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ABSTRACT

Capital markets allow surplus income to be invested into productivity-enhancing projects. Despite their prominence in general accounts of growth little is known on their role in the emergence of modern economic growth. In this paper we ask whether capital market performance might explain why Britain surged ahead of China in the 18th century. We employ an asset-pricing model together with information on regional grain prices to derive interest rates, and then compare capital market development in large parts of Britain and China. We first calibrate the method and show that it can replicate key features of the United States' early 19th century capital market, where more systematic data from bank interest rates is available. Using this approach we estimate interest rates for Britain that are at least 20% lower than those for China, for the years 1770 - 1860. Moreover, the regional integration of British capital markets, measured in terms of bilateral interest rate correlations, was far greater than it was in China. The Yangzi Delta correlations come close to the British average at distances below 200 kilometers, but at larger distances interest rate correlations in Britain are twice those of the Delta, and three or more times as high as elsewhere in China. We also find that Britain's advantage over China in terms of market integration existed already in the late 18th century. Backcasting on the 19th century trends suggests capital market divergence started by the year 1690. Overall, our results provide support for the hypothesis that divergence in capital market development occurred before income divergence, and may therefore be an important factor in explaining the Great Divergence.

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I. Introduction

Why did modern economic growth begin in Northwest Europe, and not in China? Some time ago Kenneth Pomeranz addressed this classic question in his seminal *The Great Divergence* (Pomeranz 2000). Despite the progress that has been made over the last 15 years, there is no consensus on the cause for the Great Divergence. Financial development was an important factor for early growth in Europe and North America (Davis 1965, Sylla 1969, Rousseau 2003), and it contributed to Japan's catch-up with the West starting in the late 19th century (Mitchener and Ohnuki 2009).[5] Were there significant differences in financial development between China and England? We employ an asset-pricing and storage model together with information on regional grain prices to compare capital market development in large parts of Britain and China over the 18th and 19th centuries to assess differences in capital market development.

Financial markets matter because in their absence any surplus income cannot be invested into productivity-enhancing projects. The price of capital is the interest rate. A relatively low interest rate is not only indicative of an economy not being constrained by the availability of capital, but it also points to relatively low levels of risk in capital market transactions (North and Weingast 1989). Low interest rates in Europe, or, a high wage-rental ratio, may also have given relatively strong incentives to mechanize, thereby pulling Europe ahead of other parts of the world (Allen 2009).

One challenge is that an interest rate is typically a price that is specific to a particular transaction, and numerous aspects of that loan are unobservable. This makes it difficult to compare any given interest rate. Pomeranz, for example, notes that while there are numerous interest rates for China's Shandong province, "most cannot be used in systematic comparisons, however, because they omit information about who was charged a particular rate, what security there was, how interest was paid, and so forth" (1993, p.32). We address this issue by providing consistent

[5] The link between financial development and economic growth has been emphasized since Bagehot (1857), Schumpeter (1911), and Gurley and Shaw (1955). Rousseau and Wachtel (1998), Rousseau

interest rate estimates based on high-frequency regional grain prices. Furthermore, because even in highly developed capital markets such as the U.S. today, regional interest rate levels will typically vary due to various observed and unobserved factors, we take market integration as another measure of capital market performance. Thus, low capital market integration is a sign of high barriers to the division of labor and investment, as well as high levels of risk, whereas highly integrated markets ensure that capital can flow to the location of efficient use.

Because stored grain competes with other assets to convert current into future consumption, grain price movements reflect regional interest rates. An asset-pricing and storage model provides the framework to estimate regional interest rates from monthly grain price series. We choose our empirical approach by calibrating the asset-pricing and storage model to key features of the early 19th century U.S. capital market. Furthermore, we account for variation in storage and other grain-specific costs by using information on historical climate, transport routes, and cropping patterns in Britain and in China.

The resulting interest rates are employed to evaluate capital market performance as a prime cause of the Great Divergence. The first step is to compare interest rate levels in Britain and China, and how they evolved over the period of 1770 to 1860. We then analyze the integration of capital markets in Britain and China by examining the correlation of interest rates across regions with varying geographic distance. The higher is the correlation for a given distance, the stronger is the integration of capital markets. Comparing capital market performance in terms of integration has the advantage that slow-changing factors—which might be present but are not observable to us—do not affect our results on market integration. We find that interest rate level and integration results give the same answer: British capital markets appear considerably less capital constrained as well as more integrated by the 18th century, if not earlier.

We contribute to a large literature in historical development that has examined the divergence between China and Europe to distill lessons on the causes of economic development (Needham 1969, Pomeranz 2000, Rosenthal and Wong 2011, Lin 2014). While considerable progress has been made in terms of accounting for the Great Divergence through income and national accounts studies (Allen et al. 2011, Broadberry et al. 2014), explaining the Great Divergence in quantitative terms has been a greater challenge.[6] We provide a new empirical grounding for explanations of the Great Divergence that refer to capital market development. This paper contributes to this literature by presenting a new set of interest rates for large parts of China and Britain starting in the 18th century. In addition, most of what we know about early capital market integration is based on the 19th century U.S. (Davis 1965, Bodenhorn and Rokoff 1992) and 19th to 20th century Japan (Mitchener and Ohnuki 2007, 2009).[7] We extend this literature by performing the first study of capital market integration using interest rates for the 18th century, and by providing a first set of results on co-movements of interest rates as a measure of capital market integration for China.[8]

