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Words and Numbers: A New Approach to Writing Ancient History

Interdisciplinary history can enrich the approach of disciplinary histories. According to Beard, the author of a recent definitive history of the Roman Republic, "What is missing [from ancient history] is the perspective of those outside this exclusive group [of well-known authors]: the view of the ordinary soldier or voter, of the women or . . . the slaves." Thinking about the economy in ancient Rome provides a window into the ordinary lives of ancient Romans. It expands our view of history and helps to integrate ancient history with the economic history of more modern times.[1]

But interdisciplinary history is difficult to produce. Scholars can receive training in economic history or ancient history but not in interdisciplinary history per se. Instead, historians aspiring to think about economic activities start from different disciplines according to their tastes and training to infer "the view of the ordinary soldier" or farmer. The question is how diverse scholars can communicate to provide an interdisciplinary history of the Roman economy and our economy today when their epistemologies are so divergent. As Beard stated, most knowledge of ancient history comes from words; ancient historians are trained primarily to parse words. Economic historians, however, are interested in numbers. Interdisciplinary workshops and talks routinely expose the different emphases of these disciplinary biases. The two ways of interpreting the scant evidence lead to different approaches. Ancient historians focus on narratives; economic historians focus on probabilities.

We all like stories to which we can relate emotionally. Thinking about the stories passed down in ancient history, however,

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1 Mary Beard, *SPQR: A History of Ancient Rome* (New York, 2015), 350.

poses questions that arise from contemporary issues, but these questions are obscured by the small amount of hard evidence about life in ancient Rome that has managed to survive for 2,000 years. Words alone, copious as they are, cannot answer them. The task for modern historians is how to generalize from the little that we know about ordinary people in the past. We can tell stories about individuals, but how are we to know how characteristic any individual is? Can we translate one person's experience into a description of a society as a whole?

Consider a noneconomic example. King Agrippa II stood on the roof of his palace in 66 A.D. to deliver a speech warning his subjects about the revolt against Rome looming ominously in Judaea, which eventually ended with the destruction of the Jewish Temple in 70. Agrippa II appeared to be acting as a spokesman for some part of the Jewish population. But how many people do we think heard his stirring speech? We know about the speech only because the ancient historian Josephus recorded, or fabricated, it. Ancient authors commonly placed opinions into the mouths of their contemporaries. Thanks to this practice, modern authors have acquired the opportunity to personalize and dramatize ancient ideas, but we still do not know how many people heard and believed Agrippa II. Was he speaking to a large collection of people who had the power to arrest the progress of the growing revolt, or was he speaking to a few of his friends as the revolt gathered strength?[2]

Goodman, who authored a book quoting Agrippa, used the speech to introduce his attempt to understand the growth of the doomed revolt against Rome. Goodman described Jerusalem as a prosperous city to which Roman tourists flocked to see sights that were ancient even in classical times. To what extent were Roman tourists like tourists today? Did they have groups or leaders to show them the sights? Did they arrive on private ships that transported them from, say, Italy to Jerusalem? Was it easier for rich Roman tourists to book ship passages and accommodations in Jerusalem than it was for poor tourists? In short, did Judaea, a small area on the fringe of the Roman Empire, have a market economy?[3]

2 Martin Goodman, *Rome and Jerusalem: The Clash of Ancient Civilizations* (New York, 2007), 63–65.

3 *Ibid.*

I tried to answer this question by examining prices, because prices are integral to market economies, and in order to determine whether the available prices were market prices, as opposed to administrative or ceremonial prices, I used a simple statistical test to see how they behaved. A simple regression on a few prices can provide answers to these questions, though not detailed answers or irrefutable answers. The aim is to generalize about the Roman economy, to choose between administered or market prices or between prices and barter, not to summarize all the details about commerce in a simple regression. The results come only as a series of probabilities that offer the choice of accepting the generalizations or not. Paying attention to simple regressions on a few numbers can aid in understanding Beard's question and suggest tentative answers. The point of the statistics is not to supplant the written sources but to amplify their importance by providing descriptions of the world in which the written sources emerged.

Such was the method of my book, *The Roman Market Economy* (Princeton, 2013), which opened with a small regression—hypotheses tests that draw implications from a basic correlation—and followed with a succession of chapters that explain in detail how the various parts of a market economy operated in Roman times. The goal is hardly to preempt narrative but to provide context for individual narratives. An analysis of the disagreements about my regression with the aid of statistical theory is instructive, leading to reflections about what this debate portends for interdisciplinary history.[4]

UNCERTAINTY IN HISTORY: WHEAT PRICES IN ROME In his book, *The Corn Supply of Ancient Rome*, Rickman noted that the six wheat prices that he was able to find were all reasonably close to each other in value: "Curiously enough ... what evidence we have about corn prices had rather greater unanimity than we might have expected." What could have caused this unanimity of prices around the Mediterranean? Given so few observations, two explanations are possible—(1) chance or (2) an influence that forced prices into the same order of magnitude. Do these six prices that Rickman managed to collect hint at a pattern? At first glance, chaos seems to be more likely than order. Rickman provided several reasons

4 Temin, *The Roman Market Economy* (Princeton, 2013).

why a pattern might be difficult to detect: "There would seem to be as many different prices for wheat as there were different places and different periods in the history of the ancient world."[5]

Although Romans talked incessantly about money, only a few prices are available after 2,000 years to be quoted in modern books. In addition, only a few of the surviving prices pertained to a uniform commodity like wheat and only a few conformed to a uniform currency that permits comparisons. Given these circumstances, what connections around the large geographical area that comprised the Roman world could cause such unexpected uniformity in the seemingly disparate prices that Rickman discovered? What kind of pattern, if any, is behind it? Can these scattered prices help to answer Beard's question about ordinary people?

The Importance of Statistical Theory We can have confidence in the patterns that statistical analyses are able to distill from random bits of information. Ancient historians are not taught statistics, but economists rely on them. Because ancient and economic historians have different skill sets, their attitudes toward ancient data, and their epistemologies, are often at odds. Ancient historians focus on the accuracy of individual observations, ascertaining whether they are typical of their time and place as recorded and translated. Economic historians study groups of observations, called samples. Although accuracy is important to them as well, they are more interested in testing hypotheses about the generalizations and patterns that might lurk within their observations than they are in the individual observations themselves.

An introduction to certain statistical concepts can clarify these differences and facilitate interdisciplinary history. The *central limit theorem of probability* states that the sum of random variables with varied probability distributions is a random variable with a *normal distribution*. The normal distribution also is known as the *bell curve* because of its shape. The normal distribution is so called because it is so common. For example, consider the ancient prices recorded by Rickman. Some of them were recorded as actual sales, and some of them were guesses made at the time. Other records of prices disappeared for unknown reasons in the intervening two millennia. Values observed today, which are the result of the various probability distributions involved in the recording and preserving of

5 Geoffrey Rickman, *The Corn Supply of Ancient Rome* (New York, 1980), 145.

these prices for 2,000 years, are described by a normal distribution. To identify the normal distribution that applies to these prices, we need only find its mean and variance—that is, the location and thickness of the bell curve.

