How Wide Was the Ocean?

U.S. and Swedish Commodity Price Dispersion from 1732 to 1860.*

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Abstract

We construct a 14 commodity panel of local currency prices spanning locations within the United States and Sweden annually from 1732 to 1860. The panel is used to study the time series and cross-sectional patterns of LOP deviations. We find substantially more geographic price dispersion attributable to time series variation around the long-run average LOP deviations than in the variance of long-run average LOP deviations themselves. This contrasts sharply with the conclusions of Crucini and Telmer (2007) who document the opposite ranking in the EIU city panel of retail prices. We find a robust positive relationship between price dispersion and geographic distance. We also attempt to estimate the width of the Atlantic ocean, analogous to the Engel and Rogers (1996) estimate of the width of the North American border in the modern era. Using either the time series variance or the mean absolute deviation, the effect of distance is statistically significant and positive. Pooling all commodities the estimated width of the ocean (beyond the role of distance) is 672,000 kilometers when the time series variance is used and 1,350 kilometers when the mean absolute deviation is used. However, the time series estimate is not statistically different from zero and the confidence interval for the mean absolute deviation estimate extends down to 490 kilometers. Addressing the Gorodnichenko and Tesar critique of Engel and Rogers leads to modest effects on the estimates. Turning to the good-by-good results, the coefficients on distance are of the expected, positive, sign in 26 of 28 cases. We find it difficult to reject the hypothesis that the ocean adds as much to price dispersion as would be expected given the greater distances spanned by cross-ocean location pairs. This finding could be due to the fact that the coefficient on the ocean dummy variable is poorly identified due to a high correlation between ocean crossing and distance, a problem not encountered in the Engel and Rogers (1996) study. In a nutshell, we find commodity markets are segmented by geography, but not necessarily more so across countries relative to across locations within countries.

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"Stockholm therefore, for the purposes of the argument may be considered as within fifty miles of Philadelphia." Daniel Webster, Philadelphia, 1824.

1 Introduction

The statement above was made by Daniel Webster during heated Congressional debate on proposed tariff legislation in 1824. His statement reflected his knowledge of the fact that the money required to ship one ton of merchandise by ocean freight from Stockholm to Philadelphia could alternatively purchase about fifty miles of overland transport from Philadelphia to points inland.[1] Webster went on to argue that the United States should draw on much cheaper textile labor abroad than at home and allocate home labor to greater domestic advantage. What this suggests about the historical evolution of the width of the border is that the positive width of borders measured in the contemporary academic literature may reflect a more rapid retreat of natural and official barriers to trade within countries than across them over long historical periods.

Official barriers include both currency arrangements and more direct impediments to commerce across locations such as tariffs, while natural barriers to trade reflect the physical environment, infrastructure and the state of transportation technology. During the earlier period of history that we study there were multiple currencies circulating within both the United States and Sweden. The metallic content of coins was suspect in both countries. In the U.S., Colonial currencies circulated at fluctuating discounts relative to each other and pounds Sterling. Transportation infrastructure developed significantly over time and differentially across locations. Canals were developed within the US and were overtaken by rail during the period we study, greatly reducing the cost of overland transport relative to ocean shipping. Superimposed on these evolutionary changes were military conflicts, trade embargoes, and tariff changes as well as abrupt movements in nominal exchange rates and monetary regimes.

The goal of this paper is to sketch the evolution of commodity price dispersion within Sweden

[1] The reader may be interested to know that 'as the crow flies' Stockholm is actually 4,000 miles from Philadelphia. A great resource of educational material on the geography of transport systems may be found here: http://people.hofstra.edu/geotrans/eng/ch3en/conc3en/ch3c3en.html

and the United States as well as across the two nations. In doing so, we hope to shed light on the broader issue of the role of various impediments or enhancements to trade which ultimately influence price differences and the volume of trade across locations. The central question we address is: Does an ocean crossing increase or reduce price dispersion relative to overland hauling of goods in these two countries?

To achieve this, we utilize two primary data sources. The first source is the data published in the Statistical Appendix to the volume edited by Arthur Harrison Cole (1938): *Wholesale commodity prices in the United States: 1700-1861.* We created an electronic archive of all the data contained in the appendices of this volume. These commodity price data were mostly drawn from newspapers and business accounting records and invoices. The observations are monthly and span six cities: Boston, Charleston, Cincinnati, New Orleans, New York and Philadelphia. In total there are 46 goods and 549 varieties of goods; the number of varieties ranges from a high of 26 for cotton to a low of 2 for potash. Charleston and particularly Cincinnati are important for us because of their distance from the three cities in the northeast and their different stages of economic development.

The second data archive was chosen to match the Cole data for purposes of international price comparisons. It is drawn from Lennart Jörberg (1972) who led a team which collected the Swedish price data. The numbers come from market price scales that were used for taxes, tithes, and other payments. There were a total of 32 counties or regions at various times. The coverage and averaging across districts within a county changed several times. As many as 180 commodities were included, but some were found in only a few counties and so were not reported by Jörberg. Reflecting the main objectives of our study, for the time being, we collected annual prices for commodities that are closely matched to the goods also found in the Cole micro-archive: wheat, beef, pork, butter, tallow, cod, hops, wool, coarse cloth, tallow candles, wax candles, pine wood, log timber, pig iron, bar iron, copper nails, salt, saltpetre, and tanned cow hides.

Advancing the debate to the contemporary academic literature, Charles Engel and John Rogers (1996) estimate a substantial increase in relative price variability for cities across the Canadian-U.S. border relative to within country city-pairs. They coined the phrase *width of the border* to describe the additional distance one would need to add to intranational city pairs to arrive at comparable price variability to what is observed internationally. Their answer: 75,000 miles. In the language of ER, the *width of the ocean* should be negative if Webster's statement is valid. The central question of this papers is: Does his statement about the ocean hold water when subjected to empirical scrutiny?

We find a robust effect of distance on alternative measures of price dispersion, both in our pooled estimates and at the individual commodity level. However, given the geography of our sample, it is difficult to separately identify the effect of the physical distance between between international pairs and effect of the ocean that separates them. In other words, unlike a national border, an ocean is in fact physically wide. When we extrapolate from intranational relationships between price variability and distance we find the international cross-ocean price variability lies on the same regression line. Thus the width of the ocean is not puzzling if you think overland and ocean transport of the same distance involve the same trade costs. If like Webster, your prior is that the ocean distances are less economically significant, then you would be wrong.

2 Related Literature

Our goal is to study both international and intranational price dispersion for the US and Sweden in the 18th and 19th centuries, using a range of commodities. While we are not aware of work that directly does this, we can draw on a wealth of recent research that provides benchmarks. This work looks at the extent of price convergence between locations, its evolution over time, and the causes of and obstacles to that convergence.[2]

First, several studies assess the LOP internationally. For example, Rogoff, Froot, and Kim

[2]There is, of course, a voluminous literature on the quantity side documenting the negative impact of distance on bilateral trade volumes. As far as we know there are no studies comparing the intranational and international differences of the impact of geographic distance covering the historical period of our work. An interesting paper by Disdier and Head (2008) examines the evolution of distance effects in the last 50 years of the twentieth century and finds some upward drift in distance effects during the 1960-1980 period associated with increased trade among less industrialized countries where trade costs are deemed to higher. This increases average global 'gravity' through a compositional effect.

(2001) describe the price differences between London and Amsterdam for 7 commodities over many centuries. They find large volatility in LOP deviations, with little decline over time. They also report a common, country-specific component in deviations across this set of goods (which makes measurement error unlikely as the source of volatility). One thing that does change over their historical period is the share of nominal exchange-rate fluctuations relative to variation in relative prices across countries. This ratio became significantly larger in the 20th century. O'Rourke and Williamson (1994) study 13 commodities traded between the US and UK from 1870 to 1913, again generally with one city per commodity. They report a convergence trend for these international price-differentials. Klovland (2005) studies 39 commodities in Britain and Germany for a similar period, from 1850 to 1913. He averages over locations or uses prices from a single location in each country. He reports that the half-life of LOP deviations was quite low, around 1-1.5 years. But there was considerable variation across commodities, in part because of commercial policy.

Second, several studies examine LOP deviations intranationally. For example, Dobado and Marrero (2005) document how corn prices converged across 32 Mexican states from 1885 to 1908. Trenkler and Wolf (2005) study wheat flour prices across Polish cities in the interwar period. The work of Slaughter (1995) is of particular relevance to our study, as he studied prices in the 19th-century US. He found annual averages for 1820–1860 for 10 goods in the Cole data: coal, cotton, iron, molasses, nails, butter, coffee, flour, pork, and sugar. Arguing that transport costs could be additive or multiplicative, he calculated both differences and ratios of prices across cities. He estimated that differences converged at a rate of about 4% per year, while ratios did so at a rate of about 1% per year. He argued that city-based data understate the scope of convergence because much of the transportation revolution was in local transport with hinterlands. And he described the roles of canals, steamboats, and railroads in the convergence.[3]

Third, a large number of studies compare international and intranational price dispersion but for a single commodity: wheat. Studying wheat has four distinct advantages: (a) it is storable (and was so historically); (b) it is internationally traded; (c) in some cases its price is recorded according

[3]He goes on to show wages were not equalized over time, so commodity price convergence did not bring about factor price convergence.

to standardized varieties; and (d) in some cases shipping costs can be collected. These features suggest that arbitrage could operate, with the passage of time, as emphasized by Pippenger and Phillips (2006) in their study of wheat prices in the late 20th century.