We are not the first to shed light on historical capital markets by examining the behavior of grain prices (McCloskey and Nash 1984, Taub 1987, Pomeranz 1993, Brunt and Cannon 1999, 2009, Clark 2001, and Shiue 2002).[9] While we find the approach appealing, one might be concerned about its reliability. The grain-price based approach to interest rates requires that peasants are buying and selling grain over time, connecting grain prices to capital markets. Is there any evidence that markets worked sufficiently well, and were 18th century peasants economically rational enough and able to engage in this trade?[10] For 18th century China, at least, we know that peasants moved their assets back and forth between cash and grain

[6] Two related papers are Shiue and Keller (2007) and Studer (2008) who focus on commodity market integration as explanation for the divergent paths of Europe and Asia. Li and van Zanden (2013) provide evidence on relatively low interest rates in Europe that may have induced capital-using technical change, thereby explaining the relatively high GDP per capita in early 19th century Netherlands, compared to China's Yangzi Delta.
[7] Good (1977) and Brunt and Cannon (2009) study 19th century Austria and England, respectively.
[8] Other evidence on China's capital market development includes Zelin (2005) who shows that salt merchants were able to raise substantial funds in southern Sichuan during the late 19th to early 20th centuries, and Pomeranz (1993) who discusses the variation in 20th century regional interest rates in Shandong province. Before the 19th century, work on capital market integration has typically relied on interest rate proxies, including the number of real property transactions (Buchinsky and Polak 1993 for England).
[9] The approach goes back to theory by Working (1933, 1949) and Kaldor (1939).
[10] A critique of the grain-price & storage approach along these lines is Komlos and Landes (1991).

with merchants intermediating.[11] Such shifts in assets would have had the effect of dampening price fluctuations as traders tried to find a better return, and it is reasonable to assume that their counterparts in Britain did this as well.

Another concern about the asset pricing methodology relates to how much of the interest rate we can expect to capture. Given that we are resorting to the method in the absence of reliable interest rates, what can we say about the accuracy of the estimates? We provide, to the best of our knowledge, the first comparison between grain-price based interest rate estimates and actual bank interest rates—in our case, for the early 19th century U.S., a context in which both types of data are to some degree available. Using data for the U.S., we show that the grain-price based approach to interest rates captures some of the major features of early capital markets. This presents a new form of validation for the asset-pricing approach to interest rates. Our benchmark yields information about the potential and limitations of the asset-price based approach, arguably important for studying capital market development in historical and contemporary economies where regional bank interest rates are unavailable.

In the main analysis, we use the same approach to estimate base interest rates for Britain and China between 1770 and 1860. An important component of our approach is that we try to net out other factors, such as differences in storage from climatic shocks, which could affect the estimated interest rate. Our findings demonstrate that Britain's capital markets performed considerably better than China's during the period under consideration. We find annual rates in Britain were about 5.5% on average, while China's were about one third higher (about 8%). Storage costs are important for estimating interest rates from grain price changes. Without netting out storage costs our estimates would be about 40% higher.

We also find that the regional integration of British capital markets was far greater than regional integration in China. Correlations for the Yangzi Delta come close to the British average at distances below 200 kilometers, while at larger

[11] Described in a memorial from the 18th century by a Qing official named Tang Pin in *Da Qing li chao shilu*, Gaozong (Qianlong) reign 286: 24b-25a (4154-55); see Pomeranz (1993, 32; 2001). Also, Zhang (1996), Pan (1996) on rural borrowing and merchant credit.

distances interest rate correlations in Britain are twice those of the Delta, and three or more times higher than elsewhere in China. And while Britain increased its advantage over China during the period of 1770 to 1860, already by the end of the 18th century there was a substantial gap in capital market integration between the two countries. Overall, our results suggest that capital market development might be an important factor in explaining the Great Divergence.

The remainder of the paper is as follows. The following section 2 reviews the existing direct evidence on interest rates in China and Britain. We then introduce and calibrate a simple asset-pricing model that can be employed to infer interest rates from monthly grain price changes. We describe the data in section 3. Our empirical results on comparative capital costs and capital market integration are given in section 4, which also discusses the influence of a number of factors on the results. A concluding discussion is provided in section 5.

2. Direct evidence and grain-price based evidence

2.1 Early modern interest rates in China: what do we know

There are numerous but scattered interest rates that can be found for China. These studies provide support for the notion that the riskiness of the terms of the loan affected the reported interest rates charged. They also show that credit was used regularly by peasants for purchasing fertilizer or consumption (Pan 1996, Huang 1990) as well as entrepreneurs investing in large commercial ventures (Zelin 2006), and that merchants involved in long-distance trade in grain acted as intermediaries between peasants and brokers in physically carrying the grain to market. Most of the long-distance trade in China consisted of grain and textiles, and merchants were apparently able to secure loans from domestic banks at just 10% per year in some places prior to the 19th century (Zhang 1996, 127). Recorded information about rates for more rural areas tend to be much more sparse and limited. Anecdotally, Qing official Chen Hongmou claimed that private loans taken in the spring for grain and repaid in the fall were 30-40% (Rowe 2001, 285). Another Qing contemporary, Wei Jurui, observed that peasants borrowing 20-30 *taels* were required to pay as much as 200-300 *taels* at the end of a year (cited in Zhang 1996, 102-3), an example that suggests how interest rates might become worthy of official record once they reached especially high levels. From these type of sources, we cannot learn much about the mean or overall distribution of the rates.

