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LONG-RUN PATTERNS IN MARKET EFFICIENCY AND THE GENESIS OF THE MARKET ECONOMY: MARKETS AROUND THE MEDITERRANEAN FROM NEBUCHADNEZZAR TO NAPOLEON (580 BC AND 1800AD)

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ABSTRACT

Long-run patterns in market efficiency and the genesis of the market economy: Markets around the Mediterranean from Nebuchadnezzar to Napoleon (580 BC and 1800AD)*

Price volatility, reflecting the ability to absorb exogenous supply- or demand shocks, is an important dimension of market performance. In this paper we present a model to study the factors determining the price volatility of markets of basic foodstuffs in pre industrial societies. This model is used to explain the development of price volatility on markets in countries around the Mediterranean between 580 BC and 1800 AD. This is the region for which we have the oldest evidence of functioning markets (from Mesopotamia), so that we can track their development in time over a period of more than 2000 years. We find a break in market performance: medieval markets had a much lower level of volatility than ancient markets--a fact we try to explain within our model. Moreover, we suggest that this reduction in price volatility may have had important consequences for the economic behavior of farmers: price variability had to be reduced to the level that we find for the post-1000 period to induce farmers to specialize.

JEL Classification: D40, E30, N13, N15 and O13
Keywords: economic history, market performance, market prices and Mediterranean

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1. Introduction

Market performance, defined as the capacity of the market to absorb unexpected supply or demand shocks, is often seen as a driving force in economic development (e.g. Allen and Unger, 1990; Persson 1999, Findlay and O'Rourke, 2003; Jacks, 2004). Development requires more or less reliable markets, which supply information to, for example, farmers about the relative prices of their outputs (and inputs), in order to induce them to specialize and increase productivity. Market prices which fluctuate erratically and violently, therefore cannot be a proper guide to this kind of decision making.

A reduction in price volatility therefore is a prerequisite for economic development since it generates security for farmers and, hence, allows them to specialise production. The main reason for such a reduction in price volatility (and increase in market performance) is, according to the New Institutional Economics, mainly a reduction in the level of transaction costs, which in its turn is related to the quality of the institutional framework (North, 1982).

This paper presents a model of the main determinants of price volatility of pre industrial markets of basic foodstuffs, focusing on a broader range of factors, including the level of agriculture productivity and the structure of the urban system. We next analyse the actual changes in the variability of those markets in the very long run, using major (and partly new) datasets of a large sample of pre industrial societies, from ancient Babylon via Egypt, Athens and Rome to Medieval and Early Modern Europe and the Middle East. By applying our model to the available data about market prices, we can determine what factors drive the reduction in price volatility and, hence, the increase in market performance. Moreover, by focusing on markets in a region with similar climatic conditions - the countries enjoying the Mediterranean climate – we can eliminate this factor from the analysis and concentrate on the institutional and agricultural determinants of market performance.

We show that markets in Medieval Europe were much more stable than those of ancient societies. The most importance cause of declining market volatility is the sharp reduction in transport and transaction costs that occurred in Europe in the Middle Ages; we do not find a similar increase in market performance in the Middle East (confirming Söderberg, 2006). Finally we address the question what the strong decline must have meant for farmers (and other producers), and argue that the decline in volatility made it possible to more or less predict market prices in the future, and therefore to start a process of specialization for the market. The levels of price variability in ancient world, and in Medieval Iraq, Egypt and Mecca did on the other hand not facilitate such a process of market specialization. This divergence between Medieval Europe and the Middle East is also confirmed by recent research into the level of GDP per capita in these regions.

2. A model of price volatility

2.1 Introduction

In the following we introduce a simple model of grain production and trade in a single centre (single market) framework, in order to find out what the relationship is between the size of market (or the size of the centre as these two should be related) and the residual volatility of prices. We will demonstrate that as long as the cost of transportation and the productivity (output per area unit) of agriculture relative to magnitude of supply shocks are about the same everywhere, and we allow for a spatial correlation of output shocks, regions with multiple smaller centres (cities) will experience lower degree of relative price volatility. Once however one region experiences a reduction in transaction costs and/or its average output grows relative to the magnitude of supply shocks, a single large centre may lead to lower price volatility. This line of thinking leads us to the hypothesis that regions with small degree of centralization (a low degree of urban hierarchy) like medieval Italy experienced less volatile grain prices than Ancient Rome (with its giant capital) or Babylon. Later however, with the advent of modern transportation technology and better agricultural technology in the West, England and the Low Countries, regions with multiple urban centres, necessarily surpassed the old centres in terms of price stability.

*2.2 Price volatility and variance of supply*In order to develop the model, we follow the simplest approach that suffices our needs, so we assume that all population lives in the urban centre and only a single good (Q) is produced. We use the quantity theory of money, where nominal income (or total nominal expenditures) equals the amount of available money (M) and we assume that the velocity of money (v) is constant. Then, if we assume that the nominal income elasticity of demand is constant (c) we obtain the following for the prices.

$$p_t = \frac{M_t^c \overline{v}}{Q_{St}} \quad (1)$$

We can assume that there are shocks in nominal income (or money supply) acting as demand shocks, but this would not add much to the model so we take M as a deterministic process for now.[2]

The log prices can be written for period t:

$$\ln p_t = \ln \overline{v} + c \ln M_t - \ln Q_{St} \quad (2)$$

The variance of the log prices can be written as:

$$Var(\ln p_t) = c^2 Var(\ln M_t) + Var(\ln Q_{St}) \quad (3)$$

[2] In this paper we compare the volatility of the residual of log prices under different assumptions about transportation costs and productivity. Unless we believe that more developed economies are more likely to experience disproportionally bigger demand shocks than less developed ones, introducing demand shock would not change the results.

In order to arrive at the variance of the logarithm of the residual that we use as an indicator of the ability of market in reacting on unexpected shocks, we need to subtract the expected prices and then estimate the variance:

$$\ln p_t - E(\ln p_t) = c(\ln M_t - E(\ln M_t)) - \ln Q_{St} - E(\ln Q_{St}) = \ln Q_{St} - E(\ln Q_{St}) \quad (4)$$

Where we could get rid of the effect of nominal income simply since we assumed that M is a deterministic process.

$$Var(\ln p_t - E(\ln p_t)) = Var(\ln Q_{St} - E(\ln Q_{St})) \quad (5)$$

That is, in our model the residual price volatility will be determined by the variance of the log of supply, or the CV of supply.

2.3 Determinants of the log variance of supply

How can we determine the variance of supply? We assume a homogeneous space, where a centre, which serves as market, is surrounded by a market zone of which has the same production capability per area unit (q_0) plus a random shock (e_i) the latter are being spatially correlated. Only a single good is produced.

The centre serves as the sole market within a radius (R), and the transportation and transaction costs expressed per unit of distance from the centre (τ) expressed in terms of goods are equal everywhere. We use an iceberg type transportation costs, that is, a part of the goods produced is lost during transportation.

The number of production units that supplies to the centre equals the area of the circle with radius R is $N_R = R^2\pi$, and the production of a single area unit is: $q_{im} = (q_0 + \varepsilon_{im})e^{-\tau m}$. The random shock affecting producer i situated on the circumference of radius m is denoted by ε_{im}. The shocks are assumed to have zero mean, they are homoscedastic, and they are allowed to be spatially correlated: $\varepsilon_{im} \sim (0, \sigma_\varepsilon^2)$, $E(\varepsilon_{im}\varepsilon_{jn}) \neq 0, \quad m,n = 0...R, \quad i = 0...2\pi m,$ j=0...2πn

We can express the amount of total goods that arrives at the centre (Q_s) as follows:

$$Q_s = \int_0^R \int_0^{2\pi m} q_{im} didm = 2\pi q_0 \left(\frac{1 - e^{-\tau R}(1 + R\tau)}{\tau^2} \right) + \int_0^R \int_0^{2\pi m} \varepsilon_{im} e^{-\tau m} didm \quad (6)$$

Since the random shocks have zero mean and are uncorrelated with the effect of distance, the expected value of the total supply is:

$$E(Q_s) = 2\pi q_0 \left(\frac{1 - e^{-\tau R}(1 + R\tau)}{\tau^2} \right) \quad (7)$$

As $\lim_{\tau \to 0+} \left(\frac{1 - e^{-\tau R}(1 + R\tau)}{\tau^2} \right) = \frac{1}{2} R^2$, in the absence of transportation costs, the expected value of total supply simplifies into $E(Q_s) = \pi q_0 R^2$ as expected.