The application of statistics to the collection of prices in Rickman's book entails the observation that these prices were not the only Roman prices. In other words, they are a *sample* of Roman prices. As we will see, other Roman prices that have survived can be combined into other samples. In addition, these prices are a *random sample* of Roman prices, meaning that Rickman's prices had the same probability of being selected as any other relevant Roman prices. Although we do not know Rickman's motives, we know that the chance of any individual price surviving for 2,000 years is separate and small and that our history of this period in antiquity is based on a small fraction of the records actually composed at that time. Hence, we can invoke the central limit theorem of probability, which states that variables drawn from many separate distributions converge to a bell curve, also known as a normal distribution.[6]

These descriptions are simple and even obvious, but they differ from the assumptions made by ancient historians, who predominantly study the people who collected Roman prices, not bell curves. They think of prices individually, not as samples of a larger population, although they often extrapolate casually from single observations. Both ancient and economic historians want to generalize—to create a picture of the ancient economy—but they approach this goal with different tools. What is important to note, however, is that the two kinds of tools are complementary; they should be used together.

Subject to the simple descriptions just presented, *regressions* can help us to choose between order and disorder. A regression determines the best line that is closest to a set of points in a normal distribution—like a collection of Roman prices—and generates a measure that enables us to decide whether these prices follow a pattern or are unrelated to each other. This measure, known as the *t-statistic*, summarizes calculations that can assess the accuracy of, say, Rickman's conclusion about the chaos of pricing. To use tables of *t*-statistics, we need to know only the number of

6 Stephen Greenblatt, *The Swerve: How the World Became Modern* (New York, 2011).

degrees of freedom in a regression. Degrees of freedom are found by subtracting the number of necessary relations among observations from the total number of observations. Rickman listed six prices. The simplest regression specifies the best linear relation between the observations. A straight line has a slope and an intercept, that is, two relations. That makes four degrees of freedom. One of Rickman's observations is problematical in this test; omitting it leaves us with only three degrees of freedom.

The regression of Rickman's prices on the estimated distance from Rome confirms with 95 percent probability that transport costs were proportional to distance and that the effects of distance were larger than the idiosyncratic influences of particular markets and places. This finding implies a unified wheat market extending from one end of the Mediterranean Sea to the other. The probability found in this instance is the same percentage of likelihood that the Federal Drug Administration employs today to declare a medical drug safe and effective. Yet, several eminent ancient historians reject regression on the grounds that it is too simple to be useful—an objection that exposes the epistemological gap that tends to confound interdisciplinary history. The *t*-statistics show the results to be highly significant despite the few degrees of freedom—in fact, nearly the fewest degrees of freedom necessary to calculate *t*-statistics. Only a simple relation can be tested with so few observations. Simple models are not as appealing to ancient historians as they are to economists, but they are common in ancient history nonetheless, under the rubric of generalizations. Simple models, or generalizations, can always be elaborated into more subtle stories.[7]

Rathbone, who collected many Roman prices, objected, "The thesis of Kessler and Temin (2008) just does not fit the Roman data as a whole ... at least in the simplistic form in which it is presented." In Scheidel's words, "Moses Finley's famous observation that 'ancient society did not have an economic system which was an enormous conglomeration of interdependent markets,' [has been] countered by Peter Temin's repeated claim that the Roman Mediterranean did indeed form a single integrated market for goods and labor. ... Given the paucity and uneven quality of the available local price data, it is easy to find fault both

7 For the likelihood of drugs being safe and effective, see Temin, *Taking Your Medicine: Drug Regulation in the United States* (Cambridge, Mass., 1980).

with the underlying premise and the practical execution of Temin's analysis. After carefully exposing these problems in great detail, Gilles Bransbourg has repeated this exercise with a revised and expanded sample of local grain prices from twelve different sites." Similarly, Bang dramatically stated, "Peter Temin argued that Finley was quite simply wrong. This is an extraordinary claim. One might conceivably imagine that some markets had begun to be linked by middle- and long-distance trade. But to see the entire economy, spanning several continents, as organized by a set of interlinked markets is quite another matter."[8]

The main market in any set of interlinked Roman wheat markets would have been in the city of Rome, the center of imperial administration, where the largest number of potential consumers lived and the largest supply and demand for wheat would have existed. The price of wheat would have varied over time as harvests fluctuated across the Roman world, and government actions altered the value of the currency. Normal variations in supply and demand elsewhere in the empire would have affected the price, although most fluctuations would have been small relative to total production and consumption at Rome. Most places outside Rome would have had an excess supply of wheat, the price of which would have been set in Rome, where the excess supply and demand would have met.

Yet, even though under normal circumstances, wheat outside Rome would have taken its value from the price in Rome, the status quo did not always hold. Certain isolated areas outside Rome could have had an excess local demand as well as an excess local supply, because of famines and gluts. For example, the usual price of wheat in Palermo, Sicily—which was the price in Rome minus the cost of transporting wheat there from Palermo—would temporarily fall below the level normally set by Rome if, say, a storm prevented shipment. Furthermore, if a harvest failure in

8 David Kessler and Peter Temin, "Money and Prices in the Early Roman Empire," in William V. Harris (ed.), *The Monetary Systems of the Greeks and Romans* (New York, 2008), 137–159; Dominic Rathbone and Sitta von Reden, "Mediterranean Grain Prices in Classical Antiquity," in Robartus J. van der Spek, Jan Luiten van Zanden, and Bas van Leeuwen (eds.), *A History of Market Performance: From Ancient Babylonia to the Modern World* (New York, 2015), 149–235, 188; Walter Scheidel, "The Shape of the Roman World," *Journal of Roman Archaeology*, XXVII (2014), 7–32; Peter Bang, *The Roman Bazaar: A Comparative Study of Trade and Markets in a Tributary Empire* (New York, 2006), 31.

Sicily created a local famine, the price of wheat in Sicily would have risen above the level indicated by the Roman price until new wheat supplies were available. In the absence of such extreme events, however, a unified market would have kept Sicilian prices near the Roman price less the transportation cost.

More concretely, given a unified market, competition would have determined Sicilian prices. If the Sicilian price of wheat rose above the Roman level minus transportation costs, it would not have made sense for merchants to buy wheat in Sicily to sell in Rome. The amount of wheat demanded in Sicily would have fallen, thus dropping the price. If the Sicilian price of wheat dropped below the Roman level minus transportation costs, merchants would have bought more wheat in Sicily since they could have made an unusually high profit by taking it to Rome and selling it there. Merchants would have bid against each other, raising the Sicilian price.

