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Markets in pre-industrial societies: storage in Hellenistic Babylonia in the medieval English mirror*

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Abstract

At least some ancient civilizations used various risk-management strategies to minimize price volatility. In this article, we examine one such strategy, grain storage, by means of a dataset recently made available that provides agricultural prices for Babylonia during the Late Achaemenid and Hellenistic periods (c.400–65 BCE). A comparative analysis of medieval England and Hellenistic Babylonia reveals a low level of inter-annual storage in both economies, and helps us to compare the costs and benefits in each society. Costs are largely equated with interest rates, and benefits with seasonal price changes. Unlike in England, Babylonia's dual crop structure (barley and dates) reduced seasonality and thus the potential benefits of storage. There is no evidence, however, that storage costs – that is, interest rates – were likewise lower. This suggests that interest rates were primarily determined in the urban and commercial sectors, not the agricultural one. Consequently, measures of seasonal price changes in pre-modern economies may tell us relatively little about interest rates. While the McCloskey–Nash methodology may be helpful in analysing particular economies, it is perhaps of limited use for comparing them.

Keywords ancient and medieval economies, Babylon, England, risk reduction, storage

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Introduction

Market efficiency – defined as the capability of markets to use trade, technology, and/or storage techniques to reduce the risk of shortage – has in recent years become the focus of considerable attention.[1] With the exception of medieval England,[2] however, quantifications of the magnitude of storage have rarely been attempted for pre-industrial societies.[3] This is in spite of the often rich evidence found for many societies – from Nigeria *c.*600 BCE to the Inca empire to classical Rome.[4] This can partially be explained by a lack of quantifiable data, that is, prices.[5] Fortunately, a dataset for the city of Babylon, only recently made available, allows precisely such an analysis for the second half of the first millennium BCE, the so-called Hellenistic era, when the region fell under the sway of Alexander the Great and his successors, known collectively as the Seleucid dynasty. The data are available from the 'Astronomical diaries'.[6] These cuneiform tablets recorded a variety of observed celestial, climatic, ecological, and economic phenomena, alongside accounts of historical events. One of the largest collections of observational data available from any ancient period in world history, they consist of hundreds of tablets spanning several hundred years (*c.*400–60 BCE). Among the economic information that they contain are price quotations of, *inter alia*, barley

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1 See, for example, Karl-Gunnar Persson, *Grain markets in Europe, 1500–1900: integration and deregulation*, Cambridge: Cambridge University Press, 1999; Peter Temin, 'Price behavior in ancient Babylon', *Explorations in Economic History*, 39, 1, 2002, pp. 46–60; Roman Studer, 'India and the great divergence: assessing the efficiency of grain markets in eighteenth- and nineteenth-century India', *Journal of Economic History*, 68, 2, 2008, pp. 393–437.

2 See Stefano Fenoaltea, 'Risk, transaction costs, and the organization of medieval agriculture', *Explorations in Economic History*, 13, 2, 1976, pp.129–51; Stefano Fenoaltea, 'Transaction costs, Whig history, and the common fields', *Politics & Society*, 16, 2–3, 1988, pp. 171–240; Donald N. McCloskey and John Nash, 'Corn at interest: the extent and cost of grain storage in medieval England', *American Economic Review*, 74, 1, 1984, pp. 174–87; John Komlos and Richard Landes, 'Anachronistic economics: grain storage in medieval England', *Economic History Review*, 44, 1, 1991, pp. 36–45; Donald N. McCloskey, 'Conditional economic history: a reply to Komlos and Landes', *Economic History Review*, 44, 1, 1991, pp. 128–32; Nicholas Poynder, 'Grain storage in theory and history', unpublished paper for third conference of European Historical Economics Society, Lisbon, 1999; Jordan Claridge and John Langdon, 'Storage in medieval England: the evidence from purveyance accounts, 1295–1349', *Economic History Review*, forthcoming, http://onlinelibrary.wiley.com/doi/10.1111/j.1468-0289.2010.00564.x/full (consulted 10 April 2011).

3 Exceptions are, for example, Kenneth Pomeranz, *The making of a hinterland: state, society, and economy in inland north China, 1853–1937*, Berkeley, CA: University of California Press, 1993, pp. 32–3.

4 See, for example, Giovanna Vitelli, 'Grain storage and urban growth in imperial Ostia: a quantitative study', *World Archaeology*, 12, 1, 1980, pp. 54–68; Terry Y. Levine, *Inka storage systems*, Norman, OK: University of Oklahoma Press, 1992; Detlef Groneborn, 'An ancient storage pit in the SW Chad Basin, Nigeria', *Journal of Field Archaeology*, 24, 1997, pp. 431–9.

5 Important studies of price data of antiquity include Dominic Rathbone, 'Prices and price formation in Roman Egypt', in J. Andreau, P. Briant, and R. Descat, eds., *Économie antique: prix et formation des prix dans les économies antiques*, Saint-Bertrand-de-Comminges: Musée archéologique départemental, 1997, pp.183–244; Gary Reger, *Regionalism and change in the economy of independent Delos*, Berkeley, CA: University of California Press, 1994; Sitta von Reden, 'Price fluctuations in Babylonia, Egypt, and the Mediterranean world, third to first centuries BC', unpulished paper for 'Too Many Data? Generalizations and Model-building in Ancient Economic History on the Basis of Large Corpora of Documentary Evidence' conference, Vienna, 17–19 July 2008.

6 H. Hunger and A. Sachs, *Astronomical diaries and related texts from Babylonia*, 3 vols, Vienna: Verlag der Österreichischen Akademie der Wissenschaften, vol. 1, *652– 262 BC*, 1988; vol. 2, *261–165 BC*, 1989; vol. 3, *164–61 BC*, 1996.

and dates, Babylon's two main staple crops.[7] In theory, reliable data (in some cases multiple observations) are available for every month, but in fact, on account of numerous gaps in the documentation, price data for barley are available for only 13.76% (or 535 out of 3,887) of the months spanned by the dataset. As for dates, the percentage is slightly lower, at 12.58%. Földvári and van Leeuwen contend, however, that the missing data are 'missing at random' and therefore uncorrelated with our key variable: seasonality.[8]

In the pages that follow we use this unique dataset to compare storage in Hellenistic Babylon and medieval England. Scarcity of data is always a problem when it comes to historical research, and our decision to compare the market mechanisms operating in these two societies is largely a consequence of the existence of these data. This issue is, in fact, of little consequence, however, since it turns out that what we are able to glean from the data concerning risk-reduction strategies can be extended to pre-industrial societies generally. This generalization follows from the difference between the two societies. Although we are dealing with a pair of societies that, being agrarian, did not need to import basic foodstuffs, there the similarity ends. It is the difference between their crop structures that enables us to test the validity of the McCloskey–Nash storage model for pre-industrial economies in general, and to assess its cross-regional value.

According to McCloskey and Nash, the price that a given season's grain commands after the harvest must exceed the price that it had commanded prior to the harvest by a sum equal to the marginal cost of its storage.[9] On the one hand, if there is a profit in storing grain, and thereby delaying its sale, this will be done. On the other hand, if this causes the post-harvest price to fall so far that the storage profit margin shrinks to nothing, the post-harvest price must cover the cost of storage: more specifically, of foregone investment, barn rental, and loss of stored grain to spoilage.[10]

Storage seems a straightforward method of risk management, but several studies indicate that during their pre-industrial period few societies practised it to a significant extent. McCloskey and Nash, as well as Clark, argue that in England high interest rates significantly reduced the financial advantages of storage.[11] This explained its rarity.[12] As we show, this argument holds for Babylonia, too, even though the two societies' agricultural

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7 For prior analyses of the data, see Alice L. Slotksy, *The bourse of Babylon: market quotations in the Astronomical diaries of Babylonia*, Bethesda, MD: CDL Press, 1997 (with the important review by R. J. Van der Spek and C. Mandemakers, 'Sense and nonsense in the statistical approach of Babylonian prices', *Bibliotheca Orientalis*, 60, 2003, pp. 521–7); Peter Vargyas, *Les prix des denrées alimentaires de première nécessité en Babylonie à l'époque achémenide et hellénistique*, in Andreau, Briant, and Descat, *Économie antique*, pp. 335–54. For additional price data, see Alice L. Slotksy and Ronald Wallenfels, *Tallies and trends: the late Babylonian commodity price lists*, Bethesda, MD: CDL Press, 2010.