If we treat R, τ and q_0 fixed, the variance of the supply depend only on the variance of the sum of the supply shocks times the effect of transportation costs, denoted as the integral: $\int_0^R \int_0^{2\pi m} \varepsilon_{im} e^{-\tau m} didm$.

$$Var(Q_s) = \int_0^R \int_0^R \int_0^{2\pi n} \int_0^{2\pi m} \left(\varepsilon_{im} e^{-\tau m} \right) \left(\varepsilon_{jn} e^{-\tau n} \right) didjdmdn = \pi^2 R^4 E\left(\varepsilon_{jn} \varepsilon_{im} e^{-\tau n} e^{-\tau m} \right) \quad (8)$$

We can make use of the assumption that the distance effect is independent of the shocks.

$$Var(Q_s) = \pi^2 R^4 E\left(e^{-\tau m} e^{-\tau n} \right) E\left(\varepsilon_{im} \varepsilon_{jn} \right) = \pi^2 R^4 \frac{4e^{-2\tau R}(1 - e^{\tau R} + R\tau)^2}{R^4 \tau^2} \pi^2 R^4 E\left(Cov(\varepsilon_{im} \varepsilon_{jn}) \right) \quad (9)$$

Since $E\left(\varepsilon_{im}^2\right) = E\left(\varepsilon_{jn}^2\right) = \sigma_\varepsilon^2$ due to the homoscedasticity we assumed about the shocks, we need to assume something about the expected value of the covariances.

For the linear correlation between any two points we assume that:

$$\rho(\varepsilon_{im}, \varepsilon_{jn}) = e^{-d_{imjn}} = \frac{Cov(\varepsilon_{im}, \varepsilon_{jn})}{\sigma_\varepsilon^2} \quad (10)$$

from which we can express the covariance as follows:

$$Cov(\varepsilon_{im}, \varepsilon_{jn}) = e^{-d_{imjn}} \sigma_\varepsilon^2 \ (11) \ \text{ and } \ E\left(Cov(\varepsilon_{im}, \varepsilon_{jn})\right) = E\left(e^{-d_{imjn}}\right) \sigma_\varepsilon^2 \ (12)$$

The expected value of the distance between any two points in a circle with radius R can be specified as (http://www.mathpages.com/home/kmath324/kmath324.htm):

$$\bar{d}_{ij} = \frac{2}{\pi} \int_0^\pi 2 \cdot R \cdot cos\left(\frac{\theta}{2}\right) sin(\theta)\left(\theta - sin(\theta)\right) d\theta \quad (13)$$

Which yields 0.9054R. We can slightly modify above expression to arrive at the expected value of the transaction costs:

$$E(e^{-d_{ij}}) = \frac{2}{\pi} \int_0^\pi e^{2 \cdot R \cdot cos\left(\frac{\theta}{2}\right)} sin(\theta)\left(\theta - sin(\theta)\right) d\theta \quad (14)$$

Since the solution to this integral is very complex, in order to be used in simulations we approximated the sum of distances, $E(e^{-d_{ij}})\pi^2 R^4$ with a function of the radius.

We estimated the sum of distances for radius 0.1 to 5 (with 0.1 steps between 0.1 and 1, 0.2 between 1 and 2, and 1 between 2 and 5) and searched for the functional form that yielded the best fit. The following cubic function yielded a very good fit, the relationship is almost deterministic:

$$E\left(E(e^{-d_{ij}})\pi^2 R^4 \mid R\right) = e^{(1.472 + 3.262\ln(R) - 0.264\ln(R)^2 - 0.034\ln(R)^3)}$$

R-sq=0.99996, N=17 (15)

We arrive at the following estimate of the variance of supply in the centre:

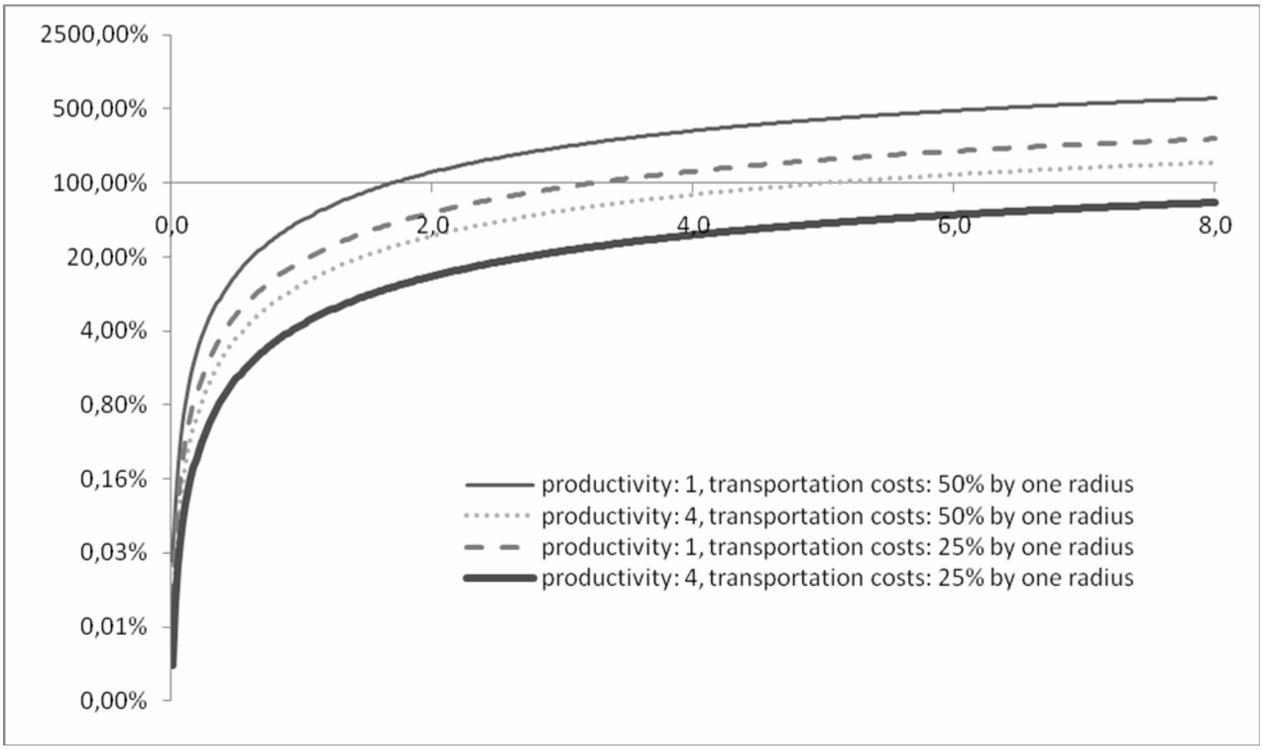
$$Var(Q_s) = \frac{\pi^2 4 e^{-2\tau R}(1 - e^{\tau R} + R\tau)^2}{\tau^2} e^{(1.472 + 3.262\ln(R) - 0.264\ln(R)^2 - 0.034\ln(R)^3)} \sigma_\varepsilon^2 \quad (16)$$

In other words, the variance of supply at the centre is determined by the transaction costs and the radius of the trading area of a centre.

*2.4 Simulating the model*From above model it follows that price volatility is caused by output volatility, which in turn is determined by transaction costs and the size of the trading area. We carried out a simulation using some assumptions regarding the key parameters of the model. As we saw earlier, once we disregard demand shocks, and assume that all income is spent on one good, the relative price volatility around the mean will equal the (CV- or log-) difference of the supply shocks). The results are reported in below Figure where on the horizontal axis is reported the radius from the market and on the vertical axis the CV of the

Figure 1

Simulation of the relationship between coefficient of variation of the supply and of the size of the urban centre