Wheat at Lusitania in Spain would have been worth less than wheat at Palermo because it was further from Rome. Because the cost of transporting wheat from Spain to Rome was higher than the cost of bringing it from Sicily, the price of wheat in Spain would have been lower. The reasoning is exactly like that for Sicily; only the transport cost is different. But although each price was established on the basis of that in Rome, the price in Spain would have been lower than that in Sicily in a unified market. We do not know the transport costs around the Mediterranean in any detail, but we are reasonably sure that the price of wheat would have decreased with distance from Rome, given a unified wheat market. As Smith stated, "The corn which grows within a mile of the town, sells there for the same price with that which comes from twenty miles distance."[9]

In the absence of a unified market, prices in the independent local markets would not have had any relationship to Roman prices, as Rickman and Bang suggested; prices would have been determined only by local conditions. The prices would have moved together at times—if storms across the Mediterranean caused simultaneous harvest failures, or currency debasements

9 Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (London, 1776), 307–310 (Book III, Chapter 1), available from the EE-T Portal at https://eet.pixel-online.org/files/etranslation/original/The%20Wealth%20of%20Nations.pdf.

caused prices to rise—but they would not have been related to each other as a rule; any single identity of prices would have been a coincidence. If we find wheat prices in different places, however, we can test whether any pattern that we notice is due to coincidence or an underlying process.

The question is not whether an efficient market existed or whether particular forces brought separate local markets together but whether the historical facts lie closer to one end of the continuum than the other. Many interventions into Roman markets and local actions elsewhere around the Mediterranean are well known. Local grain shortages and famines must have occurred from time to time. Was the normal state of affairs based on interconnected markets in which prices typically were related or on separate, independent markets in which no systematic relationship between location and grain price obtained?

The simple model supplies a clear representation of Roman trade across the Mediterranean within which wheat prices in outlying provinces were related to those in the city of Rome. Given the extremely limited data about Roman prices, no more complex model could be tested. The simple model treated herein is compatible with a complex pattern of actual Roman trade. Wheat must have been shipped to provinces around the Mediterranean, rather than to Rome, when local scarcities from famine, bad weather, or war occurred, but Rickman's small set of Roman wheat prices suggests strongly that these special cases were unusual. All of the diverse trade during the late republic and early empire went first and foremost through the city of Rome.

THE PROS AND CONS OF A SMALL REGRESSION The Rickman sample of price pairs is not an overwhelming amount of evidence, but it is enough to test whether the patterns in the data are random. In each case, the Roman price was subtracted from the price at a distant location to yield a price differential. According to Rickman and Duncan-Jones, wheat prices at Rome were subject to slow inflation. Ancient historians characterize this period as having stable prices elsewhere, with an allowance for slow and gradual price changes to be described below.[10]

10 Rickman, *Corn Supply*; Richard Duncan-Jones, *The Economy of the Roman Empire: Quantitative Studies* (New York, 1982; orig. pub. 1974); Temin, *Roman Market Economy*.

The distances of the price observations from Rome are calculated as straight-line distances on a map, which represent only an approximation of the actual distances that wheat traveled. This added randomness reduces the possibility of finding evidence of an integrated market. Added randomness contributes to a judgment that the various prices are unrelated.

Epistemology is important in the treatments of these samples. Roman historians look closely at each individual observation to ascertain who collected it and under what conditions. Economic historians view individual errors in the underlying data merely as obstacles to climb in their quest to discern overriding patterns. If individual observations have differences between them—say, in the time of year when they were observed—they are no more than extraneous noise in the testing of a hypothesis unrelated to the season. Formally, we refer to "ideal" observations, as distinguished from the added errors, or noise, that reduce the possibility of finding a pattern by introducing something irrelevant.

The Prices in the Regression The price closest to Rome, which was from Sicily, derives from an accusation in Cicero's *Verrine Orations* that Verres did not transact business at the market price, even though he acknowledged its level in a letter (Cicero, 2 *Verr.* 3. 189). Cicero's observation, like most other reports, gives the prevailing local price in round numbers. Since it is not the record of any actual transaction, it is likely to be an approximation. This casual quality militates against finding any systematic relationship between prices, as just noted. It introduces more noise into any relationship between prices because of the unknown difference between the reported averages and actual prices. These implications about the difficulty of drawing conclusions all depend on the randomness of the observations. Whenever systematic biases enter into observations, something more than general rules is necessary.

The second price came from Polybius (34.8.7) in his discussion of conditions in Lusitania; it, too, is a general statement about a prevailing price. Although having a genuine average price can be helpful, the casual quality of the averaging process adds noise into any comparison of prices in different places.

The third price, which derives from the Po Valley in Italy, also comes from Polybius (2.15.1). The Po Valley is closer to Rome than are Sicily and Lusitania, but although its connection

to Rome was more by river than by sea, a bulk commodity like wheat may well have gone by sea, anyway. Fortunately, the distance that wheat would have traveled along both routes was similar. The calculation of the prices there is based, first, on Diocletian's *Price Edict*, which fixed river transport prices at five times the level of sea transport prices. Although this evidence dates from more than a century later than any of the other prices, Greene maintains that the ratio of sea and river transport costs remained constant over time. Hence, we include the Po Valley in the price data by multiplying the river distance from Rome by five. Calculating the sea distance along two straight lines to get around the heel of Italy arrives at an observation slightly different from other results, even if measured by sea. As it turns out, however, the distance by sea from the Po Valley to Rome roughly equals the distance calculated from the Diocletian *Edict*. Despite the small sample, the data are sufficient to test whether this unusual attention to distance affects the statistical result.[11]

The fourth price comes from an official intervention in the local market, an inscription recording that the wheat price in Pisidian Antioch was high in a time of scarcity. The normal price was eight or nine *asses* per *modius* (a Roman weight); the acceptable limit price was one *denarius* per *modius* (*AÉ*1925, no. 126b). This inscription reveals several important aspects of the Mediterranean wheat market in addition to reporting the normal price. The need to reduce famine prices indicates that local markets were subject to local scarcities; these markets were not so well linked that wheat from elsewhere would be available instantly to alleviate a local shortage. The apparent success of such interventions, in this case limiting the price to double its normal range, indicates that many famines were not severe.