8 Peter Földvári and Bas van Leeuwen, 'The structural analysis of Babylonian price data: a partial equilibrium approach', unpublished paper for World Economic History Congress, Utrecht, 2–7 August 2009.

9 McCloskey and Nash, 'Corn at interest'. See also Gregory Clark, 'The cost of capital and medieval agricultural technique', *Explorations in Economic History*, 25, 3, 1988, pp. 265–94; Poynder, 'Grain storage'.

10 McCloskey and Nash, 'Corn at interest'; Poynder, 'Grain storage'.

11 McCloskey and Nash, 'Corn at interest'; Clark, 'Cost of capital'.

12 On the other hand, some authors argue for a much larger role for storage. For example, Stefano Fenoaltea, 'Risk', p. 139, suggests that storage in England could easily be in the order of magnitude of 1.5 times the annual consumption. However, two preconditions for such a high storage rate are sharply

supply situations were radically different. In England, the outputs of the two main crops, barley and wheat, were positively (though weakly) correlated, sharing as they did the same harvest period. It was as if English agriculture was dominated by a single food crop. Instead of wheat, Babylon cultivated dates, which were harvested in the autumn, and were thus negatively correlated with the other main crop, barley, harvested in the spring. This dual crop structure implies that intra-annual price changes, and thus the financial advantages of storage, were probably reduced.[13] Thus, if we assume that the agricultural sector alone determines the interest rate, storage costs (foregone interest, primarily) must have been lower as well. In an ancient society such as Babylonia, dominated as it was by agricultural credit, with the interest rate driving seasonality, one would expect the combination of a dual crop structure with relatively low seasonal volatility to lead to an interest rate substantially lower than medieval England's, but this was not the case. There are two possible explanations: either the costs of barn rental and crop-storage losses were considerably lower in Babylon or in both economies – despite their being pre-industrial – the interest rate was determined by sectors other than agriculture, in which case comparison of their seasonal price changes cannot provide a reliable basis for a comparison of interest rates across economies.[14]

In the following section, we discuss the evidence for storage, the benefits and costs of storage, and the discrepancy between costs and benefits. In the fifth and last section we offer our conclusions concerning not only storage in Hellenistic Babylon but also the role of the interest rate in pre-industrial economies generally.

Evidence for storage

There is little direct evidence for crop storage in pre-industrial societies. A simple model would suggest that, in order to assure a smooth consumption path, in the case of a single crop harvested once a year (or two related crops harvested at roughly the same time) the entire crop was stored for six months, on average. In England prior to the Black Death, which peaked in Europe in the middle of the fourteenth century, we can distinguish barley and wheat as the two main crops. Broadberry et al. estimate the share of barley and wheat

higher grain-yield variances and the disappearance of the phenomenon of recurrent famine, both of which are extremely unlikely.

13 Dates played a fundamental part in the dietary habits of the Middle East until well into the twentieth century. According to a study quoted in Michael Jursa, *Aspects of the economic history of Babylonia in the first millennium BC: economic geography, economic mentalities, agriculture, the use of money and the problem of economic growth* (with contributions by J. Hackl, B. Janković, K. Kleber, E. E. Payne, C. Waerzeggers, and M. Weszeli), AOAT 377, Münster: Ugarit Verlag, 2010, p. 50, an Iraqi small-scale farmer consumed 65.1 kg of dates a year compared to 75.3 kg of wheat, barley, and rice; the two commodities together accounted for about two-thirds of total caloric intake. A similar proportion in antiquity is indicated by the 'ration' system of the Ebabbar temple of Sippar, in northern Babylonia, which ideally provided workers with equal amounts of barley and dates: see M. Jursa, 'The remuneration of institutional labourers in an urban context in Babylonia in the first millennium BC', in P. Briant, W. F. M. Henkelman, and M. Stolper, eds., *L'archive des fortifications de Persépolis : état des questions et perspectives de recherches*, Persika 12, Paris: De Boccard, 2008.

14 A third possibility, outlined in Komlos and Landes, 'Anachronistic economics', is that when it comes to storage small-scale farmers may be hampered by socioeconomic limitations, even if not by the opportunity costs to large-scale producers and traders.

in the total output of England's arable sector around 1300 to have been close to 60%.[15] Winter wheat was harvested in May/June, whereas spring barley was harvested in late August/September. In the period before the Black Death, barley was milled for flour and baked into bread, but by 1600, according to Overton and Campbell, only 35% of England's total barley output was put to this use. Furthermore, by the late sixteenth century, 'most English ale was being brewed from barley, in contrast to the situation 300 years earlier when significant quantities had been brewed from dredge and oats'.[16] It therefore seems safe to make two assumptions: that barley and wheat were the main foodstuffs before the Black Death, and that during three seasons out of four – that is, except in summer – the English had to rely on storage.

Babylon was similar to England prior to the Black Death in that it too had two main crops, barley and dates; but it differed from England in that the two harvest times were farther apart, in March/April and October. We follow the literature in assuming first that the shares of the two crops in the diet were roughly equal and second that the two crops were perfect substitutes.[17] It follows that if starvation was to be prevented, in principle each crop had to be stored for only three months on average – that is, until the harvest of the other crop. Additionally, we must take into consideration that, whereas the quality of barley and wheat deteriorates with storage, the quality of dates may actually improve, and therefore their value may increase. Since fresh dates cannot be stored (they would rot on account of their high water content), about two months after the harvest dried dates started to dominate the date market.[18] Dried dates have a higher sugar content and a lower volume than fresh ones. Because dates were sold by volume (per *qa*, conveniently close to a litre), soon after the harvest the price started to rise, as the proportion of fresh to dried dates diminished over time. This seasonality must be factored into any calculation of the costs and benefits of storage.

Since people have to eat between as well as during harvest periods, every economy needs at least a basic form of short-term storage system. Given that roughly a twelfth of the crop harvested is consumed each month, it follows that six months is one harvest's average storage time, if it were not for the possibility of carryover from one year to the next (inter-annual storage). According to McCloskey and Nash, there is direct evidence that in medieval England carryovers averaged 5% of the harvest at best and were limited, for the

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15 Steve Broadberry, Bruce Campbell, Alex Klein, Mark Overton, and Bas van Leeuwen, 'British economic growth, 1300–1850: some preliminary estimates', unpublished paper for World Economic History Congress, Utrecht, 2–7 August 2009.

16 Mark Overton and Bruce Campbell, 'Production et productivité dans l'agriculture anglaise, 1086–1871', *Histoire et Mesure*, 11, 3–4, 1996, pp. 255–97, table 12.

17 G. G. Aperghis, *The Seleukid royal economy: the finances and financial administration of the Seleukid empire*, Cambridge: Cambridge University Press, 2004, and the literature quoted therein; Jursa, *Aspects*. See also the information provided above, n. 13. An important corroboration is the finding in Vargyas, *Les prix*, that the date harvest constituted a relief in the supply situation of the food market, resulting in higher barley equivalents, that is, lower barley prices. As we explain later, this assumption can be defended in times of famine, when the vital need is for any calories. Barley and dates are thus considered simply as sources of kilocalories, and hence as substitutes.