Shiue (2005) describes the differences in grain prices across cities in Germany and its neighbors as the *zollverien* customs union spread between 1815 and 1855. She compares these differences with those between German and non-German cities and finds a small border effect. She also provides interesting measures of spatial correlation, as an alternative to calculating all bilateral distances. Nason, Paterson, and Shearer (2005) study grain and flour markets in the mid-19th century in London, New York, Toronto, and Montreal. They attribute a large role in convergence to the liberalization of commercial policies. Keller and Shiue (2008) use annual wheat prices for the 19th century in 68 central European cities, mostly in Germany. They investigate three conduits of convergence: (a) steam trains; (b) the customs union of zollverein; (c) currency unification. They use instrumental-variables regressions to allow for the possibility of endogeneity; *e.g.* opening a train line may have been more profitable with a large price difference between cities. Their conclusion is that trains were the dominant factor in price convergence.

In a series of original and thorough papers, Jacks (2004, 2005, 2006a, 2006b) has studied wheat prices for a wide range of time periods and cities. For example, Jacks (2005) studies the period 1800-1913 for up to 100 cities in 10 countries including the US, where quotations come from up to 11 cities. He documents price convergence using several different statistics. Jacks (2005) uses (a) coefficients of variation across cities, graphing their decline over time and comparing them to late 19th century values for Berlin-Chicago-London. He also reports on (b) a measure of correlation across cities. Jacks (2006a) uses (c) an asymmetric threshold error-correction model. In keeping with the warning of Taylor (2001) there is no adjustment within a band but adjustment to differences outside a band, where the width of the band reflects transport costs and is estimated along with the speed of adjustment. Jacks (2006b) in addition reports on (d) the standard deviation of the log relative price, a statistic used in some studies of contemporary LOP deviations by Engel and Rogers and Parsley and Wei.

Jacks also discusses the causes of convergence and the impediments to it. He considers such factors as transport costs, other transactions costs or improvements such as the rise of bills of exchange, price manuals, marine insurance, the effects of wars, and mercantilist policy (such as the 17th century Navigation Acts in Britain). He first compares trade costs for wheat to price differentials, finding that the differentials are up to twice as large as reported trade costs. For his 1800-1913 data, he also regresses measures of price dispersion on variables such as distance, exchange-rate volatility, and dummy variables for borders, port and railway status, or a common currency. He finds a decline in the effects of both distance and border-crossing over time.

Jacks observes that the secondary literature on the US suggests that there was considerable convergence in prices internationally, but not intranationally, in keeping with Webster's suggestion. We can directly make this comparison for 14 commodities. Sweden is not in Jacks's data set, but wheat is in the Swedish data set, so for that commodity we can compare trends in relative prices to those he found.

3 Price Data and Monetary Arrangements

The commodity price data used here are drawn from original sources. Each source consists of a large panel of local currency prices of individual commodities sold in different locations within the country. The U.S. panel data is taken from the Statistical Supplement of the volume edited by Arthur Harrison Cole (1938): *Wholesale commodity prices in the United States: 1700-1861.* The Swedish panel data is taken from Jörberg, Lennart (1972) *A history of prices in Sweden 1732-1914. Volume I: Sources, methods, tables.* Lund: CWK Gleerup. We supplement this data with exchange rates and geographic distance, both are discussed further below.

Other potential sources of price data exist because of the work of the International Scientific Committee on Price History in the 1930s and 1940s, described by Cole and Crandall (1964). These sources include the monographs by Posthumus (1946) on Holland, Elsas (1936, 1949) on Germany, Hauser (1936) on France, Hamilton (1947) on Spain, and Pribram (1938) on Austria. The Danish price history project begun by Friis and Glamann (1958) is another rich source. But data for these countries involve significantly less overlap with the US data in commodities or years and fewer intra-national locations.

One of our goals is to put US price dispersion in context by comparing US prices with those in a European country. We chose Sweden because its data overlap with those from Cole in both time span and commodity composition is greater than other sources for other countries. The Swedish data also satisfy the criterion of evaluating the role of currency fluctuations in that they include numerous regions in a common currency area. Coincidentally, they allow us to assess Daniel Webster's observation.

3.1 United States (1700-1861)

The volume edited by Cole summarizes a number of independent scholarly efforts on US price history under the auspices of International Scientific Committee on Price History, funded by the Rockefeller Foundation. The data we use for the US are drawn from the statistical supplement of this volume. While this data is not exhaustive of what is available for the US, it is the single largest collection of such data in terms of commodity, city and time span.[4]

The commodity price data were drawn mostly from newspapers and business accounting records and invoices. The frequency of the data is monthly; spanning 46 goods and six cities: Boston, Charleston, Cincinnati, New Orleans, New York and Philadelphia. In total there are 549 varieties of goods, ranging from 26 varieties of cotton to 2 types of potash. Each city's prices were compiled by or under the direction of a different researcher.

To facilitate comparisons of price across locations it is necessary to express prices in common units. First, we convert weights and measures to common physical units. This is somewhat more involved in the United States than Sweden because, unlike Sweden, the same commodity price may be quoted for different physical units across cities within the country. On rare occasions, units of measure change over time. We relegate detailed discussion of physical unit conversions to the data appendix and discuss monetary arrangements next.

[4]The details of data collection, unit conversions and monetary arrangements are elaborated in a companion Data Appendix to this paper.

Given the data span more than 150 years, it should not be surprising that the media of exchange evolved over the sample period. A comprehensive list of media of exchange (excluding barter and IOUs) includes: (a) gold and silver (specie), (b) British pound sterling, (c) foreign coins (*i*.e. primarily Spanish pieces of eight), (d) colonial paper money, (e) bank notes (before official bank charters these would be lumped into private notes, effectively promises to exchange notes for specie), and (f) commodity money (the first governor of Tennessee was paid 1,000 deerskins for his public service).

The evolution of media of exchange divides roughly into three eras, though it should be noted that over some periods alternative media of exchange circulated simultaneously. In the earliest period of the sample, the pound sterling was the unit of account. The Spanish dollar circulated at the same time, but prices quoted in this unit of account are rare in our data. This was followed by a period in which colonial currencies circulated alongside other media of exchange. Colonial currencies were official government fiat, used to pay expenses, often of armed conflicts, and to pay taxes. They were also used in transactions by the private sector. The last era is the post-Revolutionary War period which, in terms of monetary history, begins with the introduction of the Continental dollar and bimetallism after Confederation. The U.S. data sample ends before one needs to be concerned about Union and Confederate currencies.

The Cole volume reports exchange rates of local colonial currencies per silver dollar . Charleston, for example, had a stable domestic currency at 7:1 with the pound sterling from 1732 to the Revolutionary War (1775), which translates to 32 shillings and 8 pence. Cole refers to these as *normal exchange rates*. However, our source for colonial exchanges rates is the work of McCusker (1992) who devoted much of his career to understanding monetary arrangements during the colonial period. His work, McCusker (1978): *Money and Exchange in Europe and America, 1660 to 1775: A Handbook* is the basic source of our currency exchange rates from the start of our sample until 1775. In this volume McCusker provides exchange rates of local colonial currencies per 100 pounds sterling for Massachusetts, New York, New Jersey, Pennsylvania, Maryland (for Maryland there are actually two exchange rates, one for hard currency and one for paper currency), Virginia, North Carolina, South Carolina and Georgia. Without McCusker's monumental historical work this project would not have able to span much of the 18th century.

The reason McCusker's volume ends in 1775 is that, following the American Revolutionary War, the Continental Congress altered monetary arrangements by introducing the *dollar* in 1777 at par with the Spanish dollar. The Spanish dollar circulated widely within the U.S. and internationally as a media of exchange; it remained legal tender in the U.S. until 1857.[5]

Also during Confederation, three commercial banks were chartered by the Congress: the Bank of North America, the Bank of New York, and the Massachusetts Bank. Each had the right to print and issue its own bank notes, and did so. Each bank's notes tended to circulated at a discount outside the city of issue. Other banks were later chartered and followed suit. From the time of Confederation until about 1865 these bank notes circulated as currency.