With regard to Egypt, our model preserves the spirit of Rickman's enterprise but improves his data; Rathbone reworked the sale prices that Rickman took from Duncan-Jones. Our price for Egypt—seven *drachmae* per *artaba* (a unit of dry capacity)—is an

11 Harris, "Trade and the River Po: A Problem in the Economic History of the Roman Empire," in Jean-François Bergier (ed.), *Montagnes, fleuves, forêts dans l'histoire* (St. Katharinen, 1989), repr. in *idem*, *Rome's Imperial Economy: Twelve Essays* (New York, 2011), 188–197; Kevin Greene, *The Archaeology of the Roman Economy* (Berkeley, 1986), 40.

average of seven Egyptian prices from agricultural areas during the "famine" of 45 to 47 C.E., not from a Mediterranean port. Dividing these prices by 4.5, as Duncan-Jones specified, converts them from Egyptian currency and units to HS (*sesterces*) per modius.[12]

Distant Palestine provides the sixth price to be compared with roughly contemporaneous prices at Rome. Taken from Frank's *Economic Survey*, it, like Egypt's, is also an average of a few actual transactions.[13]

Rickman argued that the price of wheat in Rome was between three and four HS per *modius* in the late Republic, rising to five to six HS in the early empire. Duncan-Jones confirmed the general price level, and Rathbone confirmed the smallness of inflation, at least for Egypt where the data are more abundant. The order of observations is almost chronological, even though the order of exposition is by distance. Six prices in almost two centuries do not constitute an overwhelming amount of evidence, but they are enough to test for patterns in the data. In each case, subtracting the Roman price from the price at the distant location gives a price differential. More prices come to light all the time, but this small sample provides a way to answer our question, at least provisionally. The prices and the differences between the prices in Rome and the local prices are shown in Figure 1. The differences are all negative, consistent with general observations that agricultural prices were lower outside Rome. Wheat prices clearly were lower outside Rome.[14]

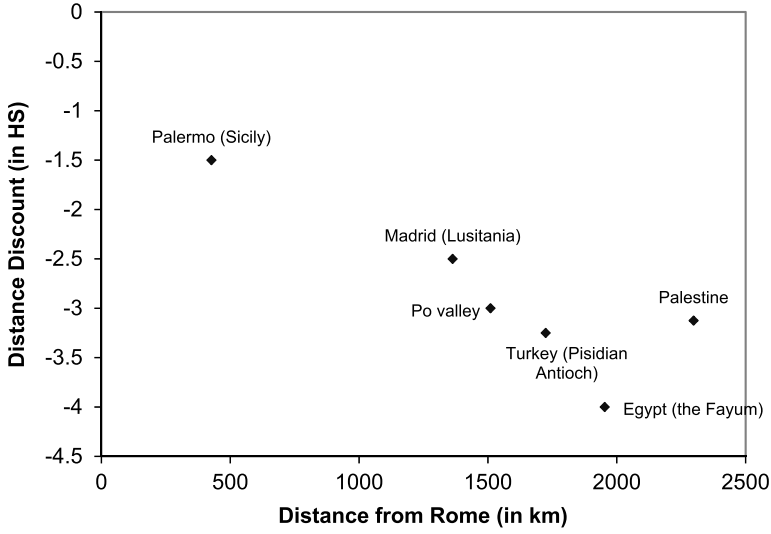
The graph of the price differentials against the distance from Rome in Figure 1 is striking. The further from Rome a place was, the lower was its price for wheat, and the price differentials appear to have been proportional to distance. These prices come from all over the Mediterranean and from various times in the late republic and early empire. Without a unified grain market, we would have no reason to expect a pattern in these prices. Even with a unified market, our inability to find more prices or more accurate transportation costs might obscure any true relationship among the

12 Rathbone, "Prices and Price Formation in Roman Egypt," in Jean Andreau (ed.), *Économie antique : Prix et formation des prix dans les économies antiques* (Saint-Bertrand-de-Comminges, 1997), 183–244; Duncan-Jones, *Structure and Scale in the Roman Economy* (Cambridge, 1990), 372.

13 Fritz M. Heichelheim, "Roman Syria," in Tenney Frank (ed.), *Economic Survey of Ancient Rome* (Baltimore, 1938), IV, 181–83.

14 Peter Garnsey, *Cities, Peasants and Food in Classical Antiquity* (New York, 1998), 241.

Fig. 1 Plot of Price Discounts by Distance from Rome

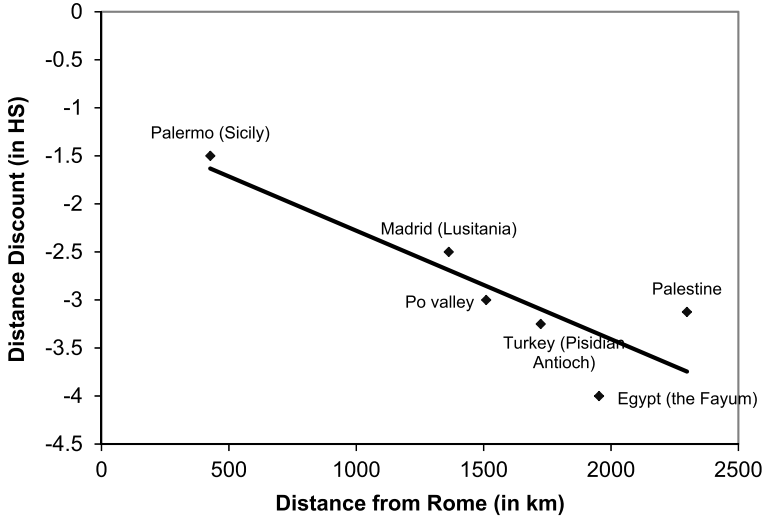


prices. Yet Figure 1 reveals a clear pattern, even though we should treat it as only a suggestion—a slim thread of evidence on which to hang a grand story of market integration. However, regression analysis can evaluate how likely a picture like Figure 1 could arise by chance. We can test the probability that the separate areas of the early Roman Empire were isolated economically from Rome. Their prices would have been determined by local conditions, including perhaps the degree of monetization. The price levels would have had no connection with distance from Rome.

We start by drawing a line that relates the price difference between local price and Roman price to distance from Rome. We then adjust the line to make it the best description of the data, in the sense that it minimizes the squared distance of the individual observations from the line. This process of regression analysis is known as the method of "least squares," and the resulting least-squares line is the regression line (see Figure 2).[15]

15 We use the square of the distance to minimize the distance from points both above and below the line and to simplify the mathematics.

Fig. 2 Relationship between Distance from Rome and Discount



One of the benefits of regression analysis is that it generates tests of a hypothesis being tested. We can ask if an apparent relationship between the price discount and the distance from Rome is an illusion, a result of observing only a few prices rather than the result of a systematic process. In order to draw this line, we assumed a relationship between the distance from Rome and the price discount. Regression analysis tests the validity of such an association by revealing how unlikely it is to find a line like the one shown in Figure 2 by chance. Assume that the prices gathered from Rickman were randomly drawn from an underlying distribution of price observations. In another world, different prices could have survived from this same distribution. Taking account of the random quality of the observations at hand, how unlikely is it to find the line in Figure 2 by chance?

Regression analysis acknowledges that the slope of the line in Figure 2 is not known with certainty. It is the best line that can be drawn with the current data, but it is subject to errors deriving from the incomplete sampling of the underlying distribution. In the jargon of regression analysis, the slope of the line has a standard error. If all the points in Figures 1 and 2 were in a straight line, the slope of the regression line would be clear, and the standard error

of the slope would be close to zero. If the points are spread out as they are in these figures, the line is not as clear, and it might have no slope at all; that is, it might not indicate any relationship between the distance from Rome and the price difference.