18 See, for instance, V. H. W. Dowson, *Dates and date cultivation of the 'Iraq*, Agricultural Directorate of Mesopotamia, part 1, 1921, p. 41.

most part, to manors and royal storage facilities.[19] Although they show that in plentiful years there may have been some carryover,[20] it was rarely of any significance. Beveridge concurs, concluding that little in the way of grain was stored beyond the following harvest.[21]

Similarly, Jursa estimates that storage in Babylonia during the first millennium BCE was minimal, mostly because of the socioeconomic situation. He argues that, in order to meet tax requirements, the big producers (that is, the temples) were forced to sell the lion's share of their cash-crop production immediately after harvest. Having revealed a seasonal pattern in the sales of dates from the Ebabbar temple in Sippar (with dates usually being described as the temple's main cash crop), he concludes that 'by and large the temple did not hoard dates with the intention of making them available to outsiders after the intensive phase of selling following the harvest'.[22] In other words, the tax demand of the central government meant that the temples were unable to store commodities on a large scale, with the aim of selling them in the following year.

In addition, among the price quotations in the 'Astronomical diaries' (ADs) one finds several observations of 'old' and 'new' barley and dates, but most of them refer to the new harvest and therefore do not prove that carryovers existed. Indeed, new barley generally appears in the texts during the harvest period (Babylonian months I and II). This 'new' (*eššu*) barley is always cheaper, and either replaces barley without additional attribute (as in AD 308)[23] or runs parallel to it (S/W texts 9 and 12).[24] In either case the price decreases. A clear example is given in Table 1, where one can see that the prices rise until day fifteen, when the new barley enters the market, and that at that point they begin to fall. This pattern can be best explained as an effect of the supply increase, with the arrival of the new crop, rather than as a change in quality. Again, we have failed to find any solid evidence that inter-annual storage was available for barley.

'New dates' followed the same pattern. It is not surprising that at harvest time, when supply rose, prices for both barley and dates fell, that of dates by about twice as much as that of barley: about 20% and 10%, respectively. The fact that dried (= old) dates have a higher weight per litre and a higher sugar content than do fresh ones accounts for the difference in the percentage of the price declines for fresh dates and fresh barley. In fact, this pattern is widespread. In his study of Roman Egypt, for instance, Drexhage reports fresh dates to have been cheaper than dried dates.[25]

The only extant reference to either old or new dates outside the harvest season is recorded on the cuneiform tablet S/W text 6. The most plausible explanation is that it refers

19 McCloskey and Nash, 'Corn at interest'.

20 *Ibid.*, p. 174.

21 William H. Beveridge, 'The yield and price of corn in the Middle Ages', *Economic History Review,* 1, 1927, pp. 155–67.

22 Jursa, *Aspects*, pp. 591–2.

23 That is, specified by neither 'old' nor 'new'.

24 S/W text x: text number in Alice Slotsky and Ronald Wallenfels, *Tallies and trends: the late Babylonian commodity price lists*, Bethesda, MD: CDL Press, 2010.

25 Hans-Joachim Drexhage, *Preise, Mieten/Pachten, Kosten und Löhne in römischen Ägypten*, St Katharinen: Scripta Mercaturae Verlag, 1992, p. 36.

Table 1. Barley prices (shekels/100 litres) in Babylonian month II 186 SE (27 April–25 May 126 BCE in the Julian calendar).

Commodity	Designation	Day	Price (shekels/100 litres)
Barley	—	day 1	5.56 (2.86)
		until day 7	5.00
		days 8–10	5.56
		day 11 until end of month	4.76
	new	day 15	2.78
		days 16–17	2.22
		day 18	2.78
		days 19–22	3.03
		day 26 until end of month	2.50

Source: Slotsky and Wallenfels, *Tallies and trends*, text 9.

to inter-annual storage. If the standard dates were the ones most recently harvested, in the autumn of 138 BCE, then the dates designated as old must be from an earlier harvest. Evidence referring to 'old' produce, defined here as produce stored for longer than a year, is thus very meagre in the rich corpus of Late Babylonian price records, which amount to more than 3,500 observations. This finding is consistent with the contention that the economic impact of carryover was minimal during the Late Babylonian era.

There is considerable indirect evidence of small-scale storage in both Hellenistic Babylonia and medieval England associated with periods of famine, most notably the great European famine of 1315–17. Since it is difficult to establish what each of the various chroniclers and historiographers of the two societies under study meant by 'famine', we shall define it broadly enough to include food crises characterized 'by rising prices, popular discontent and hunger, in the worst cases leading to death by disease or starvation', rather than restricting it to cases of mass starvation.[26] This broader definition enables us to compare the two datasets and, more specifically, to analyse the correlation of famine with extremely high prices, as is often done in the literature on both England[27] and Babylon.[28]

26 Peter Garnsey, 'Famine in history', in P. Garnsey, ed., *Cities, peasants and food in classical antiquity*, Cambridge: Cambridge University Press,1998, p. 275. Note, however, that the Babylonian famine threshold employed seems to meet one important criterion of famine as defined more narrowly, namely a 'collapse of the social, political, and moral order' (Garnsey, ' Famine', p. 275). This, at least, is how we would interpret the fact that parents were reported to sell their children in order to fend off starvation. Cormac Ó'Gráda, *Famine: a short history*, Princeton, NJ: Princeton University Press, 2009, pp. 3–7, likewise offers a pragmatic definition of famine.

27 W. G. Hoskins, 'Harvest fluctuations and English economic history 1480–1619', *Agricultural History Review*, 12, 1964, pp. 28–46; *idem*, 'Harvest fluctuations and English economic history 1620–1759', *Agricultural History Review*, 16, 1968, pp. 15–31. Hoskins defines famine years as those when the price was more than 10% above a thirty-one-year moving average.

28 Vargyas, *Les prix*; Robartus van der Spek, 'How to measure prosperity? The case of Hellenistic Babylonia', in R. Descat et al., eds., *Approches de l'économie hellénistique*, Paris: Entretiens d'Archéologie et d'Histoire, St Saint-Bertrand-de-Comminges, 2006, pp. 287–310.

On average, England experienced famine as often as every ten to fifteen years,[29] which is evidence in its own right of the lack of large-scale inter-annual storage. As for Babylon, we are fortunate to have the so-called 'siege documents', edited by Oppenheim, which provide direct evidence of what Babylonians themselves considered famine prices.[30] However, the prices in these documents are mere formulations rather than actual sale prices (in the style of 'barley costs a million nowadays') and are therefore conspicuously high.[31] In all cases, these prices ranged between 8.3 and 50 shekels per 100 litres of barley. The more reliable famine prices recorded in the 'Astronomical diaries' are considerably lower. In fact, several passages in the historical sections of the same tablets report that famines could be so severe that residents of the city of Babylon were obliged to sell their children in order to stave off starvation, a phenomenon also reported in the siege documents. Using these data, based on the notations of contemporary Babylonian scribes, van der Spek calculates that famine conditions can be said to have prevailed when one shekel could buy 39 litres of barley.[32] We set the food price slightly lower, at 40 litres per shekel, but add a constraint: the prices of both barley and dates must rise to this level or higher for the term 'famine' to be applicable, since barley and dates contain roughly the same number of kilocalories per litre, making the cheaper of the two the logical choice when starvation threatens. Using this method, we can identify nine famines in the 133 years for which we have data, a rate that works out at roughly one famine every fourteen years.

This relatively high famine frequency, in both England and Babylon, clearly indicates that carryovers of any significance were not a standard practice. We can formalize this conclusion by estimating the expected time that it will take for a famine to occur, given a certain level of inter-annual storage. The first step is to calculate the standard deviation of agricultural output: a straightforward calculation in the case of one crop, but in England we have wheat and barley and in Babylon barley and dates. These two pairs of crops are far from equivalent. Since England's wheat and barley have more characteristics in common (both being grain crops harvested in the summer) than do Babylon's barley and dates (the latter being a fruit harvested in the autumn), it follows that the output of wheat and barley in England is more closely correlated than that of barley and dates in Babylon. This discrepancy has an impact on the standard deviation, and hence on the likelihood of famines. Since the standard deviation is simply the square root of the variance, we combine, for simplicity's sake, the variances of the two series: that is, we treat barley and dates as a perfect pair of substitutes. This assumption can be defended since, when threatened by famine, people maximize their calorie intake,[33] and dates and barley have approximately the same per-litre caloric content,[34] permitting us to convert quantities into calories. Thus we start with

29 Donald N. McCloskey, 'English open fields as behavior towards risk', in P. Uselding, ed., *Research in economic history*, vol. 1, Greenwich, CT: JAI Press, 1976, p. 144.