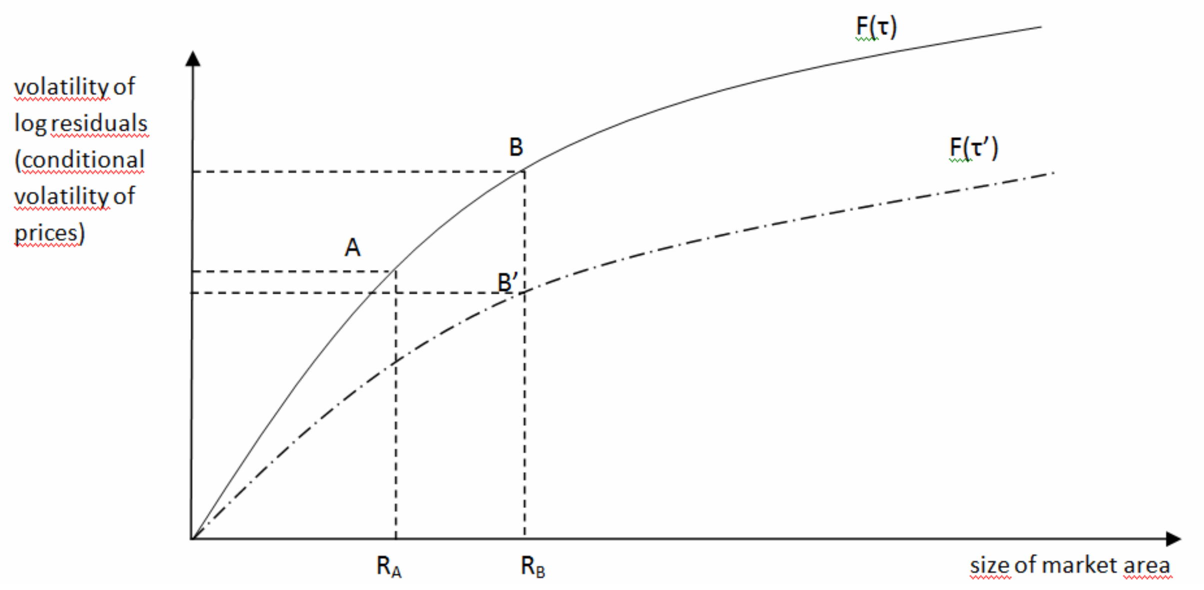
Note: we assumed in all cases that the standard deviation of the production is 30% of unit production, that is, σ_ε^2=0.09. If a productivity increase causes the standard deviation of the supply shocks to grow proportionally, productivity improvement will have no impact on the CV of the supply.

supply. Figure 1 shows that if one increases the radius, the CV will increase quite rapidly, leveling off after about 2 radiuses. However, this increase of the CV is faster the higher the transportation (or transaction) costs. Hence, from Figure 1 it follows that economies with a number of smaller centers (cities) performed better in terms of residual price volatility than economies with a single or a few large dominant centers. When the transaction costs declined, this picture may change since the radiuses can increase with a similar (or lower) CV.

In the Figure 2 below, we show this mechanism. Let us assume we have two economies: A has smaller market zone than B. If they face the same transportation costs and have the same productivity, they are both along the same curve F(τ). In this case smaller market size means less conditional volatility. If B experiences a decrease in transaction costs (or its productivity increases relative to the size of production shocks) its curve representing

Figure 2

The relationship between market size, transaction costs and residual volatility of grain prices



the relationship between price volatility and market size will shift become less steep (F(τ‘)). That is, even with the same market size as before its conditional price volatility will be lower than in A.

This finding applies to regions with multiple smaller centers (cities) and a single dominant center as well. The average price volatility of smaller centers with lower degree of city hierarchy (for example, Northern Italy in the Middle Ages) will have lower residual price volatility as long as there is no difference in transportation costs. Once however Western Europe experienced an improvement in transportation and agricultural productivity, we can expect their grain markets to start to exhibit lower degree of residual price volatility.

3. The data In order to test above model, we need to have information on the conditional price volatility in several markets in Ancient and Early Modern period around the Mediterranean. Unfortunately, even though most complex societies knew some kind of market exchange, only a few kept records of prices of traded commodities. The starting point of this paper is the extremely rich collection of price data available in the clay tables of various dynasties in Mesopotamia between ca 580 and ca 120 BC. The datasets available for other ancient societies (Athens, Egypt, Rome) are much smaller and more problematic. Only during the Middle Ages (after about 1200) we find datasets which are similar in quality and scope; these mainly European datasets are the end point of our inquiry. They have been studied intensely by economic historians, and therefore can be used as a standard to compare ancient markets with.[3] Economic historians working on the ancient economy have also studied the functioning

[3] But in spite of the abundance of sources for the post 1200 period, there is still considerable debate about the performance of European markets between 1200 and 1800, about (for example) the question if their volatility fell over the long run and if market integration increased similarly; Some authors emphasize the connection between

of markets in Mesopotamia and the Roman Empire (e.g. Temin 2002; Erdkamp, 2005; Romero et al,. 2010). These studies are however not really comparable with each other, because they use different methods and approaches – and do not systematically try to explain the causes of volatility. This paper aims to fill this gap, by applying the same methodology to the available data, and measure the efficiency of markets in a systematic way. We hope to answer the big question: how efficient were markets in the past, and when did their performance change overt time.

Market performance is measured here through the volatility of the price series. The underlying idea is that the more volatile a price series of a good, the less its institutional structure is apparently able to reduce the effect of shocks on the supply (and demand) for that product. Since volatility measures like the variance or the standard deviation are level dependent (the higher a price, the higher the variance or standard deviation will be), in recent literature it became more common to use the Coefficient of Variance (CV) (e.g. Persson, 1999; Söderberg, 2004; 2006; Ó Gráda, 2005). The CV, which is defined as the standard deviation divided by the mean, has as a big advantage that it can be compared between economies with different absolute price levels.

The simple CV is our first measure, but it has the disadvantage that it captures both the explained and unexplained variance of the prices. Since the explained variance, such as caused by seasonal patterns of market supply (low prices after the harvest, high prices just before it), may differ across regions without changing market performance, we also apply an autoregressive model to estimate the conditional expected value of the log prices, using the volatility of the residual as a measure of market performance (Foldvari and Van Leeuwen

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increasing market efficiency of markets and the gradual process of growth in the early modern period; others have stressed the presence of well working markets already in the medieval world (E.g. Masschaele,1993; Galloway, 2000; Clark, 2002).

(2011). This method requires relatively much data, however, and therefore only be applied to large datasets (such as the data on Babylon and the European Middle Ages). We will apply this more sophisticated method to check the results from the direct measurement of the CV's.

In order to calculate the CV (and the conditional expected value of log prices) as a measure of market efficiency between 600 BC and 1800 AD, one needs to collect time series for periods with sometimes scarce data. In this paper we focus on the prices of the main staple crops of the societies concerned (wheat and barley). The region we study are the countries bordering the Mediterranean, because they are (among the) oldest civilizations of the world, which dominated the western part of the Eurasian Continent until the 17th or 18th centuries. The Middle East was the cradle of city life, and probably the first region of the world with active markets. Moreover, some of these societies produced abundant data on prices of markets; the starting point of this paper is the extremely rich collection of Babylonian prices from 580 to 120 BC. Much smaller datasets are available for Egypt, Athens, the Roman Empire and the Islamic world. After about 1200 Medieval Europe, and in particular (for our purpose) the Italian city states, again produce very rich datasets which form the end-point of our inquiry.

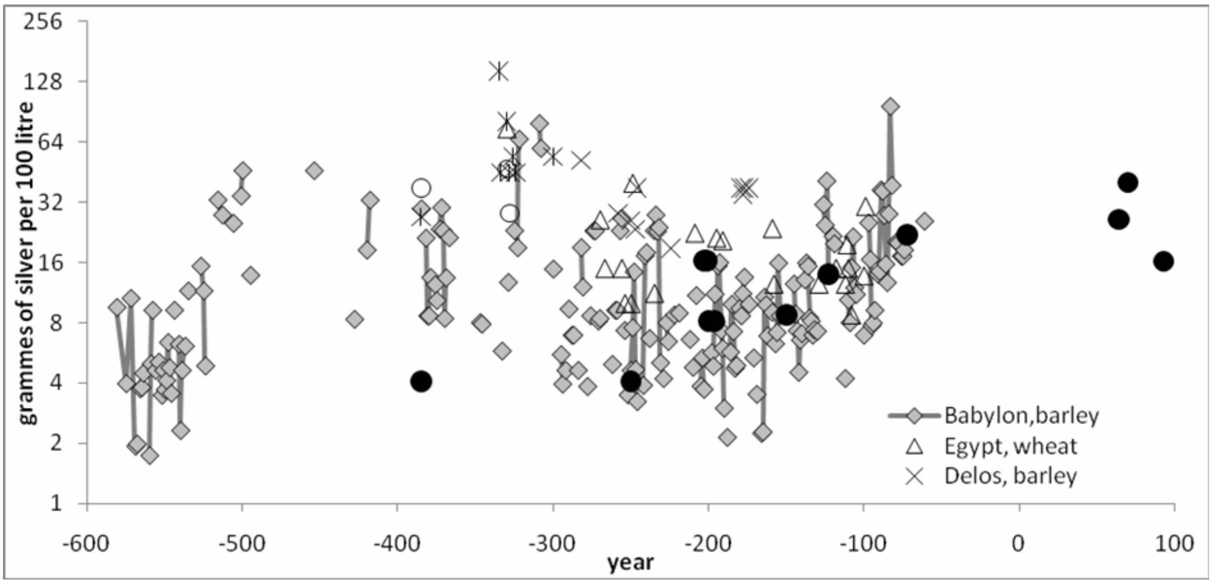
Even though in theory the conditional expected value of log prices would remove any climatic differences, the CV would not. Therefore, we focus on the region bordering the Mediterranean, which has a typical climate and a distinct agricultural system in common. This makes it possible to eliminate differences in climatic conditions from the analysis (it would be different to compare these markets with those in, for example, Russia, or England). Two agricultural systems can be distinguished: in Mesopotamia and Egypt agriculture was based on irrigation, which produced higher yields (per hectare and per amount of seed), and was probably more stable as the input of water could to some extent be controlled. Moreover, in Babylon a system of dual crops – barley and dates – came into existence; the fact that harvests of those crops were spread over the year, should also have stabilized prices (note: this is demonstrated by the fact that during the harvest of dates also barley prices tended to fall (e.g. Foldvari and Van Leeuwen 2009). The rest of the region was characterized by rain-fed agriculture, with only one harvest per year. One would expect larger supply side shocks resulting in more unstable markets there.