The test is to compare the size of the slope, the coefficient in the regression, with the size of its standard error. If the coefficient is large relative to the standard error, it is unlikely that the line was a random finding without support in the price data. But if the coefficient is small relative to its standard error, it is possible that even though the regression line has a slope, price and distance have no underlying relationship. Statisticians call this ratio a *t*-statistic, and tables can translate *t*-statistics into probabilities that a line is observed by chance. These tables take account of degrees of freedom—the number of observations minus the number of coefficients. It takes two variables to define a line, its slope, and its position (its height in the figures). Six observations and two variables offer four degrees of freedom. Omitting the observation with river transport reduces the number of observations by one and the degrees of freedom to three. The *t*-statistic must be larger with such few degrees of freedom than it is with more degrees of freedom to show that a given regression line is unlikely to be the result of chance.

Statistics, Signals, and Noise Our data—composed of only a few scattered values—might seem insufficient for statistical analysis. Statistics, however, offer the best way to distinguish signals from noise; they are particularly useful when the noise in the system is substantial. They give us a precise sense of how unlikely it is that any putative pattern would have been generated by random processes and actually is just noise. Statistics allow us to test the formal hypothesis that wheat prices around the Mediterranean Sea were related to those at Rome in a simple way. We can also derive an explicit probability that this hypothesis is true, given our observations. The key is randomness. Even a few observations randomly drawn from a population can provide information about that population as a whole. The literature that analyzes the difficulties attending this procedure is voluminous. Errors in the transcription or treatment of data militate against finding stable results capable of fostering generalization because they increase the randomness of the observations. In other words, finding a pattern in these few data points would be remarkable.

Errors in variables are a common problem in regressions. We often suspect a relationship between two variables—like the price in Rome and the price in Egypt—but cannot observe one or the other of these values precisely. We must resort to a proxy, such as the occasional price that happens to be mentioned in a surviving document. The errors introduced by such a procedure are well known. The extra uncertainty introduced by using imperfect proxies reduces the explanatory power of regressions, resulting in coefficients near zero; the addition of noise through imperfect observations makes the results look more like noise. The well-known scarcity of Roman prices therefore makes discovering a pattern in them difficult. Any such discovery, however, indicates both a strong relationship between the prices and a set of observations that is reasonably representative.

Several conclusions emerge from these results. The regression explains three-quarters of the variance of the price differentials. It is very unlikely that the correlation between distance and price is due to chance. Using the price differentials themselves, the regressions explain three-quarters of the price variance. Using logarithms of the differentials, the regressions explain even more. The discovery that the prices were part of a pattern rather than a random collection confirms the impression in Figure 1 that distance from Rome was a powerful explanatory factor in determining wheat prices around the Roman Mediterranean.

The *t*-statistics indicate whether the relationship between price differentials and distance was the result of chance. They measure the probability that each coefficient is different from zero, taking account of the number of observations used to derive it as well as their variation. If a *t*-statistic is greater than three, the observed relationship between distance and price differentials has less than one chance in twenty of being due to chance. In the more precise language normally used for regressions, the probability of observing the coefficients in the table if the price of wheat and the distance from Rome were unrelated is less than 5 percent in three out of four regressions and close to that probability in the fourth. The 5-percent value of the *t*-statistic for four degrees of freedom (six observations) is 2.8; it is 3.2 for three degrees of freedom (five observations). Higher *t*-statistics indicate lower probabilities that the observed relationship is the result of chance.

The constant terms are negative in the regressions for price discounts and positive in the regressions for the logarithms. Because they were not estimated as precisely as the relationship between distance and the price differentials, they could be the result of chance. There appear to have been other costs as well, albeit smaller and less well observed. These other costs were partly physical—the costs of trans-shipping wheat to and from sea-going ships—and partly administrative—port charges and taxes. Their presence does not detract from the effect of distance or the evidence in favor of a unified wheat market.

Finally, the inclusion or exclusion of the Po Valley makes no difference. Removing this observation reduced our comparisons to five, but it did not affect the proportion of the variance explained or the evidence that the relationship of distance to price differentials was not random. The *t*-statistics take account of the reduction in the number of observations to calculate the probability that the observed correlation was due to chance. The logic behind this finding can be seen in Figure 2. The observation for Bologna lies close to the regression line; removing it changes neither the line nor the message from this regression.

Scheidel's criticism of this regression is based on data collected by Bransbourg that did not start out as supportive of these results. The first graph in Bransbourg's article shows the effect of moving the measured distance for one of the observations, which, in his words, makes my regression "very weak to a point of near irrelevance." This claim is unfounded. Different data produce different answers. Changing the data in order to change the results does not make a sample random or allow a test of hypotheses. If you do not believe in your data, you can reach any conclusion that you desire. If you feel free to change the facts, then you leave the domains of history and economics.

The key, again, is randomness. As explained above, the Rickman sample was random, in that it was created for reasons that were totally independent of the hypothesis to be tested. The simple theory presented at the beginning of this article is designed to highlight the centrality of random samples in the testing of hypotheses. Random samples are the keys that unlock all the tools that statistics can offer.

New Samples and New Regressions After stating that "the [original] equation as formulated cannot be statistically upheld,"

Bransbourg added more prices to those reported in Rickman, and he recalculated Rickman's data to provide what he considered more accurate distances and sometimes new values. Despite the overlap with Rickman's sample, the new data set provides a new sample from this ancient price distribution that can determine whether another sample yields the same result as the first sample. The benefits of new data are legion. They can improve the probability that the hypotheses tested are in fact sound. They also can allow new degrees of freedom to make the regression more complex. Regressions are always a simplification of reality, but they can become more sophisticated as the data increase. Notwithstanding its contentiousness, this discussion has generated more observations of ancient prices.[16]

Despite Bransbourg's effort to discredit the earlier results and to stack the deck against them, his new regression obtained the same results—a distinctly negative association between price and distance. Yet, even though Bransbourg reproduced the significant effect of distance on price with his full data set of a dozen observations, he concluded that this effect explained far less of the variation in Roman prices than the original regression had claimed. Suggesting that a market may have been more of a factor for coastal cities than for inland cities, he ran tests exclusively on coastal cities. Reducing his sample size to the familiar half-dozen, he found that not only was the effect of distance clearer but that distance from Rome also explained 86 percent of the variation of prices around the Mediterranean.

If Bransbourg's reasoning is correct, a regression of the other six observations—the ones from inland cities—should have shown that distance from Rome did not have much of an effect. But exactly the opposite is true. The coefficient of distance was estimated precisely, and the regression line explained 87 percent of the price variation. This result suggested that distance was important, and similar, for coastal and inland cities.