The second change was introduced by Alexander Hamilton, the first secretary of state of the newly formed Confederation, who opted for a bimetallic standard of gold and silver, as was in place elsewhere in the world. The Coinage Act of 1792 valued silver coins by the benchmark of the silver content of the Spanish dollar. The US coinage was minted in different denominations of known fineness, the latter property eliminating the need for assay of metal before exchange.[6] Gold was set at a conversion rate of 15 times the value of silver, by weight. Not surprisingly, given uncertainty of the supply of gold relative to silver in the US and the world, rarely did both circulate widely at the same time. As gold became relatively abundant and undervalued, it was gradually replaced by silver as the medium of exchange. Hamilton responded by adjusting the ratio to 16 to 1 only to face the opposite problem, gold was over-valued leading to importation from abroad and driving silver out of circulation. However, silver remained in circulation until the US and other countries coordinated monetary arrangements by adopting the gold standard in 1900.

As one might expect from this discussion, the Cole archives contain price quotes in British

[5]The Spanish Dollar was the famed silver coin standard against which most Western nations measured their currency. Historically, the Spanish Dollar has also been called the Milled dollar, Bust dollar, Peso de ocho Reales, or Piece of Eight.

[6]This statement implicitly assumes no counterfeiting or debasing of the physical coins.

pound sterling and shillings and later dollars and cents. More precisely, the prices are mostly sterling, pounds and shillings up until the Revolutionary War. The first dollar ($) price in the entire archive is for rice in Philadelphia in 1788 and then there is a long gap, until 1791, at which point dollars and cents become the dominant unit of monetary account. The isolation of this quote suggests it was an original typesetting error.

3.2 Sweden (1732-1860)

Lennart Jörberg (1972) led a team which collected the Swedish price data. Scholars have used them to study the cost of living and real wages, but apparently not LOP deviations. The numbers come from market price scales that were used for taxes, tithes, and other payments. The prices were agreed upon and recorded at an annual meeting in each county. They were averages of current prices in market towns within each region. As the reader will gather, then, this form of collection is not as ideal as wholesale transaction prices would be, but perhaps it is superior to some institution-specific records. Jörberg argues that the market price scale data were very similar to more direct but sparser measurements, say from wholesale markets or from institutions.

For several items the prices were fixed between 1735 and 1756. At that point they were unfrozen because the state was losing revenue due to inflation. Prices were collected at *Thomasmäss* (December 21) each year. But then in 1775 the officials were allowed to forecast prices for grains over the next few months if they thought the *Thomasmäss* price was abnormal. The time of the year for collection was changed to November in 1803. The coverage and averaging across districts within a county changed several times. Jorberg (1972, page 12) summarizes the various refinements over time.

There were a total of 32 counties or regions at various times. As many as 180 commodities were included, but some were found in only a few counties and so were not reported by Jörberg. For some commodities quality also could vary from county to county, though goods were supposed to be of sufficient quality to satisfy payments due in kind. We collected annual prices for these commodities: wheat, beef, pork, butter, tallow, cod, hops, wool, coarse cloth, tallow candles, wax candles, pine wood, log timber, pig iron, bar iron, copper nails, salt, saltpetre, and tanned cow hides. This mix of foodstuffs and manufactures is typical of price history datasets.

Sweden adopted a series of unusual, self-inflicted monetary arrangements during the 18th century. From 1732 to 1775 prices are quoted in silver *dalers* (*daler silvermynt*) (with unit öre, with 32 per *daler*). From 1776-1802 they are quoted in *riksdaler* specie (with units shilling, with 48 per *riskdaler*). During this period there were two internal units of account: *riksdaler banco* and *riksdaler riksgälds*, that had a varying relative value. Jörberg (1972, p 79) notes that market price scales were quoted in *riksdaler riksgälds.* After 1803 all prices are in *kronor* (singular: *krona*) per metric unit. Weights and measures also varied over time.

To express prices in common units over time we take two steps. First, we convert weights and measures to common metric units using Jörberg's guide (1972 p). After this step, prices are quoted in *daler silvermynt* for 1732-1775, *riksdaler riksgälds* for 1776-1802, and *kronor* for 1803-1860. Second, we then use the historical exchange-rate series assembled by the Sveriges Riksbank to convert each of these prices into pounds sterling.[7] Their series for 1732–1775 is quoted in *daler kopparmynt* per pound sterling.

As each such coin was worth one-third of a *daler silvermynt* we calculate prices as follows:

$$\frac{\textit{daler silvermynt}}{\text{metric unit}} \times 3 \times \frac{1}{\textit{daler koparmynt}/\pounds} = \frac{\pounds}{\text{metric unit}}$$

Their series for 1776-1803 is quoted in *riksdaler banco* per pound sterling. The Riskbank also provides a series on the internal exchange rate between *riskdalers banco* and *riskgälds*, so we calculate prices as follows:

$$\frac{\textit{riksdaler riksgälds}}{\text{metric unit}} \times \frac{\textit{riskdaler banco}}{\textit{riksdaler riksgälds}} \times \frac{1}{\textit{riskdaler banco}/\pounds} = \frac{\pounds}{\text{metric unit}}.$$

Their external exchange-rate series for 1803-1861 is quoted in *kronor* per pound, so we calculate prices as:

$$\frac{\textit{kronor}}{\text{metric unit}} \times \frac{1}{\textit{kronor}/\pounds} = \frac{\pounds}{\text{metric unit}}.$$

Each of these series is available annually, with two exceptions. The Riksbank provides the *banco/riskgälds*

[7] We obtained this at the following website: `www.riksbank.com/templates/Page.aspx?id=27399`.

exchange rate and the *kronor*/sterling exchange rates at monthly frequency. We calculated prices in sterling first using annual averages for these two series and then again using the December values prior to 1803 and the November values after that, reflecting the months in which the market price scales were recorded.

4 Price Dispersion

The starting point for analysis of these prices involves selecting a subset of goods from the underlying U.S. and Swedish archival data with primary consideration given to the quality of the match of commodity descriptions across countries. Table 1 reports the resulting list of 14 commodities, their units of physical measurement and the number of city-pair observations available.

The commodity list includes six agricultural commodities (beef, butter, hops, pork, wheat and wool), five non-agricultural commodities (bar iron, copper, pig iron, salt and saltpetre) and three candle-related commodities.[8] There are 6 U.S. cities and 36 Swedish regions. Accordingly, the maximum number of city pairs within the U.S., within Sweden and across the ocean are 15 (UU), 630 (SS) and 216 (SU), respectively. The last two columns of Table 1 show the number of city pairs used in the analysis that follows, by commodity. The abundance of locations within the Swedish price archive provides a large number of bilateral pairs within Sweden and across Sweden and the United States. At the low end of geographic coverage a single Swedish region has available data for copper, salt, and saltpetre and there are three or fewer cities available for hops, tallow candles, and wool.

4.1 Measuring Price Dispersion

The basic object of interest is the logarithm of the real exchange rate of good i, across a pair of locations, indexed by j and k, at date t: $q_{ijk,t}$. Formally, this is defined as:

$$q_{ijk,t} = \log(P_{i,j,t}) - \log(P_{i,k,t}) \ . \quad (1)$$

[8]Tallow is rendered beef or lamb fat processed from suet, it is solid at room temperature and was used to make candles as an alternative to wax.

The real exchange rate, then, is the (log) relative price of a good across a bilateral pair of locations. At points we will refer to this relative price as the Law-of-One-Price deviation (LOP deviation). Note, that the commodities listed in Table 1 are the descriptions given in the volume by Jörberg. In the volume by Cole, commodity prices are recorded down to the individual variety in most cases (*e*.g. No. 2. Red Wheat). Also the U.S. data are recorded at the monthly frequency while the Swedish data are recorded at the annual frequency. Thus, before computing the LOP deviations, averages of U.S. prices are taken across months and varieties. This makes the two archives comparable and may reduce measurement error in the local currency prices of U.S. commodities.

Figures 1 and 2 display raw pound sterling price series (the P's in the above definition) for wheat and beef, respectively, and are characteristic of what our data entail. Some qualitative features are noteworthy. First, there appears to be a modest inflationary drift over time. The inflationary trend accelerates in the late 1700's and early 1800's and then is punctuated by a deflationary shock around 1820. Presumably these lower-frequency deviations from trend are related to the Napoleonic Wars and the War of 1812. Second, the prices appear to share a significant common factor, not only in their trend behavior, but also in annual deviations from the trend. This suggests a significant degree of commodity market integration across locations. Third, it appears that prices move more closely with each other across locations within a country than they do across countries. There appears to be a border. Whether this border is simply a manifestation of greater distances separating locations across the two countries compared to the distances separating the cities within each country is something we explore in detail below. Fourth, it appears that the relative price of wheat in units of beef begins and ends at about the same level in both countries, consistent with long-run stationarity of relative prices and long-run equality of relative prices across locations. In particular, the relative price is about 10 to 1 in 1732 and it is still at about that level 130 years later.

Precisely because there are significant common movements in local currency prices across locations (within and across nations), the extent to which the LOP fails is easier to see with the measure $q_{ijk,t}$, which effectively removes any common factor shared by city-pair j and k. Figure 3 depicts empirical density functions for $q_{ijk,t}$ pooling our entire panel.[9] Note that these data have been demeaned, so that the average deviation across all city-pairs is zero. Intra-US values are shown in red, intra-Sweden values in gold, and cross-ocean values in blue. The number of observations are 4,093, 179,156, and 43,531 for the intra-US density, the intra-Sweden density and the international density, respectively. The far greater number of observations in the latter two cases primarily reflects the greater abundance of Swedish locations in the panel.