30 A. Leo Oppenheim, 'Siege documents from Nippur', *Iraq*, 17, 1955, pp. 69–89.

31 This has also been shown by Israel Eph'al *The city besieged: siege and its manifestations in the ancient Near East*, Leiden: Brill, 2009; he argues that these prices are best considered as literary *topoi* of little historical value.

32 Van der Spek, 'How to measure prosperity?'. His estimate confirms the earlier assumption of Peter Vargyas, who made 50 litres per shekel the famine threshold: Vargyas, *Les prix*.

33 See also the text above and notes 13 and 17 on the important role of dates in the Mesopotamian diet and more particularly on the price-alleviating effect of the date harvest on barley prices.

34 Jursa, *Aspects* , p. 51.

$$X \sim (\mu_X, \sigma_X^2)$$

$$Y \sim (\mu_Y, \sigma_Y^2)$$

where μ and σ^2 denote the mean and the variance of the series *X* and *Y*, respectively, and *s* and *z* are their variances. Next, combining the totals of the two variables, we get

$$Z = X + Y$$

where the new series *Z* has a mean $\mu_X + \mu_Y$ and, if the two elements are uncorrelated, the variance is simply the sum of their individual variances. In case the series are correlated, as is the case in England, *Z* (i.e. the level of output) remains unchanged, but the variance becomes:

$$\sigma_Z^2 = \sigma_X^2 + \sigma_Y^2 + 2 \cdot \sigma_{XY}$$

where σ_{XY} is the covariance of *X* and *Y*. In other words, if the two series are positively correlated, both the variance of the sum of the series and the standard deviation will increase even further.

McCloskey and Nash assumed for England the standard deviation of crop production to have a value of 35 (with mean 100) and set the famine level at 50.[35] This figure seems to be somewhat low, since even during the Great Famine the decline in output amounted to only about 38% for wheat and 26% for barley, which means that even a 35–40% drop in production occurred only in exceptional situations such as the Great Famine. Estimated directly, the combined variance of barley and wheat output for England between 1252 and 1345 is 28.1 million.[36] As for the subseries, the variance for wheat in England is 18.5 million and for barley 8.5 million, with a correlation between the two series of 0.04. Applying the above equation, we arrive at $18.5+8.5+2.0.04(0.04)18.5^{0.5}8.5^{0.5} = 28.1$ million, being the same as the sum of the variances of the two series. Taking the square root and dividing by the mean results in a coefficient of variation of roughly 13, substantially lower than the 35 used by McCloskey and Nash, their figures being extremes occurring only during terrible crises. Even if we look at individual manors, we rarely find coefficients of variation exceeding 35.[37] However, correlations of yields between the regions in England are around 0.4–0.5, suggesting that the coefficient of variance for overall output is lower than it is for individual series. Indeed, as Ó Grádá argues, famines such as the Great European one were fairly infrequent, since ‘given that life expectancy was low even in non-crisis years, frequent famines would have made it impossible to sustain population’.[38]

Obtaining similar information for Babylon is complicated by the fact that we are working with prices rather than output data. Jursa gives the output per hectare for barley as

35 McCloskey and Nash, ‘Corn at interest’, p. 176. Their estimates of the parameters and the average waiting time between two famines are based on McCloskey, ‘English open fields’.

36 This estimate is based on the data underlying Broadberry et al., ‘British economic growth’.

37 Bruce M. S. Campbell (2007), ‘Three centuries of English crops yields, 1211–1491’, http://www.cropyields.ac.uk/ (consulted 10 April 2011).

38 Cormac Ó Grádá, ‘Making famine history’, *Journal of Economic Literature*, 45, 1, 2007, p. 8. See also the distinction between food shortage and famine made by Garnsey, ‘Famine’.

1,728 litres, while one hectare of dates yielded around 5,328 litres.[39] Clearly, these figures reflect mean yields and thus do not tell us much about the variance, but they do say something about the relationship between barley and dates. If we assume that the annual variance of barley production is equal to that of date production, and that the mean output of dates is much higher than for barley, this would suggest a correspondingly lower coefficient of variation. Indeed, among present-day Middle Eastern countries that produce a substantial quantity of dates and barley, the annual coefficient of variation of dates is about half that of barley.[40] The standard deviation of the barley output for Babylon, which we proxy by using barley output in medieval England, should be considered the upper limit, since grain-output volatility in medieval England was greater than it is today because of changes in the quality of the grain itself and since Babylon profited from a fairly sophisticated irrigation system. We thus conclude, in line with the literature, that barley and dates were produced in equal quantities and that the variance of dates was half that of barley. Furthermore, given the recent data from the Food and Agricultural Organization, the second assumption is that barley and dates have a negative correlation coefficient of −0.55.[41] In other words, a failed barley harvest is often followed by an above-average date harvest, possibly because barley and dates react differently to climatic factors. This means that the relative variance in Babylon becomes $8.5+8.5.0.5+2(-0.55)8.5^{0.5}.8.5^{0.5}=3.4$ million. Given the total hypothetical output of barley and dates of 16 million bushels, we end up with a coefficient of variation of 6%. In other words, the presence of dates reduces by nearly 50% the relative standard deviation of agricultural output for Babylon.

Using these standard deviations and the resulting famine lines (the percentage below which a harvest must drop before one can declare food-supply conditions to be bad enough to rate the term 'famine'), we use Monte Carlo simulations (500 experiments at a time) in order to estimate how many years, at a given famine line and level of carryover, will separate one famine from the next (see Appendix). As one can see, in Table 2, assuming no storage and a famine line of 90 (a 10% failed harvest) yields an approximately correct period between two famines for Babylon (roughly 19 years). For England, an assumed famine line of 90 and 0% carryover results in an inter-famine period of only 3.5 years, which works out to a frequency rate, even with a 10% carryover, that is implausibly high. Since not only the per-person output of medieval English agriculture but also its volatility was higher than that of Hellenistic Babylonia, the English famine line must have been closer to 80 than to 90, or famines would have been so frequent that population levels could not have been sustained.

However, in both cases any storage above 1% of total output is highly unlikely, since the interval between famines would have been in the range of 88–501 years for Babylon and 51–212 years for England. In other words, had there been extensive storage, famines and

39 Jursa, *Aspects*, pp. 48–53. Both values come from the northern Babylonian town of Sippar.

40 Calculated from the Food and Agricultural Organization (FAO), ResourceSTAT: land-use domain, 2010, http://faostat.fao.org/site/377/default.aspx#ancor (consulted 10 April 2011), taking into consideration only those countries where the two crops have an almost identical share in total output.

41 Calculated from the FAO, ProductionSTAT: crop-use domain, 2010, http://faostat.fao.org/site/567/default.aspx#ancor (consulted 10 April 2011), taking into consideration only those Middle Eastern countries where the two crops have almost identical shares in total output.

Table 2. Expected number of years between famines for various famine lines and carryovers (average production =100)

Country	Famine line relative to 100	Carryover (%) 0	1	5	10
England	70	93.9	167.3	2,499.0	72,915.7
	80	15.1	18.8	50.7	212.4
	90	3.5	3.7	4.7	6.3
Babylon	70	Inf.	Inf.	Inf.	Inf.
	80	2,332.3	8,292.8	Inf.	Inf.
	90	19.9	25.9	87.6	501.2

Note: 500 simulations; standard deviations: England 13, Babylon 6.

food would have been far less frequent than is indicated by extant records from the two periods in question.

Benefits in a cost-benefit analysis of storage

In the previous section we argued that in both Hellenistic Babylon and medieval England the practice of crop storage was insignificant in scope. The dual crop structure that existed in Babylon did not seem to have any effect on that finding, for it reduced intra- (and inter-) annual price fluctuation but this meant a decrease in the standard deviation of the harvest and, by extension, in the frequency of famines. The next question is: why were carryovers so small?