A further regression on all twelve of Bransbourg's observations and an additional variable—a dummy for inland cities—reproduced the results of the original regressions. The effect of distance on

16 Temin, "Statistics in Ancient History: Prices and Trade in the Pax Romana," in Giuseppe Dari-Mattiacci (ed.), *Roman Law and Economics* (New York, forthcoming), available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2217011.

wheat prices is clearly estimated: The regression explains three-quarters of the variation in Roman wheat prices around the Mediterranean, after making an allowance for the difference between coastal and inland cities. The effect of the extra cost of transportation is not clearly estimated, but it appears that the discounts from the price in Rome in coastal cities were about one *sestertius* per *modius* smaller than those of inland cities at the same distance from Rome.

Small as the new sample is, ranging from six price pairs to a dozen, it does not detract from the test of this hypothesis. As noted above, the standard errors and *t*-statistics are corrected for degrees of freedom. Having few observations makes it easier to reject hypotheses, but it does not affect the validity of the test. Bransbourg's larger number of observations confirmed the importance of distance from Rome in establishing provincial wheat prices. Nonetheless, Scheidel rejected this conclusion on the basis of Bransbourg's analysis, though his graph of Bransbourg's data, at the end of a complex study offering new ways to calculate distance in the Roman world, produced a figure that looks amazingly like Figure 1. Instead of accepting the clear impression that wheat prices were lower the further they were from Rome, Scheidel attempted to rearrange the observations.

Bransbourg had divided his data into two halves, corresponding to locations close to water and locations far from water. When asked whether the cost of transporting wheat to the Mediterranean coast affected the local price, his slightly more complex model delivered an affirmative answer, just as the original one did. But Scheidel divided Bransbourg's sample by looking at his version of Figure 1 rather than by attending to an independent characteristic of the observations. In his words, "For those eight sites whose transport cost to Rome was less than half the highest of the twelve values, relative transport costs to Rome account for merely 5 percent of variance in local grain prices." But this statistic is no longer grounded in a random sample that can be used to test hypotheses. Throwing away four observations because they do not accord with the presumption of no relation between transport costs and price makes the sample biased toward no effect. This strategy is parallel to Bransbourg's statement that the movement of one or more of Rickman's observations would destroy the correlation. Scheidel's dismissal of inconvenient data has the same

outcome—destruction of the randomness of the sample and of the ability to test hypotheses.[17]

More testing was performed on a newer data set from Rathbone and von Reden, which, at first glance, appeared to be more promising than Bransbourg's—twenty-three observations ostensibly permitting more power to evaluate hypotheses. The added data, however, served more to clarify the previous results than to make a fresh start. The eight observations in this data set that list prices at Rome could safely be ignored, since they are irrelevant to the question of transport costs, and a time variable was added to account for the slight inflation visible in Rickman's data. The result of this subtraction of eight variables and addition of one was a decrease in the degrees of freedom by nine. Averages were taken for price ranges, and prices with uncertain dates or amounts, as well as prices attributed to "extreme shortages," were discarded, as was the observation for Judaea, which was too vague and probably irrelevant. The period of this analysis, the long second century, is after the Judaean revolt mentioned above. The turmoil after the destruction of the Judean temple most likely caused trade to be disrupted. In fact, the Talmud prohibited wheat exports. Although the date and effectiveness of this prohibition are unknown, the kind of price arbitrage discussed above in setting up the regressions was probably not operative after the revolt.[18]

Regressions on this new data set of eight observations reproduce the coefficients on distance in the original regression: The coefficients are the same size, and they are known with the same precision. The regressions as a whole, however, do not have the same explanatory power as those from Rickman's data. Despite the overlap between the two data sets, this one contains more unexplained variation. The constant is larger than before because it includes an implied price at Rome in addition to any taxes or transport costs to the city. Oddly, the estimated inflation rate is large and not estimated precisely. There may be better ways of

17 Scheidel, "Shape," 29.

18 Rathbone and von Reden, "Mediterranean Grain Prices," 189; Heichelheim, "Roman Syria," 182. I did not inquire into the timing of my Judaean observation when using the Rickman data, but removing the Judaean price did not affect my results, although it decreased the degrees of freedom.

utilizing the Roman prices than replacing them with an estimated rate of inflation.[19]

Rathbone's data confirm the effect of distance on price found in Rickman's data, albeit with caveats that should be acknowledged. The exclusion of certain evidence from Rathbone's data for this new regression, though reasonable on the surface, cannot guarantee that the remaining data constituted another random sample; the included data could have been selected to produce the desired pattern, even if only unconsciously. To test the randomness of the Rickman sample, it would be better to have a data set constructed by someone like Bransbourg or Rathbone who is not invested in the original results.

As noted above, Rathbone's data set includes observations from periods of severe shortages. These few added observations provide no information about the frequency of these shortages, but they remind us that the Mediterranean wheat market was subject to events that increased the difficulty and cost of shipping wheat by sea. The market worked in general, but storage was not sufficient to alleviate the difficulties that arose from time to time.

Rathbone disparaged the simple model presented in this article, even though he agreed with its conclusions: "In conclusion, various factors made the Roman world and economy of the first to third centuries AD different from ancient Babylonia on the one hand and early modern Europe on the other. The market for wheat in the Roman world was essentially a free market, which in the imperial period comprised and was influenced by the administered market of the imperial Annona and civic intervention."[20]

Bang's negation of the original finding was not supported by the new data. He argued that Roman markets were like bazaars with no fixed prices at all. In other words, Rickman's prices were the products of random exchanges in isolated markets, manifesting no patterns in their location. Because Bang failed to see any pattern in Figure 1, he did not follow my statistical analysis showing an overwhelming probability of a geographical pattern in Roman prices. Bang's view cannot explain how enough wheat

19 For more information about these regressions, including R^2 and *t*-statistics, see Temin, "Statistics in Ancient History."

20 Rathbone and von Reden, "Mediterranean Grain Prices," 189.

was transported to Rome to feed a million or so consumers. Nor can it explain how the Roman economy was able to spread prosperity around the Mediterranean when its central bureaucracy was so small. His epistemology is too strong to be shaken by the evidence described herein.[21]

The evidence of Rathbones' "free market" is clear in a series of unified grain markets that stretched from one end of the Mediterranean to the other in the late Roman republic and early empire. The extent of the Roman market has been debated exhaustively, but previous evidence was restricted to local markets. The presence of localized market activity has ceased to be controversial, but the question of market integration is still alive. The evidence produced in this article demonstrates the existence of something approaching a unified grain market in the Roman Mediterranean.