Given the dominance of Swedish location-pairs in the panel, the fact that the density for Swedish intranational pairs is centered at zero is a consequence of demeaning the data. However, the extent to which a density has a concentration of its mass close zero is, in fact, evidence of a tendency for the LOP to hold. If the LOP held exactly, the density would have all of its mass at 0. The spike in the density for locations within Sweden is striking, indicating a very high proportion of observations for which the LOP holds exactly. Note, however, all three densities have mass extending from -1 to 1, indicating frequent and large deviations from the LOP as well.

The densities reveal a clear ranking in terms of the tendency toward the LOP, with the locations within Sweden ranking first and the international pairs last. This is also the ranking of median bilateral distances separating the locations within each group; below, we assess how much of the dispersion reflects the geography of the locations.

4.2 Sources of Price Dispersion

The descriptive analysis just presented was useful to get a sense of what the underlying data look like with theoretical restrictions largely absent. Theories do, however, place useful restrictions on LOP deviations and these restrictions are often in either the time series or cross-sectional dimension. For example, static trade models emphasize official and natural barriers to trade, suggesting LOP deviations lack time variation, making the t subscript in $q_{ijk,t}$, superfluous. The perfect contrast to such an approach would be a business cycle model asserting LOP holds in the steady-state with all the variation in $q_{ijk,t}$ coming in the form of time-series fluctuations. The distributions of figure

[9] The empirical density estimation uses an Epanechnikov kernel with bandwidth $0.79N^{-1/5}IQR$: the RATS defaults.

3 capture the combination of cross-sectional and time series variation.

To get a sense of how much of the variation is across location versus across time, at the good level, we follow Crucini and Telmer (2007) and employ a two-way analysis of variance:

$$\begin{aligned} Var_{jk,t}(q_{ijk,t} \,|\, i) &= Var_{jk}(E_t[q_{ijk,t} \,|\, ijk]) + E_{jk}[Var_t(q_{ijk,t} \,|\, ijk)] \\ V_i &= T_i + F_i \,. \end{aligned} \tag{2}$$

The conditional mean and variance operators, $E_x\,(\cdot\,|\,y)$ and $Var_x\,(\cdot\,|\,y)$, denote the mean and variance calculated by integrating across the variable(s) x while conditioning on the variable(s) y. So, for instance, $E_t[q_{i,jk,t}\,|\,i,jk]$ is the mean of the time series of relative prices for good i between locations j and k and $Var_{jk}(E_t[q_{i,jk,t}\,|\,i,jk])$ is the variance across location-pairs in these time-series means.

The left-hand-side of this expression is the variance across both time and locations of the *absolute* LOP deviations for good i. The right-hand-side decomposes this variance into cross-sectional and time series variance. This decomposition is valuable because models often make stark assumptions about them. Trade models often assume that relative prices deviate by a constant, proportional trade cost, which can vary across goods and locations, $T_i > 0$, but not time, $F_i = 0$. The variance of prices across locations would reflect the patterns of shipments of the good across the sources and destinations spanned by the locations in the data.

In contrast, business cycle models typically assume that unexpected shocks generate transitory fluctuations in international relative prices, $F_i > 0$, away from a steady-state in which the LOP holds, $T_i = 0$. We use the letter T, therefore, to denote 'trade costs and trade theory' and the letter F to denote 'frictions, finance, and fluctuations.'

The border metric used by Engel and Rogers (1996) is a measure of the influence of F alone. Continuous equality of prices at parity or up to a trade cost would be consistent with F being zero. All data reveal positive values. However, the volatility of the nominal exchange rate is a key correlate with the magnitude of F, while the same cannot be said for T. This suggests that the measure of market integration conveyed by these two metrics may be quite different. Moreover, there is a natural interaction. When trade costs are significant, more variation in the real exchange rate is expected over time, particularly when the stochastic environment is more turbulent, as is true under a system of floating exchange rates. Note that this property of the data could be obscured entirely if we average across all bilateral pairs and across time. However, if we disaggregate somewhat in either dimension, the impact should be readily apparent.

Table 2 presents a decomposition of price variance into long-run, cross-sectional variance and short-run, time-series variance. Each row reports results for a particular good. The upper panel is the time series variance (F_i) and the lower panel is the cross-sectional variance (T_i), following the notation from the variance decomposition. The four columns within each panel identify the locations being pooled in the variance decomposition: one result for all locations pooled, one for only international pairs, one for location pairs within Swedish and one for location pairs within the U.S..

The first thing to note is that time series variation dominates cross-sectional variation in almost every case. This contrasts with the findings of Crucini and Telmer (2007) using the EIU city retail price panel over the period 1990 to 2005. There are a number of reasons to expect differences. The reversal of ranking is most puzzling from the perspective of the extensive historical work on trade costs. Tariffs and shipping costs have declined significantly over time, leading to the expectation that the (T_i) would be dominant in the earlier period. However, since the statement is about relative importance of the two sources of variation, it could be that real and nominal shocks are even more significant in the earlier period than in the later period. One obvious case in point is the dramatic increase in price variability during the Napoleanic Wars and the War of 1812, reflected in Figures 1 and 2.

A second possibility is that the differences reflect heterogeneity in the goods and locations across the two studies. The EIU price data spans most of the consumption basket while our data consist mostly of commodity prices. Commodity prices have more time-series variation than location variation in the modern era, consistent what we see in Table 2. The locations in the EIU span cities at very different levels of development, which would be expected to give rise to larger long-run deviations due to Balassa-Samuelson type effects. The United States and Sweden may have a more comparable level of real income over this period of history than the typical cross-country pair in the EIU in recent years.

We turn, now, to differences in the sources of variability across the location groupings. The average distance separating locations within Sweden is 389 km, compared to 1,051 km and 6,747 km for locations within the U.S. and cross-country location pairs. In a very general sense we would expect the variances to be ranked with international pairs having the largest variance, U.S. city pairs next and the Swedish city pairs last. The columns are sorted within each block based on this expectation. The only metric that consistently matches this ranking is the time series metric (Table 2, Panel A) where 7 of the 11 goods follow the expected ranking (attention is restricted to 11 goods for which both variance measures are feasible to compute). The cross-sectional variance matches the expected ranking in only 2 of 11 cases.

Using the time series metric, international relative prices are more variable than intranational U.S. relative prices with the exception of beef and in all cases when Swedish intranational relative price variation is the benchmark. The cross-sectional variance reveals positive borders in a weak majority of cases (7 of 14) when the U.S. is the intranational benchmark but in a weak minority of cases (5 of 11) when Sweden is the intranational benchmark.

In summary, there is considerable heterogeneity in LOP variation across goods, whether one considers total variation, time series variation, or cross-sectional variation. What appears to be a border effect is evident in the time-series component of the variation, but not in the cross-sectional component of the variation. There are substantial differences in intranational variation depending on the country of reference, reminiscent of the Gorodschenko and Tesar (2009) critique of Engel and Rogers (1996). We turn next, to a more structural treatment of distance and borders along the lines set out by Engel and Rogers.

5 How Wide Was the Ocean?

In a highly influential paper, Charles Engel and John Rogers (1996) regressed time-series variation in relative prices across U.S. and Canadian city pairs on distance and a border dummy variable.

They found distance to be statistically and economically significant and uncovered a large positive border-effect. ER used 14 sub-indices of the monthly CPI of 9 Canadian and 14 U.S. cities over the period 1976 to 1995 with the exact sample and frequency varying somewhat across sub-indices. Three U.S. cities: Boston, New York, and Philadelphia are common across their data and our own. We ask similar questions to those posed by ER, with the ocean taking the place of the border in the regressions.

We consider two measures of relative-price dispersion as dependent variables. The first measure is the median of the absolute values of the log relative prices:

$$mda_{ijk} = median|q_{ijkt}|. \tag{3}$$

Next, we adopt notation for the time-series mean of each log relative price:

$$q_{ijk} = \sum_{t=1}^{T} \frac{1}{T} q_{ijk,t}. \tag{4}$$

Then the second measure of dispersion is the time-series variance:

$$Var_t(q_{ijk,t}) = \upsilon_{ijk} = \sum_{t=1}^{T} \frac{1}{T-1} (q_{ijkt} - q_{ijk})^2 \tag{5}$$

Using sub-indices of the urban CPIs of Canadian and U.S. cities, ER computed the time series variation in $q_{ijk,t}$ and regressed this variable on a constant, the great circle distance between cities j and k and a border dummy variable. Using our notation, their regression equation is:

$$\upsilon_{ijk} = \alpha_i + \beta_d \ln(\text{distance})_{jk} + \beta_o do_{jk} + \epsilon_{ijk}, \tag{6}$$

where do_{jk} is 1 when the two locations span the ocean and 0 otherwise. ER compute the border width as: $d^* = \exp(\widehat{\beta}_o/\widehat{\beta}_d)$. Basically this is the answer to the question: if one takes the relationship between intranational price variability (pooling all intranational locations in Sweden and the United States) and distance implied by the slope coefficient in the above regression, what additional distance (beyond the actual distance of trans-Atlantic city pairs) would be needed to match the price variability observed in cross-border pairs?