Although direct interest rates can be informative, our main concern with direct interest rate quotes has to do with the limited information contained in them. First, many of the sources that are available are for the late 19th century, with much fewer observations available for the 18th century.[13] Second, the spread of the rates that are available tends to be fairly large, reflecting the fact that the terms of loans are highly variable and not specifically observed. In addition, the relative riskiness of the borrower and the relationship between the borrower and lender is often unknown to an outside observer, but likely would have been known to the lender and therefore incorporated into the rate on the loan. Although the Qing state prohibited high interest rates of above 3% per month and total interest that exceeded the loan, officials were unable to enforce the statute (Isett 2006, 362-3).

Third, because the evidence on interest rate levels is spotty and subject to large fluctuations depending on the specific terms of the loan, the interest rates are rarely comparable. It is thus not possible to examine how markets reallocated capital in China across regions, and how this changed over time. Given the difficulty of estimating comparable interest rate levels, capital market performance is arguably better measured by the spatial integration of capital markets than by interest rate levels. Consistent with this, studies of capital market performance typically examine the extent to which interest rates in different regional markets co-vary with each other.

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[13] Lieu (1937) and Chao (1977) cite interest rates in the silk and cotton industries in the Yangzi Delta during the 20th century; these are discussed further in Shiroyama (2004). Dyke (2011) cites interest rates concerning traders in Canton. Interest rates can also be found outside of major urban trading centers. Pomeranz (1993) studies interest rates from Shandong Province. In 1890, rates on short-term loans in the cotton industry reportedly varied from 6 to 14.6%. Rates on long-term loans in Shanghai were around 10.5%. In the Canton trade, short-term loans in the 1880s averaged between 12 and 15%, while government loans in the 1910 period ranged between 5.3 and 7%.

Fourth, the level of the interest rate is subject to influences of the supply and demand for capital, in addition to risk. There is some evidence that investors in China were able to amass large amounts of capital (Zelin, 2006). However, the demand for capital probably differed between China and Europe by the early modern period. First, European states were a source of demand for loans, whereas the agrarian Chinese state ran a balanced budget. The English system also enabled the government to establish financial instruments with the Bank of England with which this borrowing could be carried out (North and Weingast 1989). As Europeans increasingly undertook overseas ventures, this bolstered the need for more complex financial instruments. While data on the overall volume of capital market loans or investments does not exist and is difficult to estimate, in terms of overall supply and demand for capital, the general assessment seems to be that capital supply was lower in China because demand for capital was lower, and not the other way around. Thus, while a shortage of capital could have raised interest rates, it seems that it was in Europe where we see greater demand that this could have more likely led to upward pressures on interest rates.

2.2 Grain price changes and interest rates: an asset-pricing approach

Consider a peasant living in region *i* who has harvested his grain at time *t*. We assume that the harvest is larger than what the peasant can consume in this period, and that grain is valuable (its price is positive). The peasant has two options: first, he can sell the excess grain Q_{it} on the market at a price P_{it} per unit. Second, the peasant can save the excess grain by storing it in a granary until time $t+1$. There are two costs of storing grain that we distinguish. First, the capital cost, or interest rate, r_{it}, which captures the fact that if the peasant sells his grain right away he has an income of $P_{it}\, Q_{it}$, whereas if the peasant stores his grain this potential income is not liquid because it is in the granary. Second, grain does not store perfectly but is subject to spoilage (mold, rats, mice, etc.), which we denote by the per-unit cost c_{it}.

In equilibrium, in order for the peasant to be indifferent between selling in period t and storage, the price of grain in period $t+1$, P_{it+1}, must be equal to the storage cost inclusive of price in period t, that is,

$$(1) \qquad P_{it+1} = P_{it}(1 + r_{it} + c_{it}) \text{ ,}$$

which we can rewrite as

$$(2) \qquad \hat{p}_{it} \equiv \frac{P_{it+1} - P_{it}}{P_{it}} = r_{it} + c_{it}.$$

Equation (2) shows that in a storage equilibrium, the rate of grain price change is equal to the interest rate r_{it} plus grain-specific factors c_{it} . We will refer to $\hat{p}_{it}$ as the carry cost of grain, and to c_{it} as the storage cost, broadly defined.

Figure 1 shows the price behavior from a simple model of storage. It shows that upon arrival of the new grain from the harvest, the price falls, reaching a first low in period 8. The maximum storage level in the first cycle is reached in period 13, while in period 18 the equilibrium price has reached its maximum. Storage runs out in the period with the highest price, just before the new harvest lowers the price again. The shape of the price curve between the low and the high price of grain in a given harvest year is affected by the interest rate: the steeper the curve, the higher the interest rate. From equation (2), however, we see that it is impossible to infer the interest rate from grain price changes without knowing more about storage costs.