For McCloskey and Nash, the explanation is simply that storage was prohibitively expensive in medieval England.[42] In order to test this hypothesis and also to determine whether it can be extended to Babylon, we assess the potential benefits of storage in each of the two cases and only then address the issue of storage costs, leaving our discussion of cost-benefit discrepancies until later.

With the model of McCloskey and Nash as our point of departure, we proceed on the assumption that not only intra-annual price changes but also inter-annual carryovers are equal to changes in the costs of storage, since inter-harvest prices track storage costs. After all, storing grain makes economic sense only if the benefits outweigh the costs. If the price increase is sufficient to make storage, despite its costs, profitable, then the storage rate will increase, in turn pushing up the price to the point at which the marginal costs and benefits are equal. McCloskey and Nash, as well as Clark, claim that the costs of storage consist of rental costs of a barn, losses (spoiled grain and theft), and, most importantly, foregone earnings, best approximated by the interest rate on capital.[43]

42 McCloskey and Nash, 'Corn at interest'.

43 *Ibid*.; Clark, 'Cost of capital'.

First, we need to determine the monthly increase in prices after harvest, using the methods of McCloskey and Nash. In England, harvest time for winter wheat was May/June and for spring barley early September. We will use wheat in our example, since it was the dominant crop, and September as the benchmark, thus making it easier to take account of the barley harvest. We can rewrite this as annual growth per month. In Table 3b, based on Table 3a, we take the average in the north-east corner above the month pair: for instance, for October–November we take the average of all growth rates above the combination October–November in the matrix.[44] The annual price increase for wheat is 24.4%. One should bear in mind that this estimation technique is based on the premise of a single annual harvest. If two equally important crops are harvested half a year apart, as was the case in Babylon, taking the average of the growth rates of the complete north-east corner will result in an overestimation of the growth (or, to describe it from a cost perspective, the price decline after the second harvest).

Tables 4a and 4b illustrate the situation in Babylon for barley. Again using the north-east corner of the matrix to calculate monthly averages, we arrive at an annual net revenue of no less than 37.8%. This was about 13 percentage points higher than in England, but in reality annual benefits must have been less impressive, since we can see that during the three months immediately after the date harvest the monthly growth rates shifted into negative territory (see the diagonal in Table 4a), partly on account of the new date harvest and partly on account of anticipation of the barley harvest to come in the spring. Because the north-east corner includes the positive growth rates on both sides of the harvest, the average is inordinately high, so we perform a separate calculation for the growth rate from December on, by using the north-east corner prior to December.[45] We thereby arrive at an annual potential profit from storage of 15.3%.

When we perform the same exercise for dates (see Tables 5a and 5b), we arrive at average annual benefits amounting to 31.0%, and, because the barley harvest depressed the price of dates, the potential benefits of storage reach 50.4%, which is an overestimate. In January–February the price increased by as much as 15% because, as we pointed out in the previous section, at this time of year the price at issue was that of dried, not fresh, dates. When we factor in this anomaly, the increase amounts to only16.0%, which is about the same as for barley in Babylon but much lower than for wheat in England.[46]

In sum, it is clear that, when the differences in agricultural structure of the two regions are accounted for, the intra-annual price change in Babylon proves to be significantly lower than the one in England: 16% as opposed to 24.4%, for each region's two crops combined. This discrepancy may explain why Slotksy contended that the Babylonian price data offer

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44 For example, for September–October, the growth rate is the average of September–October, September–November, September–December, etc. For October–November, the growth rate is the average of October–November, October–December, October–January, etc., and September–November, September–December, etc.

45 For example, for February–March we take the averages of February–March, February–April, and February–May, *and* January–March, January–April, and January–May.

46 We calculate the average of the north-east corner separately from that of April (i.e., the barley harvest) onwards. For January and February, we omit the high growth rates, since they were caused by the switch from fresh to dried dates.

Table 3a. Average monthly increases in wheat prices in England, 1270–1345.

From:	**To:**										
	October	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**
September	5.86%	3.51%	3.35%	5.21%	1.59%	1.83%	3.54%	3.45%	2.99%	3.29%	1.67%
October		7.27%	2.86%	4.91%	1.96%	1.09%	2.42%	2.61%	1.79%	3.41%	1.28%
November			7.54%	1.78%	1.98%	1.44%	2.36%	0.75%	0.30%	1.07%	0.62%
December				6.29%	3.77%	2.77%	2.18%	1.75%	2.11%	0.84%	0.25%
January					11.10%	4.86%	6.45%	6.60%	4.24%	0.33%	–0.71%
February						4.93%	2.81%	4.89%	2.58%	2.45%	0.80%
March							1.14%	3.39%	1.73%	0.72%	–0.80%
April								1.36%	–0.37%	1.07%	–1.90%
May									2.82%	2.81%	–0.42%
June										1.77%	0.67%
July											–1.25%

Source: Calculated on the basis of monthly price data from Poynder, 'Grain storage', downloaded from http://www.iisg.nl/hpw/data.php#united

Table 3b. Average monthly increases in wheat prices in England, 1270–1345

September–October	3.30%	March–April	2.15%
October–November	3.00%	April–May	1.71%
November–December	2.49%	May–June	1.30%
December–January	2.29%	June–July	0.96%
January–February	2.51%	July–August	0.02%
February–March	2.39%		

no evidence of seasonality,[47] a contention that has come under criticism.[48] If one applies the method of McCloskey and Nash without factoring in the dual crop structure, one gets inter-harvest price increases of 37.8% and 31.0% for barley and dates respectively: evidence that potential profits from inter-annual storage in Babylon were sharply reduced by the dual crop structure. This alone, however, is just one side of the coin: the cost of storage is the other.

Costs in a cost-benefit analysis of storage

We have seen that, whereas in England the annual benefits of crop storage may have amounted to as much as 25%, in Babylon, mostly on account of the particularities of its dual crop structure, the average was at best around 16%. This suggests that costs had to be minimal for any benefits to accrue to storage. The costs, as pointed out in the introduction, consisted mostly of three items: foregone investment, barn rental, and loss of stored grain to spoilage.

McCloskey and Nash note that in medieval England barn rental constituted only a small portion of total storage costs.[49] Moreover, there is considerable evidence that there was far less investment in the construction and renovation of barns than of houses. Around 1300, a year's house rental was roughly the equivalent of 15 bushels (or about 525 litres) of barley, a price that the Black Death would slash in half.[50] As for Babylon, Jursa estimates that house rental cost a minimum of 3–4 shekels a year, the equivalent of about 400 litres of barley, and somewhere between one month's and two months' wages for full-time work in the sixth century BCE.[51] Since presumably, as was the case in medieval England, house rental was higher than barn rental, it is unlikely that the latter exceeded 6% of the annual value of the grain stored.[52] We thus conclude that the cost of renting a barn in Babylon was slightly lower than that of renting a barn in England.

47 Slotsky, *The bourse*.

48 Temin, 'Price behavior'; Foldvari and van Leeuwen, 'Structural analysis'.

49 McCloskey and Nash, 'Corn at interest', pp. 182–3.

50 Gregory Clark, 'The condition of the working-class in England, 1209–2004', *Journal of Political Economy*, 113, 6, 2005, pp. 1307–40.

51 Jursa, Aspects, p. 686.

52 G. E. Fussel, ed., *Robert Loder's farm accounts: 1610–20*, London: Camden Society, 1936, pp. 158–9.

Table 4a. Average monthly increases in barley prices in Babylon, 350–60 BCE

From:	To:										
	July	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**
June	5.71%	2.76%	5.23%	6.41%	5.51%	7.02%	4.64%	3.55%	2.55%	2.24%	1.47%
July		–0.88%	3.92%	7.42%	3.29%	7.60%	4.75%	3.69%	2.13%	1.73%	1.29%
August			2.86%	2.79%	2.06%	4.10%	9.36%	7.71%	5.06%	3.54%	1.93%
September				1.17%	3.53%	2.62%	7.34%	6.62%	2.16%	4.28%	0.67%
October					4.14%	5.11%	6.60%	4.50%	1.61%	2.97%	0.06%
November						11.51%	11.14%	6.37%	3.59%	2.81%	2.27%
December							17.05%	9.13%	3.61%	4.33%	2.54%
January								–2.77%	–2.07%	–2.72%	–2.96%
February									–1.79%	–2.71%	–5.42%
March										–1.77%	–5.05%
April											–6.39%

Sources: Calculated on the basis of monthly price data from Slotksy, *The bourse of Babylon*; Vargyas, *Les prix*; Slotksy and Wallenfels, *Tallies and trends*.