Gorodnichenko and Tesar (GT) criticize the ER specification on the grounds that it fails to account for heterogeneity in the intranational patterns of price variance. To control for the heterogeneity, they include a dummy variable for one of the two countries. With ds_{jk} taking the value 1 for intra-Sweden pairs and 0 otherwise, the regression equation becomes:

$$\upsilon_{ijk} = \alpha_i + \beta_d \ln(\text{distance})_{jk} + \beta_o do_{jk} + \beta_s ds_{jk} + \epsilon_{ijk} \tag{7}$$

As depicted in Figure 5, this produces two estimates of the width of the ocean. One, measured by $d^*_{uu\to su} = \exp(\widehat{\beta}_o/\widehat{\beta}_d)$, is the distance equivalent of the ocean dummy when the equation for intra-US price dispersion is used to extrapolate, which is why we have the subscript $ss \to su$ on the distance equivalent measure. The second measure is $d^*_{ss\to su} = \exp((\widehat{\beta}_o - \widehat{\beta}_s)/\widehat{\beta}_d)$, which uses the intra-Swedish price dispersion equation to extrapolate the ocean width. Obviously, if the dummy variable for Sweden is zero, the two regression lines have the same intercept (they have the same slope by construction) and the ocean width is the same from either point of reference.

Table 3 reports the main findings, pooling all 14 goods. Using the same time-series variance measure that ER employed, υ_{ijk}, distance and the ocean are both statistically significant. Doubling distance increases variance of LOP by about 0.5, while the ocean adds 4.55. For the mean absolute deviation measure of volatility, distance remains economically and statistically significant, but the ocean dummy coefficient is no longer statistically significant.

Using the formula $\exp(\hat{\beta}_o/\hat{\beta}_d)$, the width of the ocean is 672,000 km with a standard error of 1,216,000 km. Using the specification advocated by GT, the border width falls to 318,000 km with a standard error of 509,000 km when intranational US price variability is the point of reference. The estimated width of the border using the mean absolute deviation metric is 1,350 kilometers using the ER specification and 1,430 kilometers using the GT specification. In both cases the confidence interval for the width of the ocean extends down close to zero.

It may seem peculiar that the distance and ocean coefficients are individually statistically significant in the case of the time series variance and yet the border width, which uses these two estimates, is so imprecisely estimated. Recall, that the ocean effect is computed as: $\exp(\hat{\beta}_o/\hat{\beta}_d)$. It is important to note that the statistical significance of this function is different from the statistical significance of the ocean dummy variable on its own. Table 3 contains an example of this distinction. In the top panel of table 3, the ocean effect is insignificant, while $\hat{\beta}_o$ is significant. In the bottom panel, the reverse is true. To see how this can happen, we note that the standard error for the ocean effect is found using the delta method, so, using *var* to denote an estimated variance:

$$\begin{aligned} var[\exp(\hat{\beta}_o/\hat{\beta}_d)] &= var[\exp(\hat{\beta}_o) - \exp(\hat{\beta}_d)] \\ &= \exp(\hat{\beta}_o)var(\hat{\beta}_o) + \exp(\hat{\beta}_d)var(\hat{\beta}_d) \\ &- 2\exp(\hat{\beta}_o)\exp(\hat{\beta}_d)corr(\hat{\beta}_o, \hat{\beta}_d)\sqrt{var(\hat{\beta}_o)}\sqrt{var(\hat{\beta}_d)} \end{aligned} \quad (8)$$

For both regressands the correlation $corr(\hat{\beta}_o, \hat{\beta}_d)$ is roughly -0.8. As the formula shows, this negative correlation itself tends to produce a large variance for the ocean effect. But one also can see that, for example, the variance of the ocean effect in the *mda* regressions will tend to be smaller simply because the standard error of $\hat{\beta}_d$ is smaller in that panel. Basically, the correlation of distance and ocean crossing in our sample makes it difficult to separately identify the two effects. Figure 4 shows a scatter plot of volatility v_{ijk} (on the vertical axis) versus log distance (on the horizontal axis). It shows the obvious correlation between distance and ocean-crossing in these data.

The estimation is repeated for each commodity separately using the same four specifications as in the pooled results of Table 3. The effect of the ocean is even more imprecisely estimated in these results and the inclusion of the dummy variable for Sweden does not much affect the results, so we focus on the distance coefficients in the ER specifications. Figure 6 plots the coefficient estimates on the distance variable along with two standard error confidence intervals for both measures of volatility. The commodities are sorted in ascending order of the lower bound of the confidence interval on the coefficients for the time series variance measure. Of the 28 coefficients, 26 are of the expected positive sign. Moreover, for only a few commodities —which tend to be those with limited data — are the coefficients either negative or the confidence interval extending into the negative range.

6 Discussion

This study of historical prices from the US and Sweden so far yields four key findings. First, time-series variation is large relative to cross-section variation: $F_i > T_i$ in many cases. Second, the regression results point to a significant, positive effect of distance on the time-series variance of LOP deviations. Third, the ocean effect is insignificant for volatility, υ_{ijk}, and significant but relatively small for median absolute values, mda_{ijk}. Fourth, the Gorodnichenko-Tesar critique does not much affect inference about the width of the ocean. In other words, intra-national price dispersion, conditional on distance, was quite similar within Sweden and the United States.

The impact of distance appears to be comparable across commodities. But the fact that the raw time series variance has a substantial good-specific component suggests that factors other than distance may be helpful in accounting for the variability. We plan to explore a number of possible explanations for this heterogeneity in future work. The most obvious possibility is that supply and demand shocks to individual commodity markets differ in magnitude and duration. One possible approach to gauge this source of heterogeneity is to examine the variance of local currency prices relative the median good in the cross-section. The idea is that these deviations represent relative price changes. Including the variance of the relative price in the regression may provide an economic explanation for the commodity-specific constant terms in the distance regressions.

The second possibility is that the heterogeneity across commodities reflects variation in the availability of data across goods. For example, if data for a particular commodity happens to be missing during a volatile historical period, that commodity market would appear unusually stable.

The lengthy historical period also provides opportunities to study shifts in the variance of LOP over time. The sources of these shifts might include changes in trade costs due to the transportation revolution, changes in the volatility of nominal exchange rates (and exchange rate regimes) as well as major disruptions of trade due to conflict and trade disputes. Much remains to be done.

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Table 1: Physical Units and Numbers of City Pairs

commodity	units	Intra-US pairs	Intra-Sweden pairs	International pairs
bar iron	ton	13	54	62
beef	barrel	6	205	84
butter	lb	10	480	150
copper	lb	5	0	4
hops	lb	3	243	60
pig iron	ton	6	6	16
pork	barrel	13	190	116
salt	bushel	7	0	4
saltpetre	lb	6	0	4
tallow	lb	10	291	113
tallow candles	lb	2	406	62
wax candles	lb	6	405	116
wheat	bushel	8	291	115
wool	lb	3	10	15
Maximum city pairs		15	630	216

Notes: A ton is 2000 lbs; a barrel is 217 lbs. The volumes are dry level bushels. To convert to metric units, a lb is 0.45359 kg;a bushel is 0.35239 hectolitres.

Table 2: Sources of LOP Variation

	All pairs	International pairs	Intra-US pairs	Intra-Sweden pairs
		Panel A: Time Series Variation (F_i)		
Bar iron	5.1	7.5	4.6	2.4
Beef	9.8	18.1	22.0	6.0
Butter	4.4	8.8	7.2	2.9
Copper	3.6	11.0	5.6	
Hops	15.6	39.1	16.3	10.3
Pig iron	4.8	6.8	2.9	1.5
Pork	5.6	8.6	2.7	3.9
Salt	12.8	15.8	11.7	
Saltpetre	21.7	46.6	5.1	
Tallow	4.0	6.2	2.0	3.1
Tallow candles	2.0	3.2	2.0	1.9
Wax candles	5.6	8.5	6.3	4.7
Wheat	3.4	6.6	3.5	2.1
Wool	8.6	10.7	3.3	6.9
		Panel B: Cross-sectional Variation (T_i)		
Bar iron	15.9	3.6	2.2	4.0
Beef	4.6	3.4	2.2	4.9
Butter	6.5	11.7	30.6	2.9
Copper	12.4	0.5	2.6	
Hops	12.0	2.9	3.2	11.6
Pig iron	19.2	1.5	0.7	0.1
Pork	4.3	2.9	2.0	4.4
Salt	3.3	1.7	3.3	
Saltpetre	2.7	5.3	0.9	
Tallow	3.6	3.2	2.2	3.2
Tallow candles	1.2	3.8	2.9	0.8
Wax candles	13.0	26.5	31.0	5.7
Wheat	2.2	4.1	10.2	1.2
Wool	14.3	14.8	5.9	15.2