We begin by making assumptions on storage costs that allow us to compare interest rates between the regions of two countries, l = C or B for China or Britain. Let there be N^l regions in each country. Further, denote by r^l the average interest rate in country l across T = 90 years and N^l regions, $r^l = \frac{1}{T}\frac{1}{N^l}\sum_t \sum_i^{N^l} r_{it}$, and denote $\hat{p}^l$ and c^l as the analogous average carry costs and storage costs, respectively, in country *l*. Using equation (2), the difference between average carry costs in China and Britain is equal to:

$$(3) \qquad \hat{p}^C - \hat{p}^B = (r^C - r^B) + (c^C - c^B)\,.$$

Equation (3) shows that the difference in interest rates between China and Britain $r^C - r^B$ is equal to the carry cost difference if and only if the average storage costs in China and Britain are equal to each other:

$$(4) \qquad c^C - c^B = \frac{1}{T}\frac{1}{N^C}\sum_t \sum_i^{N^C} c_{it} - \frac{1}{T}\frac{1}{N^B}\sum_t \sum_i^{N^B} c_{it} = 0.$$

By imposing equation (4), our first comparison of interest rates in Britain and China below will be to compare the average carry costs in each country.

Furthermore, consider the difference in country *l*'s carry costs in years *t* and *t+1*. If average storage costs in country *l* do not change over time, the change in interest rates is equal to the change in carry costs:

$$(5) \qquad \hat{p}_t^l - \hat{p}_{t+1}^l = r_t^l - r_{t+1}^l \Leftrightarrow\; c_t^l - c_{t+1}^l = \frac{1}{N^j}\sum_i^{N^l} c_{it} - \frac{1}{N^l}\sum_i^{N^l} c_{it+1} = 0, \forall\, t, l = C, B.$$

We will use equation (5) to examine interest rate trends for a given country.

In addition to making assumptions on storage costs, we proceed by modeling factors that affect carry costs in terms of observables. First, it is well known that climate greatly influences storage costs. This is true particularly for the extent of rainfall and wetness, which influences the presence of mold and pests. Second, interregional trade can affect within harvest-year price fluctuations.[14] To the extent that grain can be imported in region *i* from other regions, region *i*'s within harvest-

[14] Shiue (2002) presents evidence from 18th century China.

year price gradient will be dampened. To capture climate and trade effects, we adopt a regression approach. Dropping the country superscript *l*, we have

$$(6) \qquad c_{it} = \beta_0 + \beta_1 climate_{it} + \beta_2 trade_i + u_{it},$$

where u_{it} is assumed to be a well-behaved mean-zero error term. Notice that while the climate of a region is observed annually, our measure of interregional trade does not vary over time. Our measure of trade is waterway access through rivers, canals, and the coast because that meant that low-transportation cost transport was possible.

Using equations (2) and (6) we can purge the influence of interregional trade, storage, and other weather-related costs from carry costs and obtain

$$(7) \qquad r_{it} = \hat{p}_{it} - c_{it} = \hat{p}_{it} - \beta_0 - \beta_1 climate_{it} - \beta_2 trade_i - u_{it}, \forall i, t.$$

Under our assumption that u_{it} is a well-behaved mean zero error term, equation (7) shows that interest rates can be estimated by OLS with data on monthly price changes, climate, and access to waterways. Below we will also account for differences in cropping patterns across regions, which might affect the extent to which within-harvest year prices would increase.

Suppose that instead of being mean-zero the error term contains systematic but unobserved influences on grain price changes, denoted by x_{it}, while e_{it} is a well-behaved mean-zero error:

$$(8) \qquad u_{it} = x_{it} + e_{it}.$$

If over a certain period x_{it} does not change so that $x_{it} = x_i, \forall i, t$, interest rate levels cannot be identified separately from the systematic influences x_i. Considering the correlation of adjusted carry costs (as per equation (7)) in two regions *i* and *i'* over time, however, we see that this is identical to the co-movement in the interest rates of the two regions, because the time-invariant factors x_i and $x_{i'}$ do not affect this correlation over time. For example, there may be storage technology differences across regions. As long as storage technologies do not change significantly over the period of analysis, the correlation of adjusted carry costs in any two regions will yield information on the bilateral correlation of interest rates in the two regions. The higher is the bilateral correlation, the higher is the level of market integration. In particular, we will report bilateral correlations for different geographic distances. Because the forces of integration disappear with rising distance, bilateral correlations tend to fall with distance.

As we will show in section 4, our findings on interest rate levels and capital market integration are consistent with each other. Regions with relatively low interest rate levels typically also exhibit a relatively high level of capital market integration, and vice versa. We are able to unambiguously rank capital market performance in China and Britain.

2.3 The asset-pricing approach to interest rates: A calibration to U.S. data

One might be concerned that the asset-pricing approach does not yield good interest rate estimates. Segmented markets, incomplete information, market power, and constraints on rational behavior, as well as the data generation process of the underlying grain prices could all potentially affect the estimate. To show that the asset pricing method does generate reasonably accurate interest rates, ideally we would want to compare the estimates derived from asset pricing with actual interest rates.