In the data appendix we discuss the various datasets that we collected. One problem should be briefly discussed. Some authors, in the Finleyian (Finley, 1973) tradition, have doubted whether the prices from antiquity are “real” market prices. Yet, as pointed out by Von Reden, the Egyptian, Athenian, and Delian prices exhibit relatively strong seasonal variation. At the same time she argues that imports increased during periods of high prices, all evidence that a working market existed (Von Reden 2008). The same has also been argued for Babylon by a variety of authors like Temin (2002), Foldvari and Van Leeuwen (2009), and Romero et al. (2010). and. Van der Spek (in press) even explicitly states that ‘[t]he very fact that these prices need to be predicted based on the position of the planets shows that they are unpredictable and, hence, market prices.’ The same finding of a working market has been argued for the Roman Empire by Rathbone (2011) and, from the perspective of active trade relations, by Kessler and Temin (2005). Finally, in order to make them comparable, all price series were converted into grams of silver per 100 litres. This of course does not affect the estimated CV.

A visual examination of the main series collected for this study yields already a few interesting features of these price series (Figures 3A-3C). The Babylonic prices are more or less stable in the very long run, although a brief period of inflation occurs after the conquest by Alexander the Great in 334 BC, which lead to the bringing into circulation of huge hoards of silver. Their variability is huge, however. Prices in Delos and Athens are on average higher than in Babylon or Egypt, probably because both were dependent on large-scale imports of grains from overseas (Reger, 1994).

Figure 3A

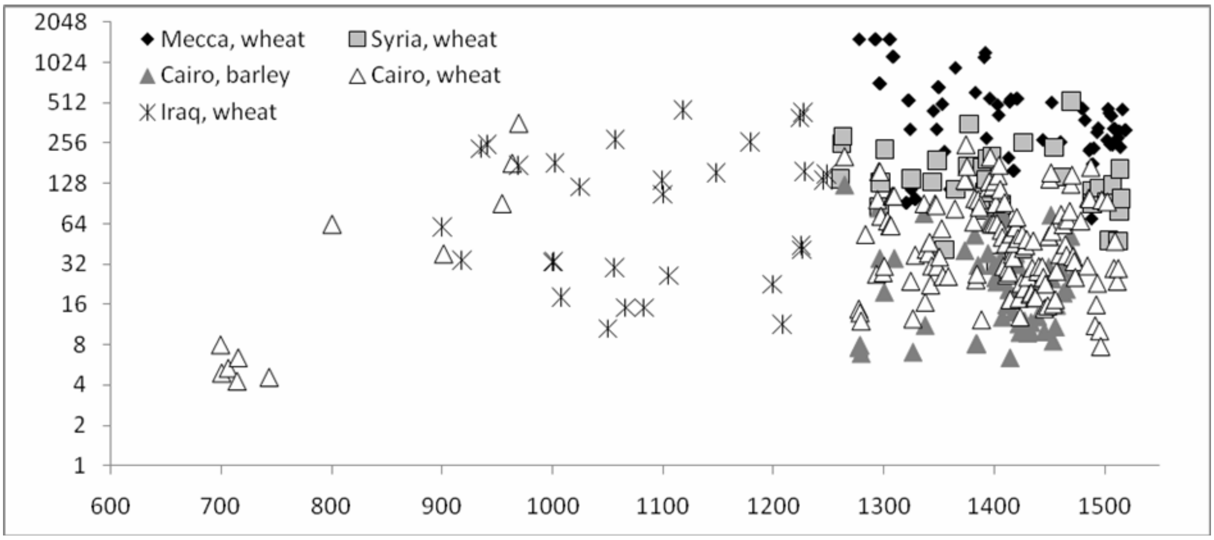
Grain prices in various ancient societies in grammes silver per hectoliter (log 2 scale), 600BC-100AD



Source: Jursa (2010); Slotsky (1997); Slotsky and Wallenfels (2009); Vargyas (2001); Von Reden (2008); Van der Spek (2010); Rathbone (2011)

Figure 3B

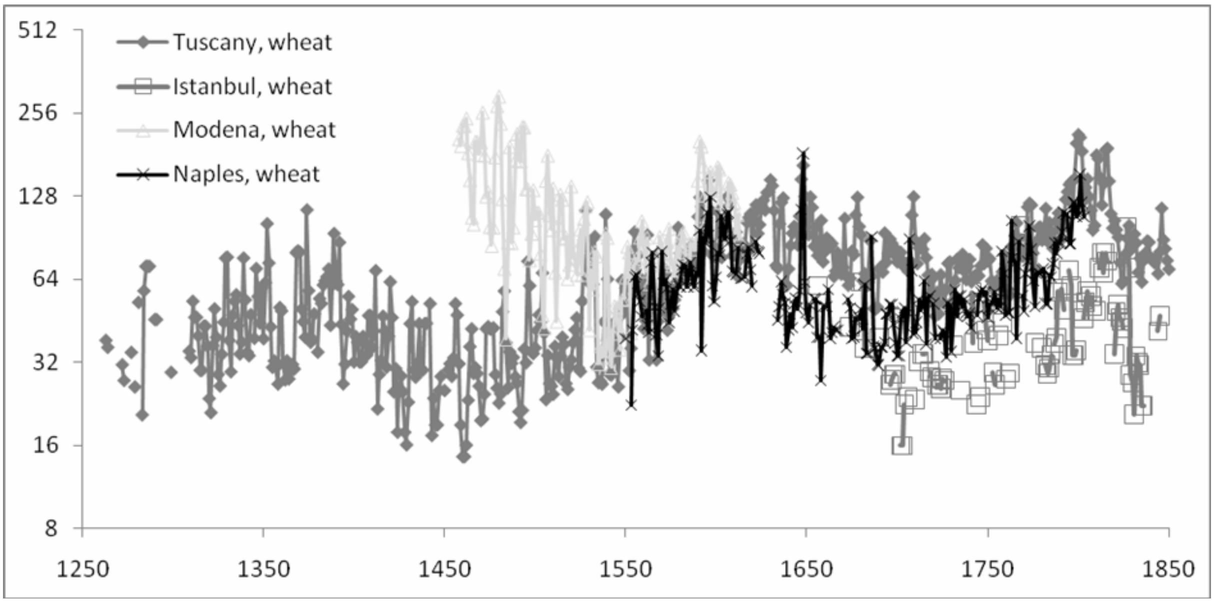
Grain prices in the Middle East during the Middle Ages in grammes of silver per hectoliter (log 2 scale), 1250AD-1550AD



Source: Ashtor (1969); Mortel (1989); Pamuk (2004); Schatzmiller, (2011)

Figure 3C

Grain prices in Europe during the Middle Ages in grammes of silver per hectoliter (log 2 scale), 1550AD-1800AD



Source: Malanima, *Aspetto di mercato e prezzi,*; Basini, *Sul mercato di Modena*; Coniglio, "La revoluzione dei prezzi,"; Romano, R., *Prezzi, salari e servizi.;* Pamuk, ''Prices in the Ottoman Empire.'

Turning to Figures 3B and 3C, it appears that on average prices during the Middle Ages were on average substantially higher than before 100 AD (in other words, the price of silver went down compared with the price of wheat). In the Middle East, the prices of Mecca stand out as being very high – again probably due to the dependence on large-scale imports (but this time via caravan routes and probably not via the sea); but this may also be caused by the fact that only extreme prices were recorded (Mortel, 1989). In both Western Europe and the Middle East the (first half of) the 15th century was a period of deflation, perhaps caused by the population decline after the Black Death of 1348, or due to the 'silver scarcity' of those years (caused by massive outflows of silver to the east, to India and China).

