der Assyriologie*, Vol.7, pp. 457-530.

Quereshi, Asad Sarwar, and al-Falahi, Adnan A. (2015). "Extent, Character, and Causes of

Soil Salinity in Central and Southern Iraq and Possible Reclamation Strategies," *International Journal of Engineering Research and Applications*, Vol. 5, pp. 84-94.

Russell, J.C. (1958). "Late Ancient and Medieval Population," *Transactions of the American Philosophical Society*, Vol. 48, No. 3, pp. 1-152.

Russell, K.W. (1988). *After Eden: The Behavioural Ecology of Early Food Production in the Near East and North Africa*, British Archaeological Reports International Series 391.

Saleh Ahmed el-Ali (1971). "A New Version of Ibn al-Mutarrif's List of Revenues in the Early Times of Harun al-Rashid," *Journal of the Economic and Social History of the Orient*, Vol. 14, pp. 303-310.

Smith, Adam (1776). *An Inquiry into the Nature and Causes of the Wealth of Nations*, http://www.gutenberg.org/files/3300/3300-h/3300-h.htm

Treadgold, Warren (1988). *The Byzantine Revival, 780-842*, Stanford, Stanford University Press.

Verkinderen, Peter (2015). *Waterways of Iraq and Iran in the Early Islamic Period*, London, I.B. Taurus & Co Ltd.

Van Bavel, Bas (2016). *The Invisible Hand?: How Market Economies have Emerged and Declined Since AD 500*, Oxford, Oxford University Press.

von Kremer, Alfred (1875). *Culturgeschichte des Orients unter den Califen*, Wien, Wilhelm Braumüller, erster Band.

von Kremer, A. Freiherrn (1887). *Ueber das Einnahmebudget des Abbasiden-Reichs vom Jahre 306 H. (918-919)*, Wien Carl Gerold's Sohn.

Waines, David (1977). "The Third Century Internal Crisis of the Abbasids," *Journal of the Economic and Social History of the Orient*, Vol. 20, pp. 282-306.

Watson, Andrew M (1974), "The Arab Agricultural Revolution and Its Diffusion, 700–1100", *The Journal of Economic History*, Vol. 34, pp. 8–35.

Watson, Andrew M (2008) *Agricultural innovation in the early Islamic world : the diffusion of crops and farming techniques 700-1100*, Cambridge, Cambridge University Press.

Willcocks, W. (1899). *Egyptian Irrigation*, . London, E. & F.N. Spon, Limited.

Willcocks, Sir William (1917). *Irrigation of Mesopotamia*, London, E. & F.N. Spon, Limited, second edition.

Wilkinson, T.J. (1994). "The Structure and Dynamics of Dry-Farming States in Upper Mesopotamia," *Current Anthropology*, Vol. 35, pp. 483-520.

Wittfogel, Karl August (1957). *Oriental Despotism: A Comparative Study of Total Power*, New Haven, Yale University Press.