To address the issue, in this section we present a benchmark for the asset pricing and storage approach to interest rates based on data for the early 19th century United States, which is the earliest historical period where we could find both grain prices as well as bank interest rates. We employ the asset pricing model to derive interest rates based on U.S. monthly wheat prices, and compare these grain-based interest rates with estimates of bank interest rates for the same regions and years. The source of the bank interest rates is Bodenhorn and Rokoff (1992), and the monthly wheat prices come from Jacks (2005, 2006).

The cities with wheat price information are New York, Philadelphia, New Orleans, Richmond and Indianapolis. We match the prices for these cities to bank interest rates for New York, Philadelphia, and New Orleans, as well as the states of Virginia (matched to Richmond) and Indiana (matched to Indianapolis). The bank interest rates are shown in Table 1. During the earlier part of the 19th century, these areas of the U.S. were quite diverse in their level of development. This heterogeneity can be seen in other ways as well. Some of the areas were major grain producers, some had relatively good access to interregional transportation, and some regions are relatively small (the cities of New York, Philadelphia, and New Orleans) while others are larger (Indiana, Virginia). This is heterogeneity is useful because similar types of differences also exist across regions in Britain and China, so we can use the U.S. sample to see how the grain asset-pricing and storage approach changes according to these variations.

To begin, a key fact to be kept in mind is that actual grain prices rarely evolve as regularly as the simulated ones in Figure 1 above. Rather, there are constant shocks affecting grain prices, and underlying the storage cycle can be stochastic trends of unknown periodicity. Figure 2 shows the price for a bushel of wheat in Philadelphia over the five years 1836 to 1840. In particular, we see a steady decline in the price for the year 1839, with virtually no months recording a price increase. This means that grain-price based interest rate estimates can, and will, be zero or negative.

Two factors help us to pin down interest rates. The first is sample size. Given a sufficiently large sample size, the times of secular price decrease and the times of price increase will tend to balance out, making it possible to estimate the average storage-related price gradient. Fortunately, samples are fairly large: around 8,000 interest rates for Britain and about 35,000 for China. The second factor is that we need to be able to suppress the influence of stochastic cycles that may have nothing to do with the storage cycle. To do this we employed a number of time series smoothing and filtering techniques. Many of these are typically used in business cycle analysis. Figure 3 shows an example: the unfiltered five years of Philadelphia wheat price data is plotted along with the price series after it is fed through a Butterworth (1930) time-series filter. While the pattern of the filtered time series does not look like the simulated data of Figure 1, the filtering does bring out the cyclical behavior of the price series more strongly compared to the unfiltered series.

The general strategy is to use calibration in order to choose the method under which the behavior of the grain-price based interest rates is as similar as possible to the bank interest rates in Table 1.

We use several criteria in order to decide on the method that we use to estimate grain-price based interest rates. They are shown together with the results in Table 2. First, we examine the level of the interest rate based on the grain-price based method, versus the bank interest rates (Panel A). Second, we ask whether the grain-price based interest rates are similar to the bank interest rates in terms of time series variation. To see this we run OLS regressions, city by city, of the grain-price based interest rates on the bank rates, and record the mean t-statistic as a measure of the time series correlation. These results are reported in Panel B.

Third, we look at the correlation between regional interest rates. One indicator of capital market integration is the *average* strength of bilateral correlations when interest rates are derived from grain prices, versus when they are bank rates. The second indicator, perhaps the most important, is to compare the *patterns* of bilateral interest rate correlations that emerge from the bank versus the grain-price based interest rates. After computing all bilateral correlations of interest rates between city pairs, we examine how the strength of capital market integration across pairs implied by the grain-price based approach compares to the capital market integration implied by the bilateral correlation pattern of the bank interest rates (Panel C). This allows us to see whether the grain-price based approach to interest rates can distinguish between regions in which there is a low level of capital market integration from others with a high level of capital market integration.

We have considered a wide range of time series filtering techniques and criteria to select months to be included in the price gradient calculation. Results from a subset of these methods are shown in columns 2 to 6 of Table 2. In all cases, we choose August to December as our storage months, that is, the annual interest estimate is computed as the average of the one-month percentage price changes in August, September, October, November, and December. Columns 2 to 6 differ only in how the price series are filtered before we compute this average price gradient.

Column 2 of Table 2 gives the unfiltered series; the price gradient is computed as the log month-to-month difference of the raw data. Column 3 shows a different approach to the asset-pricing grain storage model, a moving average smoother (uniform weights), with two lags, the month itself, and two leads. The following three columns report results from three well-known time series models, respectively: those of Baxter and King (1999), Christiano and Fitzgerald (2003), and Butterworth (1930).[16]

We begin by examining interest rate levels (Panel A). The average annual bank interest rate is equal to 5.8%, with a standard deviation of 0.018 (n = 5 cities; column 1). Using the asset-pricing model with unfiltered data, we estimate an average rate of 7.4%. Figure 4 shows our results for New York and Philadelphia. We see that the grain-price based approach to interest rates yields a figure of about 6% per year, which is only about 15% off from the bank interest rate estimates. The fact that a simple grain-price based approach comes that close to bank interest rate estimates for two of the most important markets in the U.S. provides support for our approach. The other models overestimate the level of interest rates, sometimes by a

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[16] See Canova (2007, Ch. 3) for a discussion in the macroeconomic context. Our results have been obtained using STATA. To the extent that parameters need to be set, we have chosen the parameters so as to replicate the behavior of the bank rates as closely as possible.

substantial margin (especially column 3). An exception to this is the Butterworth filter (column 6), where the average interest rate is estimated to be around 3%.