Table 3: Border Regressions 1732-1860

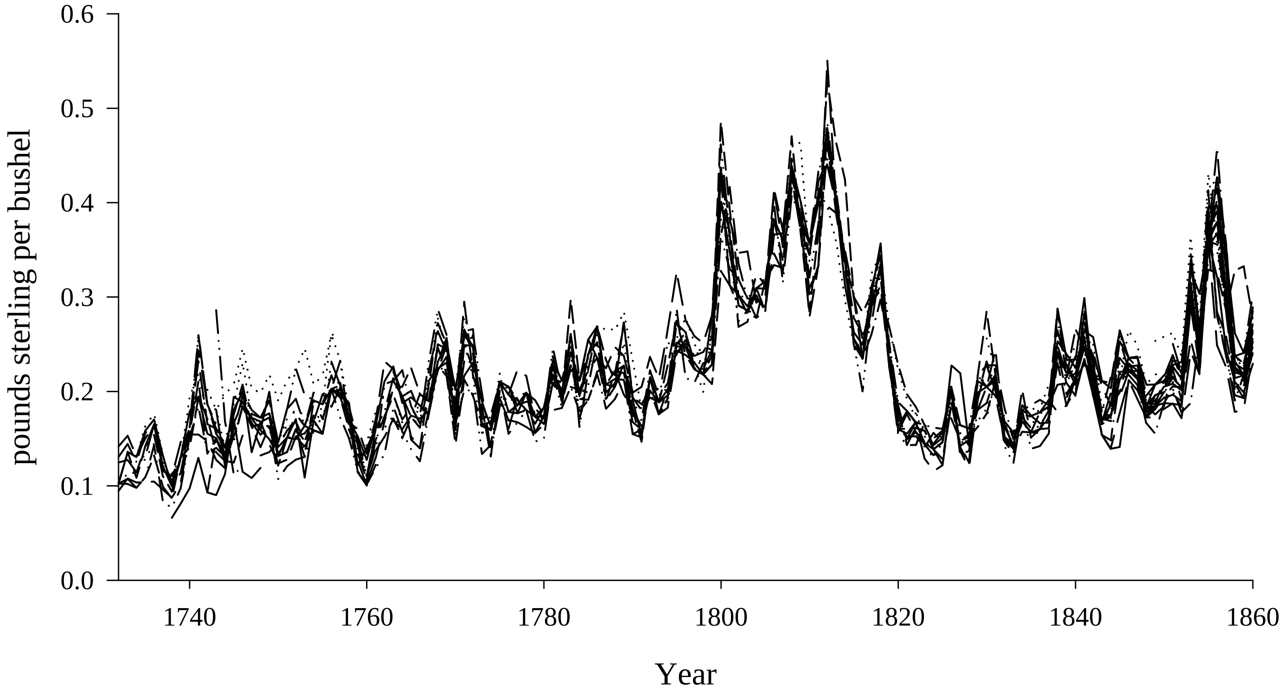
$$Var(q_{ijk,t}) = \alpha_i + \beta_d \ln(distance)_{jk} + \beta_o do_{jk} + \beta_s ds_{jk} + \epsilon_{ijk}$$

$\hat{\beta}_d$	$\hat{\beta}_o$	$\hat{\beta}_s$	$\exp(\hat{\beta}_o/\hat{\beta}_d)$	R^2	Obs
(se)	(se)	(se)	(se)		
		Panel A: $Var(q_{ijk,t}) = v_{ijk}$			
0.70	4.55	—	672	0.39	3598
(0.12)	(0.54)		(1216)		
0.73	4.20	1.90	318	0.40	3598
(0.12)	(0.53)	(0.60)	(509)		
		Panel B: $Var(q_{ijk,t}) = mad_{ijk}$			
0.53	0.16	—	1.35	0.38	3583
(0.04)	(0.16)		(0.43)		
0.52	0.19	-0.15	1.43	0.38	3583
(0.04)	(0.16)	(0.09)		(0.47)	

Notes: Distance $dist_{jk}$ is in thousands of kilometres. The dummy variable do_{jk} is 1 when j and k are on opposite sides of the ocean and 0 otherwise. The dummy variable ds_{jk} is 1 when j and k are both in Sweden and 0 otherwise. Standard errors are robust to heteroskedasticity. R^2 is the centered value so does not reflect the explanatory contribution of the intercepts. Results were very similar with a common intercept across commodities. $Obs = J \times (J-1)/2$.

Figure 1: Wheat Prices

Sweden



United States

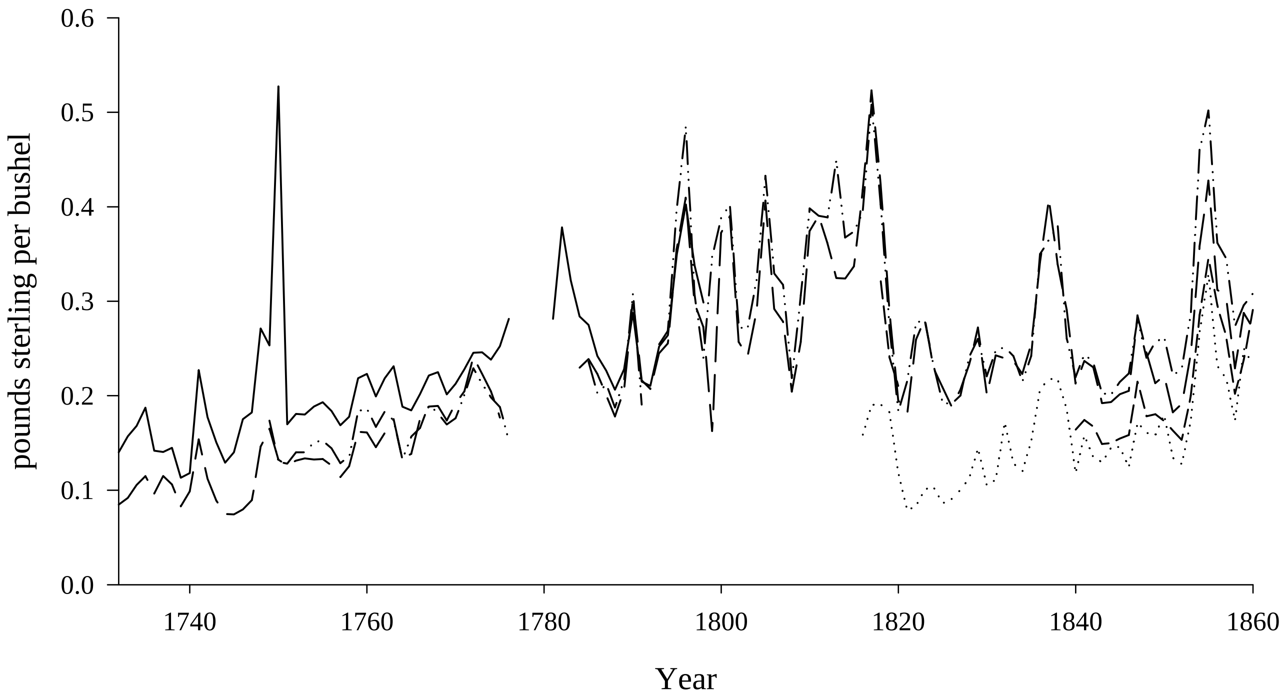
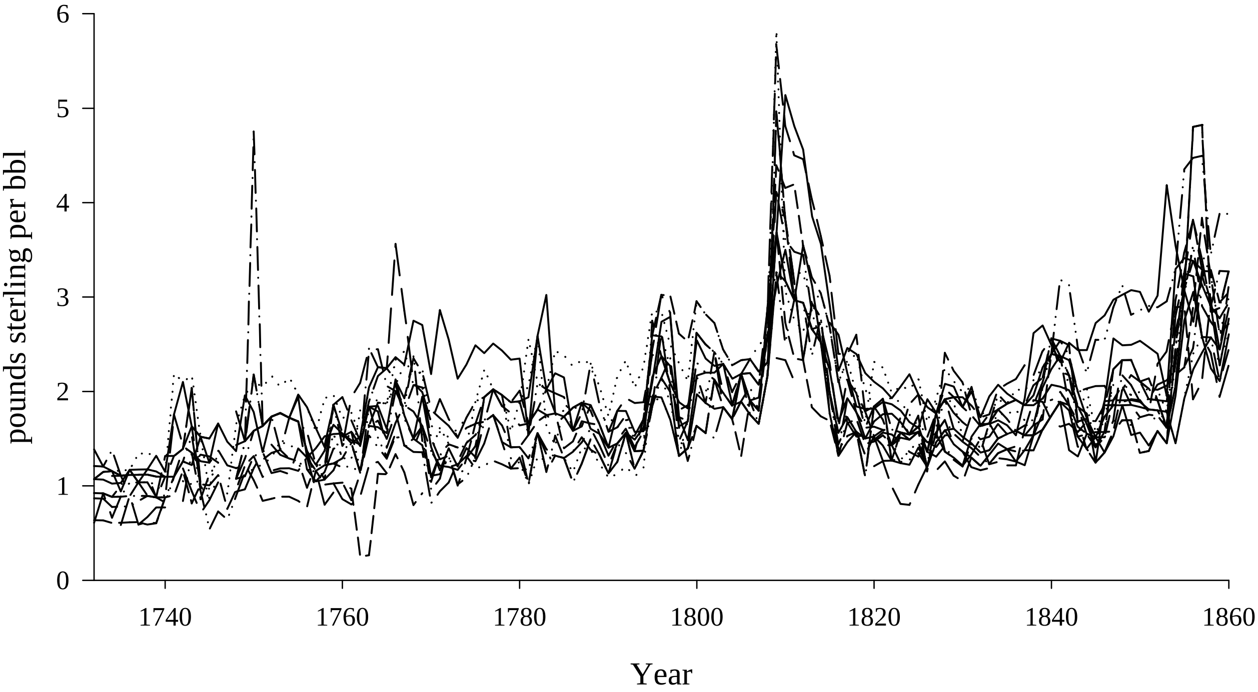