Government interventions in wheat markets demonstrate that the market could not prevent shortages even in Rome. The government tampered with local wheat markets from time to time to lower prices and alleviate shortages, particularly under Augustus. The partial list available shows that these interventions were intermittent. As Rathbone concluded, the market for wheat otherwise worked on its own. Moreover, if traders expected the government to interfere when famine loomed, they might have been discouraged from trying to corner the market in adversity. Hence, government intervention may have dampened speculation, thereby making the underlying pattern of prices easier to see.[22]

All areas were not always connected to the market in Rome, such as those undergoing local famines. Rathbone recorded examples of isolated markets—with prices that do not fit this regression line—showing prices lying outside the regular market. The regressions demonstrate many ties between far-flung Roman grain markets; more data will be able to offer a better idea of how often outlying markets were connected to the major consuming market in Rome.

This discussion parallels questions about the reach of Roman law into the provinces. Laws do not appear directly in the statistics,

21 Bang, *Roman Bazaar*.

22 Garnsey, *Food and Society in Classical Antiquity* (New York, 1999).

but they provided the context in which observed behavior took place. Contemporary observers recorded explicit governmental interventions; underlying legal frameworks need to be extrapolated from the various records that they have left for us.[23]

This article illustrates the usefulness of regression analysis in seeking testable hypotheses and arguable propositions regarding ancient history. It transforms existing information into a format that suggests the existence of a unified market, as shown in Figure 1. It also presents a test of whether the observed pattern could have arisen by chance. Given the small number of observations, a pattern could simply be a coincidence. Regression analysis allows that possibility to be quantified. The probability that the line in Figure 2 was due to chance is about 5 percent, or one in twenty, indicating a far more precise estimate of the probability of an actual relationship than has been available previously. Given the scarcity of data and the prevalence of shortages, regressions can help only to interpret existing data, not to provide additional information that can result in definitive answers to all questions.

HURDLES AND BENEFITS Ancient historians may not have appreciated the simple model reproduced herein, but economists who saw it liked it well enough. The attraction for economists was a defect for ancient historians—a sample size small enough for all the calculations in the regression to be done by hand rather than by computers. With even a little knowledge of statistics, ancient historians could see this small model as a helpful step in the description of Roman trade in basic commodities like wheat.

Rathbone's additional wheat prices, many of which were intended to show how unusual famines were, were excluded from the new regressions herein in favor of other prices that fit the regression better, although all the prices could have been included in a regression with a dummy variable for famines. The original publication of this regression was accompanied by a table of governmental famine alleviations that demonstrated the fallibility of the Roman market. As the result of market failures, famines showed where the unified market broke down. An alternative treatment would be to combine the original list of market failures with the

23 Dennis P. Kehoe, *Law and the Rural Economy in the Roman Empire* (Ann Arbor, 2007).

famine prices that Rathbone collected to see how often the market failed. Additional observations will reward further insights.[24]

FUTURE PROSPECTS FOR AN INTERDISCIPLINARY ANCIENT HISTORY

The epistemological problem is that although ancient historians are fond of collecting and even rearranging numbers, they apparently see no value in testing hypotheses. Economic historians start from the other end, collecting more data only as warranted to test a hypothesis. The discussions of regressions have exposed the effects of this epistemological difference. Ancient historians always want to know where the observations originated and the extent to which they are reliable. Economic historians accept the statistical argument that errors in the observations make patterns more difficult to identify and therefore make results more convincing. Ancient historians look for linguistic evidence, whereas economic historians rely on the theory of errors in variables to preserve the essential randomness of their samples. This epistemological difference complicates attempts to establish interdisciplinary history.

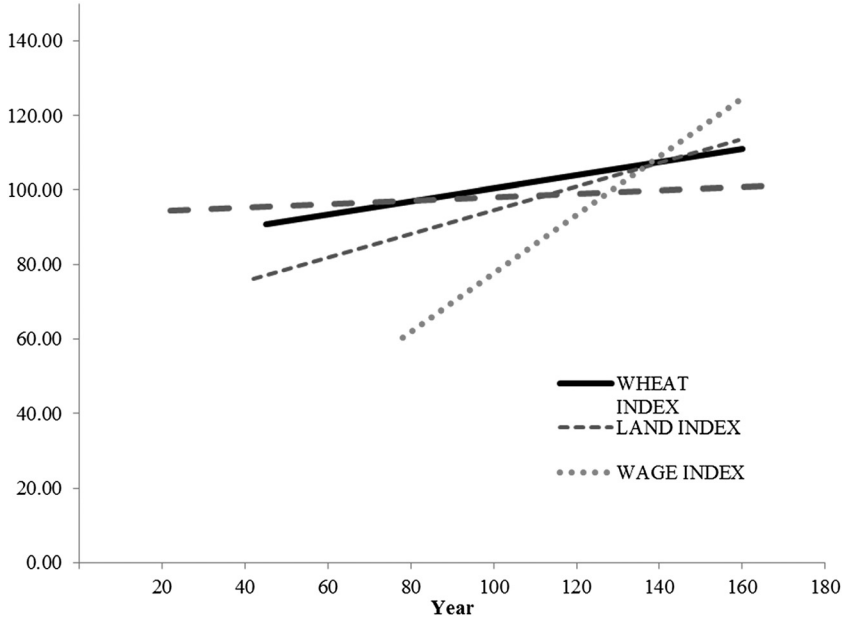
But there are signs that give us hope for the future. Michael McCormick's Initiative for the Science of the Human Past at Harvard presents interdisciplinary research from a variety of disciplines. Harper's recent book, *The Fate of Rome*, which argues that pandemics doomed the Roman Empire, follows in McCormick's footsteps. It also includes the graph reproduced herein as Figure 3. The lines in the book are not identified explicitly as regression lines, although they most certainly are; they are described as regressions in a journal article that preceded the book. They show that wages rose in the period before the Antonine plague while the price of wheat was stable. The lines in Figure 3 correspond to the line in Figure 2. Furthermore, as stated already, this action assumes that the prices being observed are market prices.[25]

This article is based on markets all around the Mediterranean; Harper concentrated on Egyptian markets that continued for the first two centuries of the Roman Empire. Unlike this article,

24 Kessler and Temin, "Money and Prices"; Temin, *Roman Market Economy*, 29–52.

25 Information about the Initiative for the Science of the Human Past is available at https://sohp.fas.harvard.edu/. Kyle Harper, *The Fate of Rome: Climate, Disease, and the End of an Empire* (Princeton, 2017), 34 (Figure 2.1); *idem*, "People, Plagues, and Prices in the Roman World: The Evidence from Egypt," *Journal of Economic History*, LXXVI (2016), 803–839.

Fig. 3 Price Trends in the Roman Empire before the Antonine Plague



SOURCE Kyle Harper, *The Fate of Rome: Climate, Disease, and the End of an Empire* (Princeton, 2017), 34 (Figure 2.1).

which looked only at the wheat market, Harper examined the price of wheat, wages, land, and the rental rates for land. In other words, wheat was not an exception; various markets and market prices were abundant in ancient Rome. We can look at the behavior of markets across space and time.