Note that while there are some differences across methods, the variation in interest rates resulting from the grain-price based approach is across the board much higher than the variation in bank rates. This high variation is the result of price shocks, both positive and negative, and trends that remain in the data after filtering. One approach to this would be to use more precise information on harvest dates to select a smaller set of periods as storage months. However this approach is not feasible for the Britain-China comparison because precise information on regional harvest dates is not consistently available. Another possibility would be to focus on the years for which the average price gradient is positive; this would likely bias upward the interest rate estimates because we tend to keep years subject to positive shocks while at the same time dropping years with negative shocks. Because it is hard to know the impact of specific assumptions we could make for comparing interest rates in Britain and China, we prefer to rely on the entire distribution of price changes during storage months for our analysis. Our solution to the issue of shocks is to include direct information on climate and other controls to reduce the influence of shocks; we also adopt alternative definitions of storage months. Our eventual focus will not be the level *per se*, but the performance of capital markets as measured by capital market integration after we have controlled for underlying shocks.

Next, we examine the relationship between bank interest rates and grain-price based interest rates in the time series. For each city, we regress the latter on (the log of) the former. Panel B of Table 2 shows the mean t-statistic of this regression as a measure of time series correlation, which is generally positive. The t-statistics are no higher than around 2, which is likely due in part to the relatively short time series (11 to 35 observations). The highest t-statistics are obtained for the Butterworth-filtered series; they range from 1.3 to 3.1, with a mean of 2.2 (column 6). Looking at the standard deviations in parentheses, we see that the

Baxter-King, Christiano-Fitzgerald, and Butterworth methods exhibit lower variation than the unfiltered and moving-average methods of columns 2 and 3.

We also investigate how the models perform in terms of capturing capital market integration, as measured by bilateral correlations in interest rates across cities. For this we focus on the years for which there are bank interest rates for all five cities (1835 to 1855).[18] With the bank interest rates we calculate an average bilateral correlation of 0.25 (n = 10), and a standard deviation of 0.33.

The grain-price based interest rate models tend to overestimate the extent of bilateral correlation, with a mean ranging from about 0.50 to 0.80 (Panel C). The method predicting the lowest mean bilateral interest rate correlation is the Butterworth-filtered series. It also has the highest standard deviation of all five grain-price based methods. The data is characterized by a combination of relatively low mean and relatively high variation, and the Butterworth method comes closest in both dimensions to the data.

Our final criterion is to compare the grain-price based bilateral interest rate correlations with the pattern of the bilateral correlations implied by the bank interest rates. Rather than predicting the mean or the standard deviation, are the grain-price based models able to distinguish regional capital markets that are highly integrated from other regional capital markets that are poorly integrated? On this account, the best methods give correlations between the bilateral bank interest rate correlations and the grain-price based bilateral correlations of 0.72 to 0.75 (Panel C, columns 2, 4, and 6). This suggests that these three models assess differences in capital market integration quite well. While the Baxter-King method comes out on top in this dimension, we nevertheless prefer the Butterworth filter because it performs relatively well in all dimensions that we have examined in Table 2. Given its simplicity and transparency, we will also employ the unfiltered grain price model of column 2.

[18] We have linearly intrapolated the series for Indianapolis and New Orleans to get this.

In the following section we introduce the data on Britain and China that will be employed.

3. Data

The Chinese grain prices are administrative records coming from the Qing grain price recording system, which cover each of the 28 provinces from the reign of Kangxi (1662-1722) to 1911. A key purpose of the Qing price recording system was to inform the government about the regional market prices of grain to avert food crises and unrest. Our sample consists of up to 252 prefectural markets located in 20 provinces, which include all of the 18 proper provinces of China (see Appendix Table A for a list of prefectural markets and provinces).[19] The source reports the price of grain for many different crops across China depending on different changing climatic and soil conditions. We focus on the four grains that had the most wide-spread coverage across China: rice, in two different qualities (first-grade [*shangmi*] and second-grade [*zhongmi*]), wheat (*xiaomai*), and millet (*sumi*). We work with more than 318,000 monthly grain price observations. Wheat is the most prevalent grain in the Chinese data, and accounts for one third of the observations. This is because climatic conditions in a relatively large portion of China are conducive to growing wheat; rice is present mostly in the central and southern provinces, while millet is grown mostly in northern provinces. These climatic conditions reflected in the composition of our sample are summarized in Figure 7.

Chinese grain prices are quoted in *tael* per *shi*, while British prices are quoted in shillings per bushel. An important observation from Table 3 is that the variability of grain prices in China and Britain as measured by the coefficient of variation (equal to the standard deviation divided by the mean) is virtually identical.[20]

[19] Earlier studies employing portions of the Qing grain price data include Wang and Chuan (1959), Chuan and Kraus (1975), Rawski and Li (1992), Shiue (2002), and Shiue and Keller (2007).
[20] For the filtered price series, Table 3 shows that the variation in the British series is higher; this goes back to more high-frequency variation in the British series, see Figures 5 and 6.