Figure 2: Beef Prices
Sweden



United States

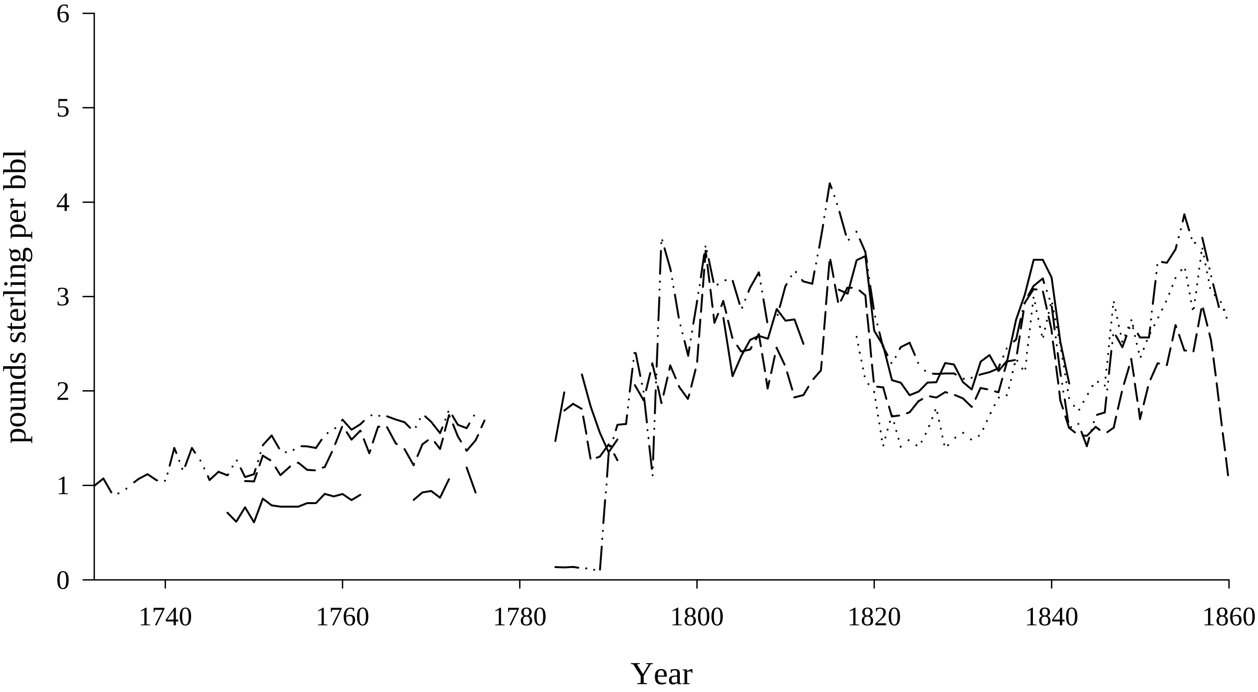
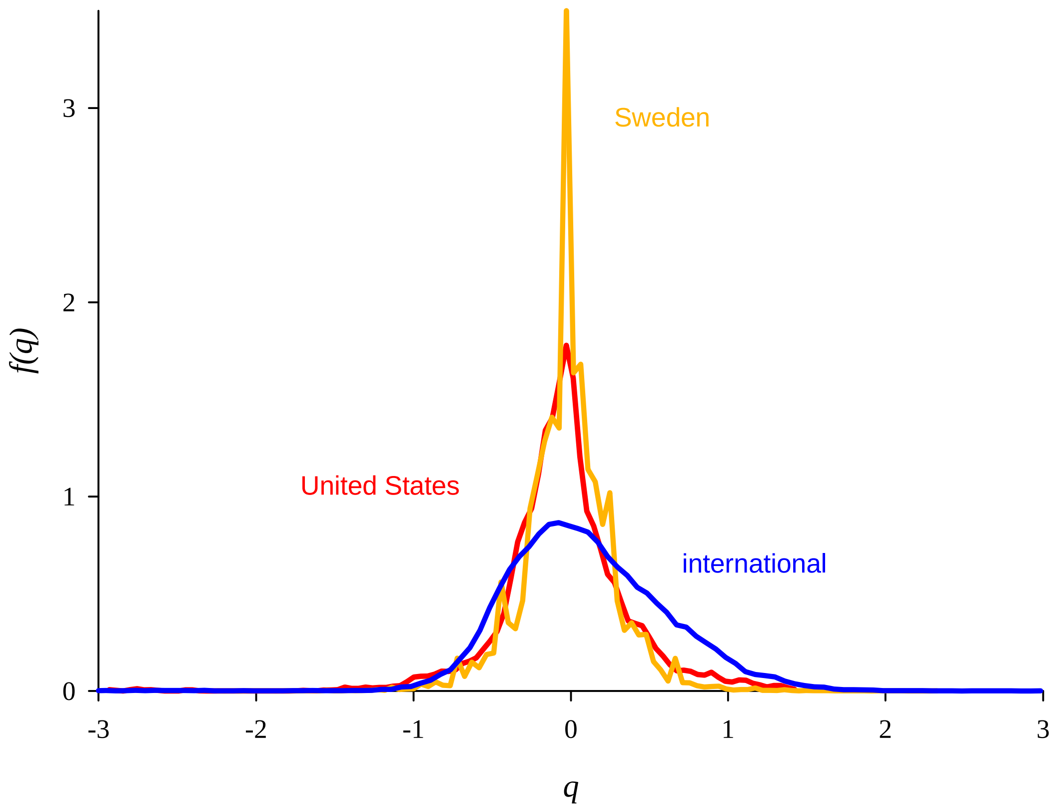


Figure 3: Empirical Density of LOP Deviations



Notes: The graphs are estimates of the density functions using an Epanechnikov kernel and bandwidth $0.79N^{-1/5}$IQR, where *q* is the log relative price between two locations for 14 commodities from 1732 to 1860.