4. Decomposing changes in market performance over time

The results of measuring the CVs of those price series mentioned in the previous Secton are reported in Tables 1and 2 below. Table 1 shows a great diversity in CVs. Most CVs are .6 or higher; Babylonic CVs are extremely high and sometimes close to 1.0. This is a striking result, as Mesopotamia was a region with high levels of agricultural productivity (thanks to the complex irrigation system) with two harvests – barley and dates – per year (not from the same land however: date gardens did not produce barley). We included the CV's for the second crop, dates, as well, to see if their market was more stable, but that is clearly not the case. The other region with irrigation agriculture (and high levels of land productivity), Egypt, also shows highly unstable markets. The only exceptions are Delos and, to some extent, Athens (for which the CV of the log of prices is rather low, but the CV of the absolute prices is quite high). However, the number of observations for both regions is very small, creating a downward bias in volatility. Both markets were highly dependent on grains imported overseas (Reger, 1994, 83-116). Absolute prices were rather high there, as a result, but somehow dependence from various overseas sources of supply was a good strategy to limit price volatility. [4]

[4] The quality of institutions may also have played a role, of course, but we can only speculate about this. Braund (2007), for example, although stressing that Black Sea imports do play an important role in the 4th century BC, also stresses the political situation in Greece and around the Black Sea. A clear example is provided by Dunham (2008) who discusses a government intervention during a negative supply shock in 388BC in Athens during which the government stimulated grain importers to form a cartel in the hope that prices would decline.

Table 1

Coefficient of Variation of grain prices in the Near East and Rome, ca. 581 BC- 72BC

Region	Product	Time	CV	mean	std dev	N
Babylon	barley	581-61 BC	0.96	13.68	13.08	188
		500-220BC	0.91	16.41	14.89	67
		200-120BC	0.71	10.11	7.15	58
Babylon	dates	570-61 BC	0.81	9.49	7.61	185
		500-220BC	0.69	12.64	8.57	67
		200-120BC	0.68	4.65	3.15	57
Egypt	wheat	330-99 BC	0.68	20.44	14.00	21
Athens	wheat	385-300 BC	0.59	61.98	36.52	8
Delos	barley	282-174 BC	0.28	33.37	9.45	10
Rome	wheat	385-72 BC	0.65	16.56	10.80	9

Sources: Jursa (2010); Slotsky (1997); Slotsky and Wallenfels (2009); Vargyas (2001); Von Reden (2008); Van der Spek (2010); Rathbone (2011)

Table 2

Coefficient of Variation of grain prices in the Near East and Italy, ca. 1261BC- 1800AD

Region	Product	Time	CV	Mean	Stdev	N
Egypt	wheat	1277-1420	0.72	70.09	50.24	72
		1420-1500	0.79	50.72	39.90	48
	barley	1277-1399	0.82	40.57	33.25	41
		1420-1490	0.60	24.90	14.87	34
Iraq	wheat	900-1248	0.97	133.58	128.96	30
Mecca	wheat	1278-1400	0.75	675.07	502.93	31
		1400-1520	0.39	329.60	128.68	38
Syria	wheat	1261-1400	0.54	145.78	79.42	24
		1400-1515	0.81	152.80	124.06	14
Istanbul*	wheaten flour	1469-1600	0.50	62.95	31.17	22
	wheat	1656-1800	0.43	37.98	16.21	58
Tuscany	wheat	1263-1420	0.38	46.11	17.44	125
		1420-1490	0.35	32.52	11.46	97
		1550-1800	0.35	80.63	28.33	281
Modena		1458-1520	0.44	141.94	62.42	63
		1520-1613	0.41	87.67	35.70	94
Naples		1520-1800	0.37	60.90	22.30	221

* In 100 kg

Sources: Romano (1965); Ashtor (1969); Bassini (1974); Malanima (1976); Mortel (1989); Pamuk (2004).

For the Middle Ages we find a different pattern. In the Middle East (Egypt, Mecca, Syria) markets are almost as unstable as they were in Babylon or Egypt 1500 years earlier. Western Europe shows much lower levels of market volatility, however; absolute CVs decline to 0.3 and 0.4, compared with 0.6 to 0.9 for Middle Eastern markets. The CVs in Medieval Italy are only half those found in (for example) Egypt.[5] Interestingly, Istanbul is in between the Middle Eastern and the Western European pattern; the explanation is that this was also a big city which imported its large needs for bread grains from overseas.

In order to analyse to what extent these factors may reduce the effect of unexpected demand and supply shocks such as wars and plague epidemics, one must however first remove all other effects.[6] The appropriate way to measure market volatility is thus to look at

[5] See Söderberg (2004) and (2006) for similar conclusions about the large gap in price volatility between the Middle East and Western Europe.

Table 3

CV of unobserved volatility proxied by the standard error of the regression on first differences (log prices)

		Barley	Dates	Wheat	Rice
Babylon	300-60 BC	0.54	0.41		
Babylon	300-200BC	0.64	0.32		
Babylon	200-120 BC	0.45	0.48		
Egypt	1277-1420AD	0.61		0.57	
	1420-1500AD	0.52		0.63	
Mecca	1290-1420AD			0.50	
Syria	1300-1500AD			0.35	
Istanbul	1469-1650AD			0.30*	0.24
	1656-1800AD			0.19	
Tuscany	1287-1420AD			0.32	
	1420-1490AD			0.28	
	1490-1650AD			0.29	
	1550-1800AD			0.21	
Modena	1550-1613AD			0.21	
Naples	1550-1800AD			0.25	

Source: see Tables 1 and 2

*wheaten flour

the residual variance after modelling the ‘predictable’ movement of prices, caused by seasonal variation in prices and time trends. A trend in price level, for example caused by the influx of silver from new sources of supply (such as Spanish America after 1520), may inflate the CV.

In order to remove this spurious component of volatility (i.e. country- and time specific demand and supply related factors and the trend), we use a conditional heteroscedasticity model, in which the variance of the residual term [=variance around the conditional expected value of the prices] is modelled, thereby filtering out the effect of the trend. The residual variance therefore captures, in a correctly specified model, only the effect of unexpected shocks. Hence, the lower the residual variance, the better markets can cope with shocks (Foldvari and Van Leeuwen 2011).

Unfortunately, since this method requires quite some data, we can only report these results for a set of regions which are given in Table 3. These results confirm the big picture that emerges from Tables 1 and 2: the 'corrected' CVs of ancient markets fluctuate at about 0.5, and Egypt and Mecca during the Middle Ages have a similar levels of volatility.

In Western Europe (after 1200) and in Istanbul markets seem to be much more capable of absorbing shocks (Syria now presents itself as an intermediate case). The results of Table 3 for Tuscany also nicely track the declining volatility (and the increased market performance) characteristic of Europe between 1200 and 1800 (Persson, 1999). That this was a general European pattern is shown by the results of the same analysis performed on the very rich data which are available for Europe between 1360 and 1800 (see Table 4). The variance is consistently low (compared with the results for Ancient economies), and Italy in the late Medieval Period is a bit of a high outlier here. The strong decline of the variance between the 15th century and the 18th century points to continuing improvements in the functioning of markets in this period.

Table 4

Standard error of the regression of first differences (log prices), 1360/1550-1650/1800[7]

	1360-1550	1650-1800
Italy	0.44	0.19
Austria	0.37	0.23
France	0.33	0.23
Belgium	0.31	0.20
Spain	0.30	0.30
Netherlands	0.29	0.22
England	0.29	0.23
Poland	0.22	0.24
Germany	0.19	0.23

Source: Allen - Unger Global Commodity Prices Database (downloaded from http://www.gcpdb.info/)

How to explain the big change that seems to have occurred when comparing ancient economies with Western Europe in the Middle Ages? Following the model presented in section II, we discuss three possible factors determining volatility of prices. The first is the productivity of the agricultural system. As pointed out by Van der Spek (2006) and Jursa

[7] Note: 1500: Austria: Stiftklosterneuber, Vienna; Belgium: Louvain, Mons; England: Chester, England, Exeter, Southern England; Douai, Grenoble, Le Quesnoy, Mauberge, Montelimar, Nancy, Paris, Strasbour, Toulouse, Tours, Valence, Valenciennes, Vienne, Voiron; Germany: Frankfurt, Munich, Wurzburg; Italy: Arezzo, Bari, Florence, Sansepolcro; Netherlands: Amsterdam, Leiden, Utrecht; Poland: Krakow, Wroclaw; Spain: Aragon, Barcelona, Madrid, New Castile, Old Castlile, Valencia, Valladolid. For 1700: Austria: St Polten and Vienna; Belgium: Antwerp; France: Aix, Angers, Arles, Avignon, Beziers, Chateu Gonier, Douai, Draguignan, France, Grenoble, Marseilles, Paris, Rennes, Strasbourg, Toulouse, Tours, Valence; Germany: Augsburg, Cologne, Dresden, Frankfurt, Holstein, Leipzig, Munich, Weyer, Wurzburg; Italy: Ancona, Bassano, Brescia, Milan, Naples, Pesaro, Pisa, Senigallia, Siena; Netherlands: Amsterdam, Arnhem, Leiden, Rotterdam, Utrecht; Poland: Danzig, Gdansk, Krakow, Poland, Warsaw; England: Southern England; Spain: Barcelona, Bilbao, Cervera, Madrid, New Castile.