The source of the grain prices for Britain is the British government's Corn Returns, which were printed in the *London Gazette* newspaper. It published the price of domestic wheat every week at the town or county level to provide information on price dispersion in food products across Britain. The Corn Returns were created to provide a reference market price of domestically produced wheat that would inform taxation and the regulation of international trade of wheat; this data has been used to examine a variety of questions (Brunt and Cannon 2013).[21] Our sample consists of the average monthly price of wheat for the period 1770 to 1860, in up to 52 counties (see Appendix Table B for a list). These prices are widely considered to be market prices. Our sample for Britain is composed of around 48,000 monthly grain price observations.

The historical data on Chinese weather comes from the State Meteorological Society (1981). The source contains historical weather data in the form of contour maps based on the climate in autumn at 120 weather stations throughout China over the years of analysis. Based on these contour maps and the location of each prefecture we categorize the climate in a given prefecture for a given year as ranging from 1 (a lot of rainfall leading to very wet conditions) to 5 (little rainfall leading to very dry conditions), with 3 being the normal level of rainfall. Reference to a "normal" regional climate implies that the average climate is close to level 3 (with an average of 2.92 for the prefectures in our sample). Figure 8 summarizes this data on climate over time across the Chinese prefectures.

We construct data on the climate in Britain with the precipitation reconstructions from Pauling et al. (2006) according to the definitions of wetness in the Chinese data. There are again five different climate categories, from 1 being very wet/the highest levels of rainfall, to 5 being very dry/the lowest levels of rainfall relative to what is normal in each particular region.[22] As a consequence, the mean (i.e. normal) climate level is, as in the Chinese data, roughly 3 (the exact figure is 3.11). Climatic conditions in Britain have been variable over time, as one would

[21] These authors also provide more details on the Corn Returns.
[22] We use annual rainfall for Britain to avoid introducing a time-varying difference between the British and Chinese weather data given the distinction between lunar and solar months.

expect (see Figure 9). Figures 8 and 9 also show the standard deviation of rainfall in a given year across regions. On average it is higher in China than in Britain, no doubt in part because of China's relatively large size. For a given region in China or Britain, weather variability over the sample period is similar, with a standard deviation of 0.98 in China, versus a standard deviation of 1.16 in Britain.

We encourage the reader to keep in mind at least three types of issues that might affect our comparison of capital market performance. The first set of issues has to do with sample selection bias. We have an unbalanced sample of regions and years, and in order to see whether this leads to a bias we will examine the robustness of our findings based on different samples.[23] Second, because we employ price data to derive interest rates, the specific characteristics of the price data are relevant. We know quite a lot about the influence of price data characteristics from findings on commodity market integration. While we will examine some of the issues, such as spatial aggregation, a full analysis of issues raised in the commodity market integration literature would take us too far afield and interested readers may want to refer to Brunt and Cannon (2014), Shiue and Keller (2007), and other papers that focus on this.[24] In the following we will focus mostly on the third set of issues, those that are specifically related to estimating interest rates from monthly price changes.

We begin by examining some of the characteristics of the data, highlighting in particular features that may potentially bias the results, and which we will want to discuss further in the robustness tests. Consider the behavior of monthly wheat prices in Bedfordshire county during the years 1828 and 1865, as shown in Figure 5, and the monthly grain price in Guilin prefecture (of China's Guangxi province) over the same period, as shown in Figure 6. Both price series exhibit the systematic,

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[23] An alternative approach would be to drop outliers and unrepresentative observations from the analysis. Experimenting with this we have found that it generally leads to similar results.
[24] On temporal aggregation, see Brunt and Cannon (2014), Taylor (2001); on spatial correlation, see Keller and Shiue (2007); on estimation technique, see Jacks (2011), Shiue and Keller (2004, 2007). For a broader review of historical commodity market integration, see Federico (2012).

within-harvest year price movements that are key to our analysis. There are also some differences. First, the British series seems to capture more short-term price movements than the Chinese series, which seems to be more regular and possesses more flat portions. This is indeed a feature of the data. In Britain, more than 99% of one-month changes are non-zero, whereas in China non-zero month-to-month changes are recorded less frequently. The fraction of non-zero month-to-month price changes is given in the last column of Table 3.

This kind of "escalator pricing" is fairly common for historical grain price series (see Shiue and Keller 2007). Since zero price changes tend to imply low levels of interest, we give greater weight to price series that exhibit more high-frequency price changes, effectively assuming that these data are of higher quality. This is another reason for examining market integration to compare capital market performance in China and Britain, instead of interest rates. Earlier work indicates that escalator pricing does not pose a serious problem for studying market integration as long as the year-to-year variation is correctly captured, as is the case in Figure 6.[25]

Second, there are also differences in grain price coverage. For a given region, the British data is nearly complete while Chinese series often have a substantial amount of missing data. The relatively large Chinese sample (up to four grains, 1,080 months, and over 250 prefectures) gives us the means to confirm that systematically missing data is unlikely to drive our results. The analysis for Britain is based on 48,314 monthly grain price observations, all for wheat. Table 3 shows summary statistics on the price data, given as the average price of wheat by year, from 1770 to 1860, for up to 52 counties in each year. The grain price sample for China consists of 318,756 monthly observations, over 252 prefectures (located in 20 provinces).