Table 4b. Average monthly increases in barley prices in Babylon, 350–60 BCE

June-July	4.28%	December–January	4.44%
July–August	3.82%	January–February	2.62%
August–September	4.22%	February–March	1.32%
September–October	4.07%	March–April	0.57%
October–November	3.93%	April–May	−0.87%
November–December	4.35%		

The costs of spoilage during storage follow the same pattern. For England, Overton and Campbell estimate these losses to have been about 10% per annum.[53] While we do not have comparable data for Babylon, Adamson shows that the loss rate in ancient Egypt was about 10%, whereas he sets the rate for Mesopotamia somewhat higher, on account of its less favourable climate.[54] Numerous references to the threat to stored produce posed by fungi and lichens are to be found in Babylonian scientific literature, indicating how serious this was. One line of the omen collection *šumma ālu* dealing with various terrestrial phenomena reads: 'If there is green fungus in a storage bin, there will be no grain in the man's house'.[55] The mere fact that an entire tablet (comprising about 120 omens) was dedicated to problems posed by these two crop destroyers speaks volumes. In general, storage losses were likely to be lower for dates than for grain; combined loss was probably on average about 10%. While this estimate has a wide margin of error, it is safe to say that storage losses constituted a small share of total losses, so the question of the degree of this figure's accuracy is academic.

This brings us to interest rates, the most important and most discussed (perhaps because the most complex) variable. They ranged from 10% on standard loans to more than 50% on consumption credit. The fact that they can be calculated in a number of different ways further complicates the situation. Suppose that a farmer who had been granted consumption credit shortly before the next harvest – that is, before grain prices begin to decline – had to repay the equivalent of two bushels of barley. Shortly after the harvest, when the price of grain had fallen by half, the cost of the credit would double, to the equivalent of four bushels.

We summarize in Table 6 what little direct evidence we have regarding interest rates in Babylon. Admittedly, most of these data – the promissory notes concerning the redemption of a silver (or, occasionally, a commodity) deposit – are to be interpreted as penalty clauses, which were effective only after an initial interest-free period.[56] These penalties

53 Overton and Campbell, 'Production'.

54 P. B. Adamson, 'Problems over storing food in the ancient Near East', *Welt des Orients*, 16, 1985, pp. 5–15.

55 Sally M. Freedman, *If a city is set on a height*, vol. 1 (OPSNKF 17), Philadelphia, PA: University of Pennsylvania Museum, 1998.

56 See Michael Jursa, 'Agricultural managing, tax farming and banking: aspects of entrepreneurial activity in Babylonia in the late Achaemenid and Hellenistic periods', in P. Briant and F. Joannès, eds., *La transition entre l'empire achéménide et les royaumes hellénistiques*, Persika 9, Paris: De Boccard, 2006, pp. 137–222.

Table 5a. Average monthly increases in date prices in Babylon, 350–60 BCE

From:	To:										
	November	December	January	February	March	April	May	June	July	August	September
October	1.52%	–4.11%	19.49%	13.26%	1.81%	2.72%	1.62%	1.04%	1.88%	1.36%	0.52%
November		2.52%	25.43%	15.84%	3.11%	3.77%	5.26%	6.28%	4.10%	2.11%	1.85%
December			12.90%	9.73%	6.38%	8.04%	4.45%	5.14%	4.63%	2.73%	2.46%
January				3.21%	0.85%	–2.63%	–0.67%	–0.54%	0.96%	–1.04%	–0.25%
February					–1.28%	–1.74%	–3.62%	–2.94%	0.06%	–0.49%	–0.48%
March						2.05%	1.38%	1.48%	2.58%	0.89%	0.39%
April							0.72%	–0.12%	1.65%	1.01%	0.95%
May								–3.09%	0.80%	–0.76%	–0.50%
June									2.50%	2.24%	3.48%
July										0.52%	0.49%
August											0.18%

Sources: see Table 4a.

Table 5b. Average monthly increases in date prices in Babylon, 350–60 BCE

October–November	3.74%	April–May	1.35%
November–December	5.49%	May–June	1.08%
December–January	6.22%	June–July	1.32%
January–February	3.44%	July–August	0.87%
February–March	1.64%	August–September	0.83%
March–April	1.54%		

(compounded monthly) were, in effect, interest rates. It is most interesting that the percentage rate of these penalties on commodity loans was always higher than the rate on official loans. For example, late Achaemenid ‘real’ interest rates ranged between 25% and 40% per month for silver loans.[57] Whereas the average interest rate on silver was about 34% per annum, the rate on commodity loans occasionally reached 100%. Evidently commodity loans were deemed high risk, even though the sums involved were relatively small: only a few shekels, as opposed to an average of about 30 for silver. In addition, payment was in kind, indicating that grain-loan borrowers were cash poor.

These interest rates are slightly higher than in medieval England, where, according to Homer and Sylla,[58] interest rates ranged between 10% for institutional loans[59] and more than 50% for individual loans.[60] The interest-rate ranges for the two periods are remarkably similar in two key respects: not only did they share a very high range but they were structurally similar as well. It was around 1220 that the term ‘interesse’, referring to a compensation or penalty for delayed repayment of a loan, and thus a way to circumvent the long-established usury laws, began to appear.[61] This was a distant descendant of the penalty clause in Babylonian contracts, according to which, after an initial interest-free period, a monthly interest payment was imposed.

Our comparison of the interest rates in Babylon and England is further facilitated by the existence of one element common to the two regions: livestock. As McCloskey and Nash observe, the profit on capital investment in livestock – that is, the net annual output of an animal divided by the total value of the animal – yields an estimate equivalent to the interest rate.[62] Of all the livestock candidates for the interest-rate comparison that follows, sheep best suit our purposes, for three reasons: they constituted one of the dominant varieties of livestock in both Babylon and England; they did not require costly feed, such as beans or oats; and their reproduction rates eliminated the problem of depreciation. To describe the

57 Sidney Homer and Richard Sylla, in *A history of interest rates*, 4th edn, Hoboken, NJ: John Wiley, 2005, p. 27, point out that the Hammurabi Code had already set a higher maximum interest rate on loans in grain than on loans in silver.

58 *Ibid.*, p. 89.

59 See also Clark, ‘Cost of capital’.

60 See also McCloskey and Nash, ‘Corn at interest’, p. 183.

61 Homer and Sylla, *History*, p. 17.

62 McCloskey and Nash, ‘Corn at interest’, pp. 183–4.

Table 6. Interest rates in Babylonia

Text	Interest rate	Amount	Date	Commodity and transaction	Literature
NCBT 1052	25% p.a. (1¼ shekels per mina per month)	55 shekels of silver	—	Promissory note	Stolper 1990, p. 22
UCLM 9–2918	40% p.a. (2 shekels per mina per month)	70 shekels of *qalû*-silver	3 VIII 14 Art	Promissory note	Stolper 2000, pp. 676f.
HSM 913.2.212	25% p.a. (1¼ shekels per mina per month)	2 minas of *qalû*-silver	6 IV 34 Art (I or II)	Promissory note	Stolper 1990, p. 5
YBC 5331	30% p.a.[a] (1½ shekels per mina per month)	16½ shekels of silver	VIII 35 Art (I or II)	Promissory note	Stolper 1990, p. 14
BM 109977	80% p.a. (1 *sūtu* per *kurru* per month)	22 *kurru* of dates	12 VI 15 Dar II	Promissory note (*imittu*)	Stolper 1990, p. 9
HSM 913.2.220	25% p.a. (1 ¼ shekels per mina per month)	8 *kurru* of barley	19 III 16 Dar II	Promissory note	Stolper 1990, p. 7
CT 49 34	40% p.a. (2 shekels per mina per month)	—	IX 3 Antigonus	Promissory note (redemption of a silver deposit)	Stolper 1993, p. 18
BM 62684	80% p.a. (2 *sūtu* per *kurru* per month)	120 litres of dates	23 *x* 3 P.A	Promissory note (redemption of a date deposit?)	Stolper 1992, pp. A2–4
BM 77203	40% p.a. (2 shekels per mina per month)	22 shekels of silver	1 I 4 Antigonus	Promissory note (redemption of a silver deposit?)	Stolper 1993, pp. A2–6
BM 109974	10% p.a. (3 *sūtu* per *kurru*)	8 *kurru* of fine barley	11 XI 5? Antigonus	Promissory note	Stolper 1993, pp. A2–8
HSM 893–5-17	40% p.a. (2 shekels per mina per month)	8 shekels of silver	23 VII 6 Alex IV	Promissory note (redemption of a silver deposit?)	Stolper 1993, pp. A2–10