(2010, 49), productivity was very high in Babylonian times. The seed-yield ratio is estimated at as high as 1:24 and even though technological development stagnated afterwards, the remarkable fertility of the earth remained. Ashtor (1976, 50) points at a seed yield ratio of 1: 10 for early Medieval Middle East (whereas in Carolingian times in Western Europe it was rather 1:2.5). The yield ratio's of the main cereals in Italy and southern France were estimated at 3 to 5, the yield per hectare at 6-10 hl (Slicher van Bath, 1963; Van Zanden, 1998, p. 69). Moreover, Babylon had the advantage of two harvests per year (barley in summer, dates in autumn), which must also have helped to stabilize prices. Assuming that land productivity had an effect on price volatility, it is therefore quite surprising that Medieval Europe had such stable markets, whereas volatility in Babylon and Egypt was and continued to be very high.[8]

The second factor isolated in the model, the structure of the urban system, is more helpful in explaining the patterns found. For this we rely heavily on Bosker et.al. (2008), which compares the evolution and the structure of the urban system in the Middle East and Western Europe between 800 and 1800. They show that the urban system of the Middle East was quite different from that of Western Europe: the first was characterized by a very high level of urban primacy, in which the largest (capital) city dominated the urban system, whereas the European urban system (after 1000) was much more balanced. The level or urban primacy defined as the share of the urban population resided in the largest city, was between 15 and 30% in the Middle East (with giant cities such as Baghdad and Cairo), whereas in Western Europe it varied between 5 and 13%. This is linked to the different political economy of the states and the cities concerned: Middle Eastern cities were closely tied to the success of

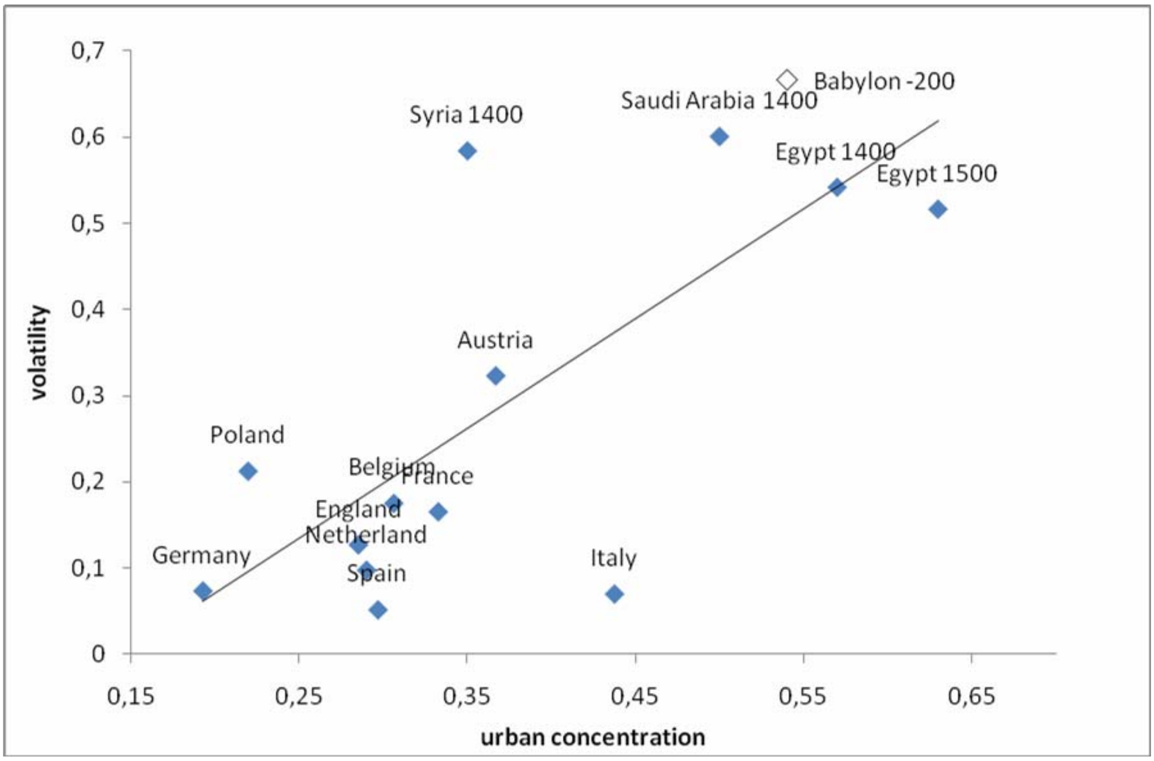
[8] However, agricultural productivity was slowly increasing in Medieval Europe: Persson (1991) estimated a growth of agricultural productivity of 0.15-0.2% growth per annum between 1000 and 1300 AD in Tuscany; Federico and Malanima (1994) arrive at a less optimistic estimate of 0.05% per capita per annum growth between the 10th and 14th centuries.

their empires, and it was in particular the capital cities that dominated the urban system. In the European Middle Ages, urbanization was a different phenomenon, based on productive activities (such as trade, finance and the production of textiles); in particular the balanced structure of the Italian urban system – with its many small and medium sized city-states – is a good example of this structure (Bosker et.al. 2008). Can we extrapolate this distinction back in time? Classical Greece clearly had an urban system with certain similarities to what we find in Medieval Europe, as had classical Italy, before the rise of Rome to world power. In Mesopotamia the process of early state formation consisted of the consolidation of bonds between more or less independent city-states, but when our data start to flow (during the reign of Nebuchadnezzar 605-562 B.C) this process has resulted in a highly centralized state dominated by the capital city of Babylon (its total population is estimated at about 200,000 to 300,000, or as large as the next ten largest cities taken together (Bairoch, 1988: 27; also Van der Spek, 2008). Similarly, for Egypt our oldest data refer to the Hellenistic period, when the country was strongly unified and Alexandria (with perhaps as much as 300,000 inhabitants) was the capital city. Summing up, with the exception of Athens and Delos (and early Rome), the ancient markets that are included in our sample are typical 'urban primates' and therefore more closely resemble the cities in Medieval Middle East than those of Western Europe. This helps to explain the rather poor performance of their markets.

We can test this hypothesis more systematically by comparing, for the 15th and 16th century (for which we have the best data) the relationship between the volatility of grain prices and the degree of urban concentration (Figure 4). We indeed find that a positive relationship between urban concentration (defined as the share of the largest city in the total

Figure 4

Market volatility versus urban concentration around 1500AD



Sources: Figure 1B and 1C; Allen - Unger Global Commodity Prices Database (downloaded from http://www.gcpdb.info/)

urban population) and market instability around 1500, confirming the expectations based on our model.

We can now quantify two factors that play a role in the presented model: in ancient Babylon and Egypt agricultural productivity was at least twice the level found in Medieval and Early Modern Europe, and its cities were also at least twice the size of the largest cities in Italy and Western Europe (250,000 to 300,000 inhabitants, whereas the largest cities of Italy counted 80,000 to 100,000 people). The third factor is transport and transaction costs. We already argued that access to overseas transport is probably explaining the low variability of prices in Delos and Athens. Primate cities such as Baghdad and Damascus, by contrast, were typically situated in the middle of their territory and therefore without access to sea transport (Bosker et.al. 2008). These differences are also related to the modes of transport linking the two urban systems. Cities in the Arab world were mainly connected by caravan routes using camels as 'ship of the desert'. This was initially an efficient solution, but productivity did not change in the long run, which helps to explain the fact that markets in Medieval Middle East were equally volatile as in ancient times. Cities in Medieval Europe were mainly dependent on transport overseas, which did change dramatically in productivity (due to a broad range of changes in ship design, in infrastructure and institutional setting). This was, according to Bosker et.al. (2008), an important reason why the European urban system was much more dynamic than that of the Middle East. At the same time, there are reasons to assume that transaction costs were much lower in Western Europe than they used to be in ancient Babylon or Egypt. First and foremost because of a different political economy in which commercial interests dominated political decision making in the Italian city republics (and in many other European communes), resulting in well protected property rights and relatively high levels of trust (Greif, 2006; Van Zanden, 2009). The literature on this is extensive and cannot be dealt with in detail here; we restrict ourselves to trying to quantify this effect on the basis of what we know about the decline of price volatility.