Harper focused on real wages in Figure 3. From his observations of Egyptian wages, he inferred a labor market in which at least some residents of Roman Egypt sold their services for Roman money. In Harper's regression, the slope of the line is significantly different from zero, but he explained less of the variation of prices than the regression in Figure 2 did. In other words, he found a pattern that was less obvious in the surviving data than in the sample of wheat prices in Figure 2. Harper's regression of wheat prices over time showed the price of wheat to have risen only slowly, if at all, before the Antonine Plague. Harper's regression

of wheat prices on time did not appear to produce a particularly good result; the slope of the curve for wheat is not significantly different from zero. But Harper did not conclude that Roman Egypt had no market for wheat. Instead, he argued for the absence of inflation (he provided evidence for the absence of inflation that I inferred from my regressions). Harper inferred markets for wheat as well as participants in that market who could observe movements in market prices.

Harper interpreted the pattern in Figure 3 as showing an increase in real wages in Roman Egypt—in other words, a rise in the standard of living. Harper apparently did not need to make explicit the preliminary steps of going from individual observations to patterns and then to institutions. He did not even think it worthwhile to mention that he was describing a labor market. His thought process shows how rapidly ancient history is progressing. *The Roman Market Economy* was ridiculed in the *Times Literary Supplement* for using the term, *labor market*.[26]

Harper argued that the early Roman Empire was not subject to any Malthusian pressure. Although population was expanding in the late republic and early empire, living standards did not decline, contra Malthus' theory. Instead, real wages rose at the same time as population totals rose. Figure 3 illustrates that important finding by showing wages rising faster than the price of wheat. The ratio of wages to the price of wheat—a good measure of the real wage in ancient times—was on the rise. But how can we explain this development? One way is through progress in agricultural technology, given the predominantly agricultural nature of the Roman economy. The other way is through trade; the ability to specialize, based on the low cost of exports and imports, improves living standards as the result of *comparative advantage*, the effect of an international division of labor. Both processes were probably in operation, but the exploitation of comparative advantage is the most relevant in this context. The extent of the wheat market shown in Figures 1 and 2 suggests that wheat from Sicily, Spain, and Egypt was coming to Rome. Hence, comparative

26 Peter Thonemann, "'Who Built the Amphora Mountain?' Review of Scheidel (ed.), *The Cambridge Companion to the Roman Economy* and Temin, *The Roman Market Economy*," *Times Literary Supplement*, 9, Aug. 2013, 10–11.

advantage, the result of increasing Mediterranean trade, was likely the cause of the increase in real wages shown in Figure 3.[27]

Harper's finding that the Egyptian price of wheat was stable before the Antonine Plague supports the lack of attention to inflation in the original regression. Harper goes further in his book to argue that this plague was the first of three plagues that cumulatively destroyed the Roman Empire. *The Roman Market Economy* argued that the Antonine Plague initiated the inflation that plagued Rome during its long decline, possibly causing political instability or vice versa. Both conditions began at the time of the Antonine Plague. The plague started both the inflation and the political instability in the Roman Empire that continued for the next few centuries.[28]

Rathbone is correct: My model is too simple to be the whole story. Solow remarked, "Oversimplification would be the bane of economists if it were not their job." Reiterating his message, Tirole recently asserted, "We adopt a simple, even a simplistic, hypothesis to get a sense of what is going on." A simple model or hypothesis is a step on the way to interdisciplinary history. The test of a simple model is whether it provides insights for more complex investigations; this article is a step in that direction. The complications introduced by Bransbourg and Rathbone expanded the message of the original simple model.[29]

We need more contributions of both numbers and of words to understand Roman markets. For example, throughout the late republic and early empire, grain merchants sent sealed pots or pouches containing a sample of their grain cargo on trading ships. When the cargo arrived at its destination, recipients could open the sealed containers to test the grain held in them against the grain in the ship's main hold; any difference suggested that the bulk of the grain had been doctored in some way. These seals were signed by a granary official, a merchant, and a witness. This practice was

27 For comparative advantage, see Temin, *Roman Market Economy*, 1–26. Scheidel, "In Search of Roman Economic Growth," *Journal of Roman Archaeology*, XXII (2009), 46–70. Scheidel's article bears the influence of a paper that I wrote to explain Malthusian theory to ancient historians. The two papers were submitted together to the *Journal of Roman Archaeology*, but mine was not published, perhaps because of its different epistemology.

28 Harper, *Fall of Rome*; Temin, *Roman Market Economy*, 70–94.

29 Robert M. Solow, "How Did Economics Get That Way and What Way Did It Get?" *Daedalus*, CXXVI (1997), 39–58; Jean Tirole, *Economics for the Common Good* (Princeton, 2017), 84.

continued or, more likely, resuscitated by the early tellers of the Bank of England around 1700. The bank mandated, "That every Teller receiving money shall immediately weigh the same, and put a Ticket on the Mouth of the Bag importing the weight and contents thereof, and the like Ticket also within the Bag." Procedures installed by the Romans to make sure that shipped commodities were not adulterated seem to have been useful almost two millennia later.[30]

Despite their initial hostility, ancient historians, who are generally not enthusiastic about regressions, have begun to accept the evidence for the existence of a Mediterranean market for wheat in the Pax Romana. Comparative advantage cannot improve real wages without free trade. This development is promising for interdisciplinary history, suggesting that the epistemological divide may be decreasing. The regression lines in Figure 3 begin to answer the question posed by Beard at the beginning of this article by showing that the growth of Mediterranean trade benefited ordinary people by increasing their real wages. The trade represented by the regression line of Figure 2 provides the framework for the description of this trade in the early Roman Empire.[31]

30 For the sealed containers, see Rickman, *Corn Supply*, 122; Kessler and Temin, "The Organization of the Grain Trade in the Early Roman Empire," *Economic History Review*, LX (2007), 313–333; Temin, *Roman Market Economy*, 97–113. Anne L. Murphy, "Learning the Business of Banking: The Management of the Bank of England's First Tellers," *Business History*, LII (2012), 150–168.

31 Interdisciplinary history enriches other areas of study as well. Beard, *SPQR*, inferred that Rome had a banking system from Cicero's apparent lack of enough cash in his pocket to purchase an expensive Roman house: "The whole transaction points ... to some system of paper finance or bonds, and so to a relatively sophisticated banking and credit system underpinning the Roman economy, for which only fleeting evidence now survives" (325). However, the interdisciplinary evidence for an impressive banking system operating in and around Rome is abundant. See Temin, "Financial Intermediation in the Early Roman Empire," *Journal of Economic History*, LXIV (2004), 705–733; Rathbone and *idem*, "Financial Intermediation in 1st-Century AD Rome and 18th-Century England," in Koen Verboven et al. (eds.), *Bankers, Loans and Archives in the Ancient World* (Leuven, 2008), 371–419; Temin, *Roman Market Economy*, 157–192.