Continues

Table 6. (Continued)

Text	**Interest rate**	**Amount**	**Date**	**Commodity and transaction**	**Literature**
CT 49 102	100% (p.a.?)	15 *kurru* of white barley	24 SE$^{?}$	Promissory note (redemption of a commodity deposit)	Stolper 1993, p. 17
CT 49 106	40% p.a. (2 shekels per mina per month)	158.5 shekels of silver	before 9$^{!}$ IX 35 SE	Promissory note (redemption of a silver deposit)	Stolper 1993, p. 12
BM 54555	80% p.a. (2 *sūtu* per *kurru* per month)	300 litres of white, good-quality barley	36 SE	Promissory note (redemption of a commodity deposit)	Jursa 1998, p. 17
CT 49 111	40% p.a. (2 shekels per mina per month)	5 vats of prime beer, 20 loaves of good bread	13 IX 42 SE	Promissory note (redemption of a commodity deposit)	Stolper 1993, p. 13
BM 59748	20% p.a. (1 shekel per mina per month)	5 shekels of silver	28 XII⊂2 42 SE	Promissory note (tithe)	Jursa 1998, p. 16
CT 49 112	40% p.a. (2 shekels per mina per month)	1/2 mina of silver	42$^{?}$ SE	Promissory note (redemption of a silver deposit)	Stolper 1993, p. 16
BM 55437	40% p.a. (2 shekels per mina per month)	6 minas of silver	4 V 46$^{?}$ SE	Promissory note (redemption of a silver deposit)	Stolper 1993, p. 15
CT 49 116	40% p.a. (2 shekels per mina per month)	---	49 SE	Promissory note? (redemption of a commodity deposit)	Jursa 2006, p.185
CT 49 119	80% p.a. (2 *sūtu* per *kurru* per month)	48 litres of barley	28 X 51 SE	Promissory note (redemption of a commodity deposit)	Jursa 2006, pp. 188f.

Table 6. (Continued)

Text	**Interest rate**	**Amount**	**Date**	**Commodity and transaction**	**Literature**
CT 49 120	80% p.a. (2 *sūtu* per *kurru* per month)	2 shekels of silver (convertible to 2 *kurru* of barley after first deadline)	XII 52 SE	Promissory note (redemption of a silver/ commodity deposit)	Jursa 2006, pp. 189f.
CT 49 121	40% p.a. (2 shekels per mina per month)	80 shekels of silver	54 SE	Promissory note (redemption of a silver deposit)	Stolper 1993, p. 14
CT 39 133	25% p.a.(?)	40 shekels of silver	25 [VII] 96 SE	Silver deposit	Stolper 1993, p. 10
CT 49 134	25% p.a.(?)	40 shekels of silver	19 [VII] 100 SE	Silver deposit	Stolper 1993, p. 11

[a] Jursa, 'Agricultural managing', p.161: missed deadline.

Sources: Matthew Stolper, 'Late Achaemenid legal texts from Uruk and Larsa', *Baghdader Mitteilungen*, 21, 1990, pp. 559–622; *idem*, 'Late Achaemenid, Early Macedonian, and Early Seleucid records of deposit and related texts', *AION* supplement 77, Naples, 1993; *idem*, 'Buildings on bow lands and encumbrances on buildings', in R. Dittmann et al., eds., *Variatio delectat: Iran und der Westen (Fs. P. Calmeyer),* Münster: Ugarit Verlag, 2000; Michael Jursa, *Der Tempelzehnt in Babylonien vom siebenten bis zum dritten Jahrhundert v. Chr.*, AOAT 254, Münster: Ugarit Verlag, 1998; *idem*, 'Agricultural managing'.

situation more succinctly, in mathematical terms,

$$i \cdot P = R - C$$

where i is the interest rate, P is the price of a sheep, and R and C are the revenue and costs of a sheep. Reformulating it in these terms, we get

$$i = (R/P) - (C/P)$$

where the costs (C/P) are close to zero, indicating that the annual interest rate is nearly the same as the annual revenue divided by the costs.

Taking as their example Crawley, the Hampshire estate of the Bishop of Winchester, for the year 1250, McCloskey and Nash estimate that its sheepstock was worth £56 and that it generated annual income earnings of £25 4s, or an interest rate of 45%.[63] The calculation for Babylon is simpler. Using silver talents as the unit of value, Aperghis estimates the overall value of the livestock consisting of 3,648 million sheep at 1,204, of their meat at 241, and of their wool at 620, yielding an interest rate of 71.5%.[64] This was lower than medieval

63 *Ibid*.

64 G. G. Aperghis, 'ABACUS historical modeling system', unpublished paper for 'Long-term Quantification in Ancient Mediterranean History' conference, Brussels, November 2009.

England's maximum rate for consumption loans, which could carry interest rates of up to 100%. However, in England the cost of such produce, being relatively abundant, was relatively low, as indicated by McCloskey and Nash's estimated interest rate for Crawley in 1250, noted above. Thus interest rates in Babylon, contrary to the indications of the McCloskey–Nash model, were probably slightly higher than in medieval England.

If we assume, in line with our discussion of the benefits of storage, the average annual benefits of storage in medieval England to be about 25%, it follows that only institutions and wealthy merchants would store grain. Such benefits would only be attractive to somebody for whom interest rates were below 10–15%, on top of a barn-rental rate of 5% and a storage-loss rate of 5–10%. Even in such cases, however, it was only profitable in exceptional circumstances. In Babylon, the storage-loss rate was the same as in England, whereas the interest rate (opportunity costs) was higher. When we add to the calculation a smaller profit from inter-annual storage, its exploitation by wealthy merchants in Babylon is even more unlikely than for their peers in England. Small-scale farmers, however, are another matter, since they did not have the same access to capital and therefore did not pay such high interest rates, and yet we found that they did not store grain to any significant extent. The question of why they did not do so is the subject of our next and last analysis.

The role of small-scale farmers

It is not surprising that in Babylon large institutions and wealthy merchants enjoyed such lucrative alternative opportunities that they would find the practice of storing grain to be profitable only in exceptional cases, in light of the fact that the interest rate on small loans was relatively high. What is surprising is how little of such storage was done by farmers at the other end of the scale: peasants whose profit margin was too slim to allow for investment in the capital market, and who therefore were not burdened with high opportunity costs.

Indeed, we find that in both Babylon and England small-scale farmers who chose to invest were obliged to pay a much higher interest rate than did major institutions, an indication that their credit worthiness was suspect. In England the problem was compounded by commodity loans that had to be repaid in cash on unfavourable terms. Standard operating procedure was to borrow at the point, just before the harvest, when farmers ran out of seed or, worse yet, out of food, and repay the loan after the harvest. According to our data, prices would meanwhile have fallen by 20%. In other words, the monetary value of 2 bushels before the harvest at 20% interest was equivalent to that of 3 bushels after the harvest, making in effect an overall interest rate of 50%, and not just the 20% established in the pre-harvest contract.