Using (7) and (16) we can guesstimate the improvement of transaction costs over time. We know that the residual price volatility in Seleucid Babylon was about 0.64, while it was 0.35 in Tuscany around 1500. If we assume that the difference in price volatility can be explained by difference in the volatility of supply, we can rely on the model in the paper. This requires that we set the output per hectare, the volatility of output per hectare and the radius of the local market relative to Babylon. We know that the size of the market in Tuscany was about the half of Babylon, meaning, that the radius was about 70.7% of the Babylonian market (this means that the area of the Tuscan market was about half of the Babylonian). We also know that the Babylonian agriculture was significantly more productive per acre than the Tuscan. For this reason we assume that the former had three times much output per area unit than the latter. The final factor we need is the volatility of output per hectare. Even though very little evidence exists, we can arrive at plausible guesstimates. Tuscan productivity might be proxied using information on contemporary England which can be considered comparable and which suggest a volatility equal to on average 25% of the mean.[9] For Babylon Van Leeuwen, Foldvari and Pirngruber (2011) estimated that output volatility per acre was about 50% of that of England.

Table 5 below reports the results of this exercise. Choosing a combination of a 4 unit radius for Babylon, result in a radius of 2.82 assuming that the market in Tuscany was half that of Babylon. The fourth row gives the volatility in output per acre. The transaction costs were now chosen in such a way that the predicted CV resembled the actual CV (std. deviation of log prices). We find that the transaction costs in Tuscany must have been around 22.5% per radius if Tuscany had an output of 1/3 that of Babylon (or 15% of the output was twice as small). Babylon, however, had transaction costs more in the order of 30%. This latter is not unlikely as Jursa (2010, 150) gives transport costs in the order of magnitude of 20% for only 2/3 of the radius, meaning close to 30% for the full radius of the Babylonian market. In other words, we have to assume a decline of about 1/3 of the transaction costs to explain the strong decline of the CV of market prices.

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[9] We calculated the output per acre on demesnes in Norfolk and Suffolk between 1270 and 1340 The data are obtained from Bruce M. S. Campbell (2007).

Table 5.

The explanation of the decline of market volatility between Seleucid Babylon and Medieval Tuscany

	Babylon	Tuscany (v.1.)	Tuscany (v.2.)
output per area unit	1	0.5	1/3
τ	0.357 (30% per radius)	0.163 (15% per radius)	0.255 (22.5% per radius)
radius of market zone	4	2.82	2.309
std dev of output per area unit	12% of the mean output	25% of the mean output	25% of the mean output
predicted CV of prices	0.635	0.331	0.357
observed residual std dev. of log prices	0.71	0.35	

5. The consequences of a reduction in price volatility for market performance

What is the relevance of a halving of market volatility between ancient Babylon and Medieval Italy? Why is it important that markets show a certain measure of stability and are able to accommodate exogenous shocks? One argument we would like to develop is that extremely high levels of volatility makes markets very unpredictable, which will reduce incentives for specialization. Farmers who are faced with the decision whether to specialize on commercial crops and to reduce the amount of inputs invested in subsistence activities, have to be able to predict the future prices of their crops. Voluntary specialization is arguably one of the key features of a market economy, and to get producers to consider this, the market price has to be a (more or less) reliable source of information, making it possible to predict future market prices. This is obviously related to the volatility of the market – the more extreme market prices fluctuate, the lower will be the information value of the current price and of the historical prices know to the producer.

We can model the link between the predictability and volatility of market prices in the following way. We assume that the log prices follow a first-order autoregressive process:

$$\ln p_t = \alpha_0 + \alpha_1 \ln p_{t-1} + u_t \quad (17)$$

Where the error-term (u) represents the random shocks, and it is assumed that: $u_t \sim N(0, \sigma_u^2)$

Since the constant plays no role we assume that it is positive and normalize the mean price to 1.

We assume that the agents are either fully informed and know the Data Generating Process or they only knew past prices and an adaptive expectations to predict future prices.

In the first case their expectation is the following:

$$E_{t-1} \ln p_t = \alpha_0 + \alpha_1 \ln p_{t-1} \quad (18)$$

while in the second case they use the following rule:

$$E_{t-1} \ln p_t = \lambda(p_{t-1} - E_{t-2} \ln p_{t-1}) + E_{t-2} \ln p_{t-1} \quad (19)$$

We assume that λ=0.8, which follows from the regressions we ran for Tables 3-4.

We assume that agents find prices only useful if they can use them to forecast dramatic price drops, or alternatively, if they can with more than 50% probability correctly forecast if the prices in year t exceed 70% of the current prices.

This means that prices are useful for if:

$$P\left[\frac{p_{t+1}}{p_t} \geq 0.7 \cap \frac{E_t p_{t+1}}{p_t} \geq 0.7\right] \geq 0.5 \qquad (20)$$

We carried out Monte Carlo simulations with different assumptions regarding the autoregressive parameter α_1 and the standard deviation of u (Tables 6 and 7).

Table 6

Results from the Monte Carlo simulation on prediction probability of minimum price (following (18)).

	AR coefficient					
standard deviation of the log error term	0	0.3	0.5	0.7	0.9	1
0.1	99.4%	99.8%	99.9%	100.0%	100.0%	100.0%
0.3	76.1%	81.1%	84.0%	86.2%	87.7%	88.3%
0.5	62.2%	65.9%	68.9%	72.5%	75.6%	76.2%
1	50.0%	51.0%	52.2%	54.7%	60.8%	64.0%
1.5	45.8%	45.6%	45.8%	47.3%	52.5%	59.4%
2	43.6%	42.9%	42.8%	43.4%	47.0%	57.1%
3	41.6%	40.3%	39.6%	39.4%	41.2%	54.9%
4	40.6%	39.0%	38.0%	37.4%	38.2%	53.6%
5	39.9%	38.2%	37.1%	36.1%	36.0%	52.8%

Note: for each combination of error volatility and AR parameter 1000 experiments were made on samples of 1000 observation. It is assumed that the price shocks are lognormally distributed. The tables reports the probability of correctly predicting that the next periods price will be at least 70% of the current price, based perfectly informed agents (knowing the DGP).

Table 7

Results from the Monte Carlo simulation on prediction probability of minimum price (following (19)).

	AR coefficient					
standard deviation of the log error term	0	0.3	0.5	0.7	0.9	1
0.1	99.4%	99.8%	99.9%	99.9%	99.98%	99.98%
0.3	79.9%	83.2%	84.9%	86.4%	87.7%	88.3%
0.5	69.3%	71.7%	73.1%	74.4%	75.7%	76.2%
1	58.3%	59.4%	60.1%	60.7%	61.0%	61.3%
1.5	52.5%	52.6%	52.5%	52.4%	52.2%	52.2%
2	48.7%	48.2%	47.6%	47.1%	46.5%	46.2%
3	44.4%	43.1%	42.1%	41.1%	40.0%	39.3%
4	42.0%	40.3%	39.1%	37.9%	36.5%	35.8%
5	40.5%	38.6%	37.3%	35.9%	34.4%	33.6%

Note: for each combination of error volatility and AR parameter 1000 experiments were made on samples of 1000 observation. It is assumed that the price shocks are lognormally distributed. The table reports the probability of correctly predicting that the next period's price will be at least 70% of the current price, based on adaptive expectations (the adaptive expectation parameter is set to 0.8).

The results suggest that the probability of correctly predicting if next period's price is at least 70% of the current price indeed reduces as price volatility increases. With reasonable choice of parameters - for the series studied here we find AR coefficients between .5 and .7[10] - we can argue that once the error of the prices has a standard deviation of between 1 and 1.5, the probability of correct forecasting drops below 55-60%. This result we obtain for both fully informed agents and adaptive expectations; both are very strong assumptions for the historical societies that are studied in this paper. Interestingly, we find that sometimes adaptive expectations slightly outperforming the case when agents know the DGP behind the prices.

[10] The AR-coefficients from Tables 3 and 4 fall within 0.5 and 07 with most being close to 0.7.

This happens if the autoregressive coefficient is close to zero. If the process tends toward unit root, however, the adaptive expectations strongly reduce in efficiency.

Summing up these results, we confirm that a drop of the CV from about 0.6-0.9 to about half that level (or even less), must have strongly increased the predictability and reliability of the market for the main agricultural goods. This must have increased incentive to voluntarily produce a surplus for the market, and reduce inputs into subsistence activities. That such a qualitative change happened in Medieval Europe, that in other words a 'market economy' emerged in that period, is also suggested by a rich literature pointing at fundamental institutional changes in exactly the same period, leading, for example, to the genesis of a 'modern' capital market (with interest rates as low as 5-6%), and the rise of an urban system of 'producer cities' (Bosker et.al., 2008; Van Zanden, 2009).