Figure 4: Volatility and Distance

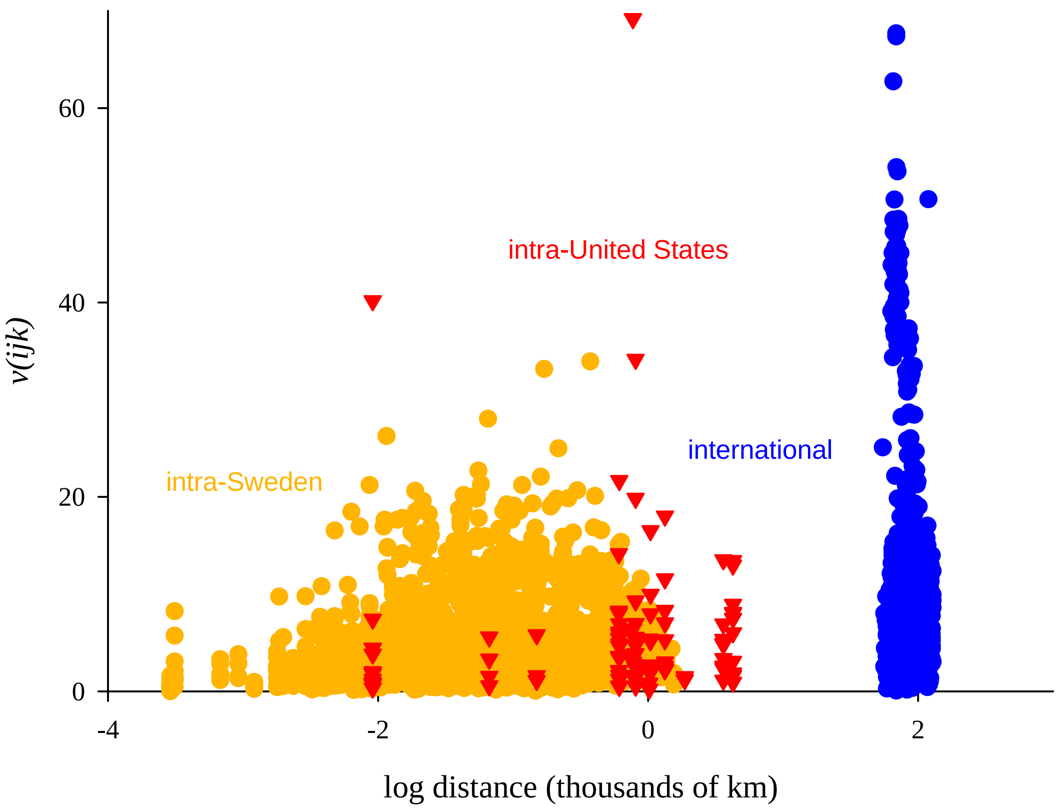


Figure 5. The geometry of ocean width estimation

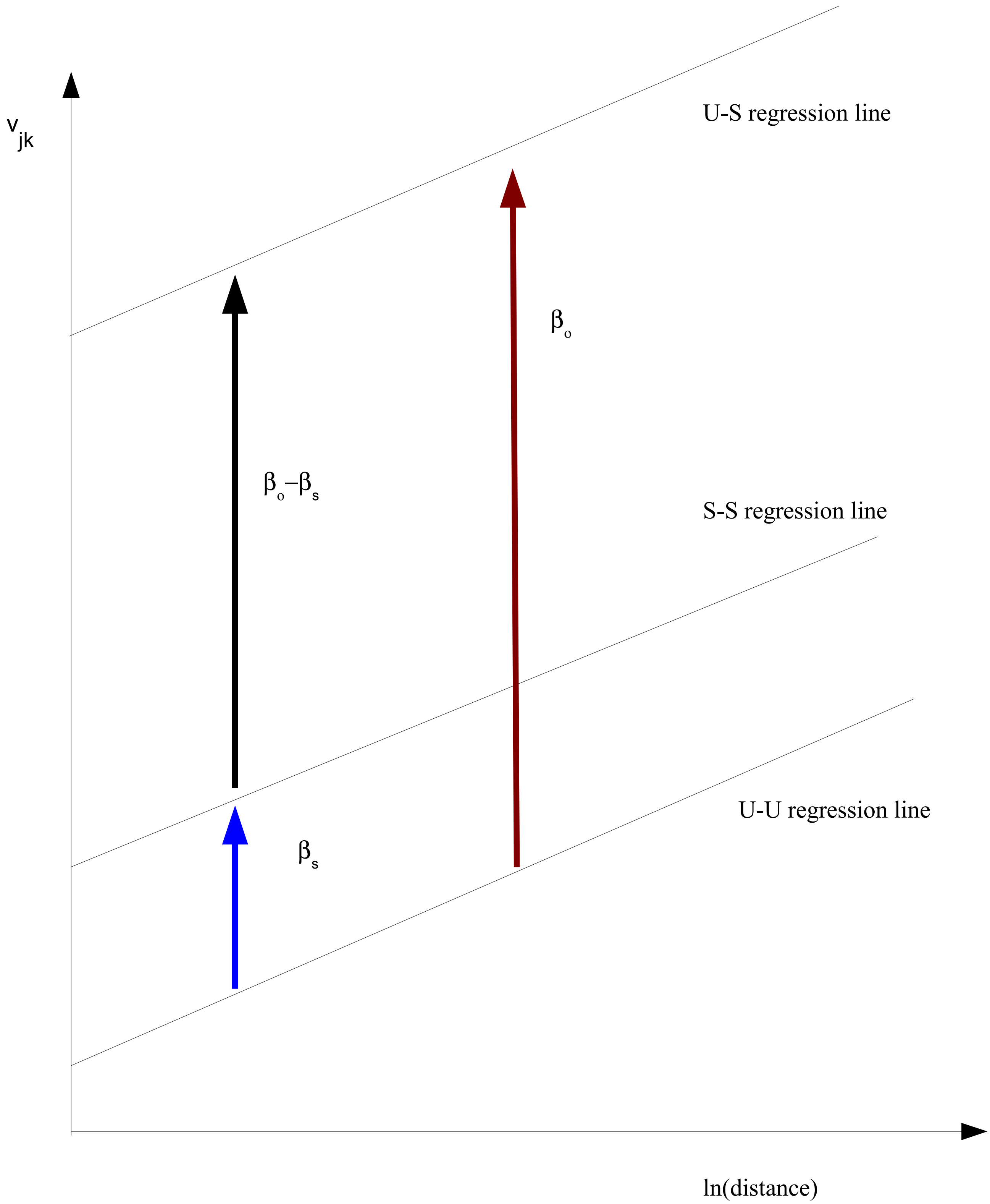
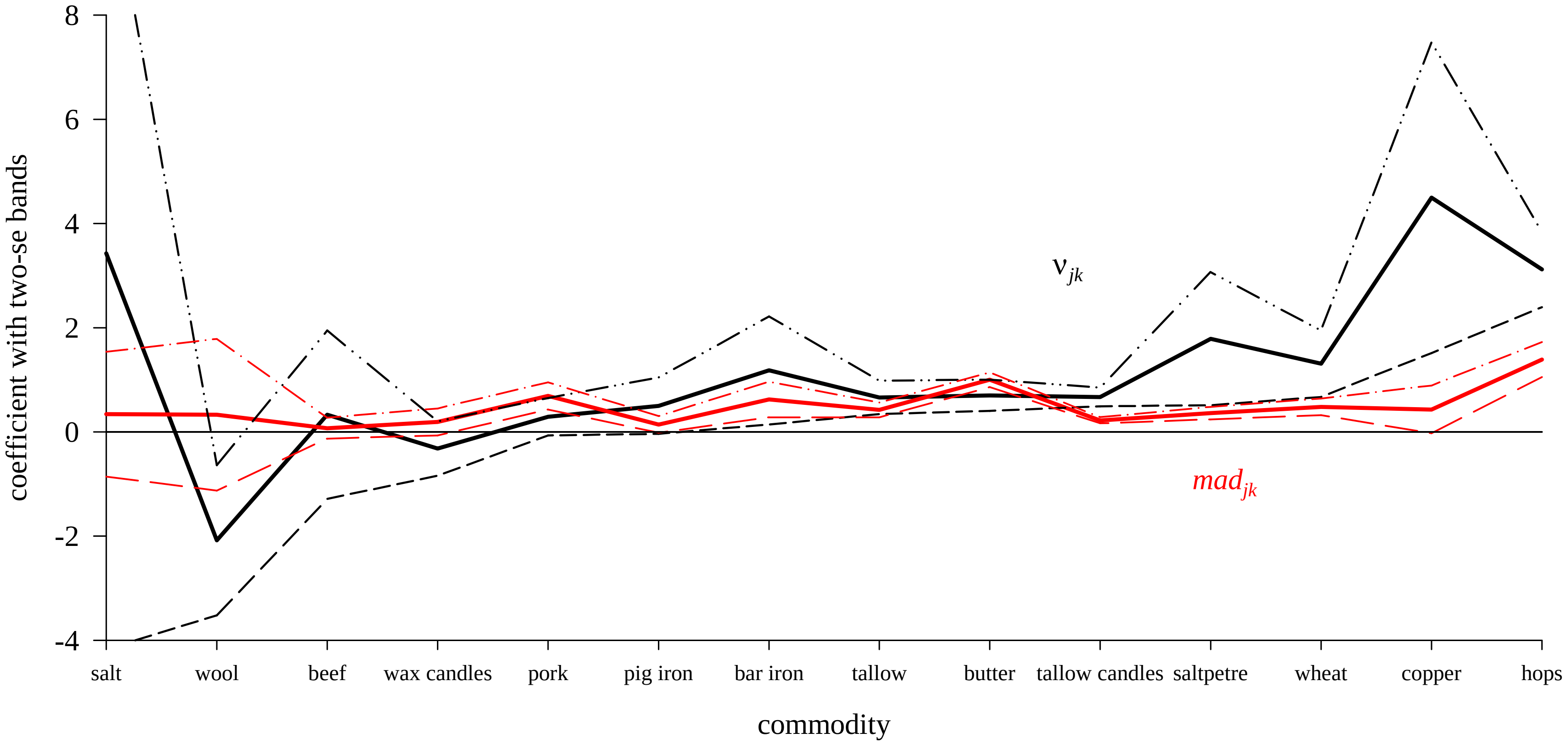


Figure 6: Distance Coefficients (β_d) by Commodity



Notes: The solid black line connect the estimates of the coefficient on log distance for the variance measure ν_{jk}, while the dashed black lines give the two-standard-error confidence interval. The corresponding red lines apply to the median absolute deviation measure mad_{jk}.