As for Babylon, the interest rate on small loans that were to be repaid in barley or dates was much higher than the rate for larger loans to be repaid in silver. Flynn and Gíraldez theorize that silver was highly valued because so little of it was in circulation. Repayment in kind was discouraged, by keeping the interest rate on it high, in order to prompt borrowers to part with their silver instead.[65] This theory corroborates one of ours: that high interest rates were due to a low level of monetization and to a paucity of silver in circulation.

65 Dennis Flynn and Arturo Gíraldez, 'Cycles of silver: global economic unity through the mid-eighteenth century', Journal of World History, 13, 2, 2002, pp. 391–427.

The sort of silver loans discussed thus far, made as they were to high temple officials and entrepreneurs with a certain cash liquidity, were by definition an urban phenomenon. Those engaged in small-scale farming, necessarily in more or less remote rural areas, lacked access to capital markets. The late Achaemenid (late fifth century BCE) promissory notes from Nippur, in southern Babylonia, preserved in the Murašû archive (and those from several other smaller archives), show that in rural areas it was specialized entrepreneurs who extended credit to tenants of 'fiefs' (the term is used here simply to denote land on which service was incumbent in a general way, and not as part of any feudal system along the lines of medieval Europe's). This was not for the purpose of paying taxes but to increase the productivity of property.[66] This was for the purpose of fulfilling tax obligation rather than to increase the productivity of property. Other archival materials reveal that with the reign of Darius I (523–486 BCE) the tax burden began to increase.[67] Again, as in the case of silver loans, credit for the purpose of improving productivity – for instance, in the form of trading partnerships known as *harrānu* – was a strictly urban and upper-class affair,[68] as opposed to consumption loans made to small-scale farmers in either Babylon or England.

There were two reasons why most small-scale farmers could not afford to store their harvests, despite the fact that their opportunity costs were low (if only because capital markets were out of reach). Lack of collateral meant that small commodity loans carried prohibitively high interest rates, and the requirement to repay loans for more immediate needs left them without the means to engage in the speculative tactic of storing grain for sale in the following year. Indeed, if the temple in Ebabbar could not afford to store grain, it is all the more unlikely that small-scale farmers could do so.[69] In addition, Babylon's high famine line of 90 meant that famine was an ever-present threat. The potential benefit of low opportunity costs was nullified by the combination of this famine threat with a heavy tax burden, rendering impracticable the use of crop storage as a means of manipulating market prices, and thereby enhancing profitability.[70] Instead, inter-annual carryover must have been mostly a matter of seasonal leftovers, and storage on the part of the government.

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66 The system was first described by Matthew Stolper, *Entrepreneurs and empire: the Murašû archive, the Murašû firm, and Persian rule in Babylonia*, Istanbul: Nederlands Historisch-Archaeologisch Instituut te İstanbul, 1985; regarding credit, see pp. 104–7. The most recent description of the system is to be found in Jursa, *Aspects*, pp.198–203. Jursa, *Aspects*, pp. 60, 252, emphasizes that the dependence of these small-scale farmers 'on outside funds in order to be able to fulfil their tax obligations' was considered 'potentially disruptive to the economy'.

67 Michael Jursa and Caroline Waerzeggers, 'On aspects of taxation in Achaemenid Babylonia: new evidence from Borsippa', in P. Briant and M. Chauveau, eds., *Organisation des pouvoirs et contacts culturels dans les pays de l'empire achéménide*, Persika 14, Paris: De Bocard, 2009, pp. 237–69.

68 Jursa, *Aspects*, pp. 206–8. On the distinction between rural consumption loans and urban credit for business activities, see also the summary remarks in C. Wunsch, 'Debt, interest, pledge, and forfeiture in the Neo-Babylonian and early Achaemenid period: the evidence from the private archives', in M. Hudson and M. van der Mieroop, eds., *Debt and economic renewal in the Ancient Near East*, Bethesda, MD: CDL Press, 2002, pp. 249–50.

69 Jursa, *Aspects*.

70 For a similar argument regarding subsistence and famine frequency, see Ó Gráda, 'Making famine history', p. 8.

Conclusion

When it comes to the market in foodstuffs, storage is one of the best ways to reduce risk and thus maximize market efficiency. Drawing on a large food-price dataset that has only recently been made available, we estimate possible storage for Hellenistic Babylonia and medieval England. Our comparison of the extent of food storage in these two regions is based on the model of McCloskey and Nash, which we are obliged to modify in order to capture the divergence between the agricultural structures of the two regions. In England, wheat and barley were comparable crops, with an annual production correlation close to zero, permitting us to combine their variances, a step that yields rather high annual price fluctuations and therefore equally high potential profits. In Babylon, the fact that the production of dates was negatively correlated with that of barley indicates that the effect of a meagre harvest of one of these two crops could be offset by an abundant harvest of the other, reducing the standard deviation of total crop output, and thus price volatility, to a level at which it was less profitable to store in Hellenistic Babylonia than it was in medieval England.

We find little evidence for any substantial storage in either of the regions. For large-scale merchants, costs outweighed benefits, especially in the case of Babylon, where seasonality, and therefore potential benefits, were less significant than they were in England. Nor do we find evidence for any significant inter-annual storage on the part of small-scale farmers, whose access to capital markets was limited, and who thus had low opportunity costs. A plausible explanation for this situation is the immense tax burden on Babylonians, which obliged even the large temples to sell their agricultural products as soon as possible after the harvest.

We also find that, even though potential benefits (that is, seasonality) in Babylon were lower than they were in England, this does not hold for interest rates, which were the main component of costs. This finding, combined with the limited possibilities of loans to small-scale farmers, suggests that interest rates were largely set outside the agricultural sector. This contradicts the finding of McCloskey and Nash that interest rates are, as a rule, positively correlated with seasonality over time within one region.[71] In reality, this is not necessarily the case across two or more regions, even if both regions are pre-modern and overwhelmingly agricultural.

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71 McCloskey and Nash, ‘Corn at interest’, p. 183.

Appendix: a Monte Carlo simulation of the impact of storage on famine

In order to explore the possible impact of storage on hunger, we have applied a Monte Carlo simulation. The model is based on the following assumptions:

1. The production (P) is a normally distributed random variable with an expected value of 100 and a standard deviation differing by region (13 in England, 6 in Babylon).
2. The famine limit (F) is 70, 80, or 90. When the production (P) drops below this level, no grain is stored; when the consumption (C) is below this limit, stored grain is consumed until the consumption reaches the famine limit or the storage is emptied.
3. The storage mechanism works as follows: when the production is less than or equal to the famine limit, people consume all the produced grain, none is stored, and, as described in point 2, the stockpile (S) may even be reduced. When the production is above the limit, a fixed percentage, denoted by a (0, 1, 5 or 10%), of the production above the hunger limit is stored.
4. Although it is evident that some of the stored grain will be spoiled, we operate on the assumption that it is not, in order to keep the model as simple as possible.

The model is the following algebraically:

$$\text{if } P_t > F_t : S_t = S_{t-1} + a(P_t - F_t) \text{ and } C_t = P_t - a(P_t - F_t)$$

$$\text{if } P_t \leq F_t \& S_{t-1} \geq F_t - P_t : S_t = S_{t-1} - (P_t - F_t) \text{ and } C_t = F_t$$

$$\text{if } P_t \leq F_t \& S_{t-1} < F_t - P_t : S_t = 0 \text{ and } C_t = P_t + S_{t-1}$$

In the Monte Carlo simulation we generate a series with 3,500 observation (simulating 3,500 years), and we run the experiment with an initial storage of zero assumed 500 times under different assumptions regarding the key parameters of the model. For each of the 500 experiments we save the number of years during which the consumption falls below the famine limit. The average of these divided by 3,500 gives the estimate of the probability of famine (p). In order to estimate the average waiting time between two famines, we use a geometric distribution with parameter p, which has the probability mass function: $(1-p)^k p$. The average waiting time is simply the expected value, that is, $\frac{1-p}{p}$.