These findings of strongly declining volatility over time for Western Europe as opposed to Iraq and Egypt are corroborated by independent estimates of national income. Existing estimates show at best a small increase in per capita GDP for the area of current day Iraq between ca. 500BC and 1500 AD. For Mesopotamia, located in what is nowadays Iraq, Foldvari and Van Leeuwen (2010) calculated about 600 1990 GK dollars in the around 500 BC. This may be linked to estimates from Pamuk and Schatzmiller (2011) for Southern Iraq around 720 AD of 656 GK dollars and around 1220 of 640 GK dollars. Likewise, for Egypt it increased from 580 to 780 GK dollars between 300 and 1500 AD. This is on the whole much lower than the estimates for Italy for the period after 1300 that show a level of per capita GDP of about 1,600 GK dollars in 1300AD (Malanima 2009). For other European countries similar but somewhat lower levels have been reconstructed – there too GDP per capita has crossed the 1000 GK dollar threshold by 1400 (Van Zanden and Van Leeuwen 2011; Prados and Álvarez-Nogal 2009).As theory predicts, the strong decline in market volatility that occurred in Medieval Europe seems to have resulted in much higher levels of specialization and productivity.

6. Conclusion

Markets existed in almost all complex societies, but specialization induced by market exchange is a much more recent phenomenon. We argue that markets have to acquire a certain degree of predictability and reliability before Smithian processes of specialization can occur (Smith, 1991). The degree of volatility of market prices of basic foodstuffs can be used as a approximation of this characteristic of markets in the past. Datasets on prices of these foodstuffs make it possible to compare market performance over the very long run, from the first Babylonian sources of market prices 2600 years ago (the age of Nebuchadnezzar) to that of Napoleon at about 1800. This paper is the first to present a systematic comparison of such datasets, focused on markets in the Mediterranean region (to eliminate climate from the analysis). This study of grain prices in the Mediterranean region finds that markets in Medieval Europe were significantly less volatile than markets of ancient societies such as Babylon, and less volatile than markets in Medieval Egypt, Arabia and Iraq.

Moreover, we present a model to analyse the main determinants of market volatility; they are: the structure of the urban system (the more concentrated the urban system will be, the more volatile markets will be); the level of transaction costs (low transaction costs will result in high levels of market integration and less volatility); and the level of agricultural productivity (high productivity will lower market fluctuations). On the basis of this model is it possible to reconstruct which factors must have caused the decline in variability of market prices (comparing Babylon with Medieval Italy). In ancient societies (1) the urban system was too much dominated by giant capital cities, but (2) agricultural productivity was much higher in systems of irrigated agriculture which dominated in Mesopotamia and Egypt, even though this factor turned out to be of little significance. We conclude that (3) transport and transaction costs must have been much lower in Medieval Europe, to explain the big gap in market performance; this may be related to the use of different modes of transport: ships versus camels.

The finding that markets in Medieval Europe probably performed better than those in other parts of the Mediterranean world and than those in ancient societies (Babylon, Egypt, Rome, Athens) may also have resulted in much higher levels of GDP per capita in this region, but these findings are still very tentative.

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Data Appendix

For the period between 600 and 500 BC the data are taken from Jursa (2010, pp. 443-457). These data refer not only to Babylon, but also to neighbouring Uruk, Sippar, Nippur, and Borsippa. Theoretically, it would be preferably to estimate a dummy regression in which we regressed the prices on dummies referring to place, year, and month as suggested by Clark (2004). In that way we can correct for regional and monthly variation. Furthermore, this kind of regression improves with the number of observations. Since our sample is small and the price level among the different cities did not strongly deviate, we decided to take the simple annual averages of the prices.

For the period ca. 500-50 BC we take the data for the city of Babylon only (Slotsky, 1997; Vargyas, 2001; Slotsky and Wallenfels, 2009; Van der Spek, 2010). These data are based on the Astronomical Diaries. These diaries are best described by Hunger and Pingree (1999, 141) as 'record(s) of observed phenomena carefully chosen from the realms of the celestial, the atmospheric, and the terrestrial.'[11] In other words, astronomers tried to predict events based on the position of the planets. One thing they noted down was the level of the prices of six commodities: barley, dates, cuscuta, water cress, sesame and wool. Theoretically, these prices exist for the period ca 400-50BC monthly, or even daily. However, many observations are missing. Still, out of a possible 4079 months, we still have observations for 512 months.[12] This allows us to correct the prices for seasonality using a regression with monthly dummies.

For other regions we have far less data. The best dataset outside of Babylon is possibly for Egypt. Von Reden (2008) reports prices for Egypt between ca. 300 and 90 BC. These data

[11] The name 'Diary' was coined by Abraham Sachs on the basis of the colophon-title *naṣāru* (EN.NUN) *šá ginê*, 'regular observation'.

[12] Average of the number of available observations on barley and dates.

are largely representative for the more densely Greek dominated parts of the country. As Von Reden points out, however, the prices are representative of normal market behaviour in Egypt. In the same paper, she also presents data for Delos, taken from Reger (1994), and Athens. Further, we use data for the second great Empire in this region, Rome, from Rathbone (2011). For the later periods from ca. 1200 onwards we have data from Iraq, Egypt, Syria and Istanbul (Ashtor, 1969; Mortel, 1989, Pamuk, 2004). The earlier estimates are normally taken from contemporary economic historians, often reporting extreme prices, while the Istanbul data refer to retail prices (Pamuk, 2004, 452). The data for the period after 1500 are more abundant. We included the retail prices for wheat from Istanbul as well as data from Tuscany, Modena, and Naples (Coniglio, 1952; Romano, 1965; Basini, 1974; Malanima, 1976; Pamuk, 2004).

Three problems surround these data. First, some authors, in the Finleyian (Finley, 1973) tradition, have doubted whether the prices from antiquity are "real" market prices. Yet, as pointed out by Von Reden (2008), the Egyptian, Athenian, and Delian prices exhibit relatively strong seasonal variation. At the same time she argues that imports increased during periods of high prices, all evidence that a working market existed. The same has also been argued for Babylon by a variety of authors like Temin (2002), Foldvari and Van Leeuwen (2009), Romero *et al*. (2010), and Van der Spek In press). Van der Spek (in press) even explicitly states that '[t]he very fact that these prices need to be predicted based on the position of the planets shows that they are unpredictable and, hence, market prices.' The same finding of a working market has been argued for the Roman Empire as well by Rathbone and, from the perspective of active trade relations, by Kessler and Temin (Kessler and Temin, 2005; Rathbone, 2011).

The second problem is that not all prices are of barley. Wheat was generally preferred in the Eastern Mediterranean and was the main staple in Egypt. However, barley, and to a certain extent dates, dominated food supply in Babylon. This was largely caused by salinization of the soil. Since wheat is less resistant against salt than barley, wheat was slowly replaced by barley in Babylon.[13] In addition, a litre of barley has around 20% less nutritional value as wheat. On the other hand, the Babylonian did not have the opportunity to choose wheat since it was not locally grown and trade was difficult. Furthermore, as argued by Van der Spek and Van Leeuwen (forthcoming), the price difference in between wheat and barley was around 60% in Egypt where wheat was the preferred grain, a ratio that we also encounter in present day Iraq. Also Von Reden (2008, 12) argues that wheat prices in Athens are around 20-30% higher than barley prices, a difference not unlike the one found in Egypt (Von Reden, 2008, 15). Since barley is the preferred grain in Babylon, however, Van der Spek and Van Leeuwen (in press) argue that its price must be closer to that of wheat. Hence, since barley was the main foodstuff in Babylon while wheat had that role in the rest of the Mediterranean we might consider them as identical, as "grain". Yet, even if we would not accept that the prices of barley in Babylon and wheat in litres may be reasonably close, it is still important to stress that we use these prices solely to calculate relative price volatility, which is independent of the level of the prices.

Finally, we have to convert all prices series to a common value, in order to make them comparable. In this paper, all price series were therefore converted into grams of silver per 100 litres. Only for the period after 1000 AD this contains a problem because gold coins entered into circulation and some prices are expressed in terms of gold. Therefore, where necessary, we follow Söderberg (2004; 2006) and use the Cairo bimetallic standard for Near East up to 1500. Although this not necessarily always correct, available evidence shows that this ratio for later periods remained almost constant. Indeed, since this is almost equal to the

[13] Jacobson and Adams (1958); Artzy and Hillel (1988). However, for a critique see Powell (1985).

ratio in Mecca 1200 AD, this is an acceptable simplification. For Babylon this question is less relevant since the money was silver based anyway. For the other series we simply use the silver contents of the coins.

The data after 1400 are taken from the Allen-Unger dataset and are given in grammes of silver per litre per annum.