Third, Figure 7 shows that there are on average more than 170 prefectures in the sample in a given year, with just under 150 from 1770 to 1820, after which the number jumps to around 215 prefectures. The increase in the number of regions is

[25] See Shiue and Keller (2007). A fixed cost of changing prices is a plausible explanation for escalator pricing. The monthly price change is small relative to the fixed costs, not literally equal to zero.

due to the publication of a reprint of these price figures that starts in the year 1820.[26] In Britain, the number of counties in the sample is on average 45. There is information for almost all 52 counties between 1790 and 1820, while during the 1820s the number of counties is only around 35. The change in regional coverage in Britain reflects to some extent changes in the influence of certain groups upon British legislation (see Brunt and Cannon 2013). We will present results for different sub-periods in order to ensure that the findings we report are robust.

Fourth, storage costs may differ by type of grain. In this respect it is useful that we have information on one type of grain in both Britain and China, namely wheat, as well as on three additional grains in China. Perhaps more importantly, storage costs change over time in relationship to climatic conditions. For example, clean and dry grain can be stored for longer periods, whereas very wet conditions are more conducive to mold unless the grain is suitably protected against moisture. We have collected annual information on climatic conditions at the regional level to take into account how weather variations might affect storage costs.

Fifth, because interregional trade and cropping patterns can affect grain price behavior between harvests, the empirical analysis below also employs indicator variables for waterway location and areas where multiple crops can be harvested in a given year.[27] We include, as the most relatively important, the following waterways in the analysis (Watson 1972, Paget-Tomlinson 1993) : the Yangzi and the Pearl river in China, and the Thames, Trent, Severn, and Lea in Britain; among the canals we focus on the Grand Canal in China and the Bridgewater Canal in Britain. We also take account of coastal location; in China separately for the North and the South, as well as in the Yangzi delta. In terms of differences in cropping patterns, the most important factor is that in parts of Southern China, rice can be harvested twice in a given year (Chuan and Kraus 1975, LeClerc 1927). We account for this by including an indicator variable for these regions.

[26] Before 1820 we rely on evidence originally compiled by Wang Yeh-Chien and ourselves (a subset of these data were used in Shiue and Keller 2007, and Wang and Chuan 1959).
[27] Our analysis abstracts from overland transport; on England's turnpikes, see Bogart (2005).

We now turn to the empirical results.

4. Empirical results

4.1 Interest rate calculation

4.1.1 Carry costs of grain

We begin by computing the carry costs of grain, $\hat{p}_{it}$, which is equal to the interest rate plus the storage cost, as given in equation (2). The carry costs are obtained as the average of one-month price changes over months with steep price gradients. The method employed in the U.S. benchmark shown in section 2 is adjusted as follows. First, we use price changes in a month for the carry costs calculation if, on average across all years, the price change for this month exceeds a certain threshold. The threshold is 0.42% per month, or 5% per year, and it is the same for Britain and China.[28] As long as the average for a given month surpasses the threshold, we use data for all years.[29] Five percent per year does not seem restrictive because as we will see below carry costs typically exceed 10% per year in both countries. Months with average price changes above the threshold are assumed to be informative for the carry costs calculation; we make this assumption because complete information on harvest times and storage months is lacking. One might be concerned that the threshold excludes regions with relatively low interest rates; however, below we show that this threshold assumption doesn't crucially matter: qualitatively, our findings remain the same even with a 0% threshold. Furthermore, we give greater weight in the carry costs computation to years, regions, and grains for which high-frequency changes are recorded because these data tend to be of higher quality.[30] We also focus on the central 95% of carry cost

[28]Throughout the paper, we calculate annual rates as 12 times the monthly rate.

[29] Given China's size and differences across grains, for China we compute the month average separately for all prefectures in a given province, as well as separately by grain.

[30] Specifically, the weight is the share of non-zero month-to-month changes in a given year, so that if for one year 10 monthly changes are non-zero and in another only 6, the observations receive weights of 10/12 and 6/12, respectively.

estimates for each grain by discarding values below percentile 2.5 and above percentile 97.5.

Table 4 shows the results. The mean monthly carry cost for British counties using the unfiltered data is about 0.85%, or 10.2% per year. In contrast, across all Chinese regions and based on all grains, the mean is about 13.7% annually. If we assume that equation (4) holds—that broadly defined storage costs in China and Britain were the same once we aggregate across all regions and all years—then British interest rates were substantially lower than China's during this period.

This first set of results yields a number of other interesting findings. First, we see that the carry costs estimates have relatively large standard deviations. This confirms our earlier findings using U.S. data. Without making further assumptions about harvest cycles and the data's time series properties, however, which ultimately cannot be tested, the method limits the testing of sharp hypotheses. In this sense, the grain-price based approach to interest rates is better suited to broadly comparing carry cost levels across regions and trends over time. Second, the difference between the carry cost estimates for different grains in China is small. This is plausible given that storage costs probably do not vary greatly across grains. Third, the result that carry costs in China were higher is not due to differences in the grains that are grown in the two countries, as the results for wheat show in row 4.

In the lower part of Table 4, we show results based on band-pass filtered price series using the Butterworth filter. These carry costs estimates are generally lower than for those based on the unfiltered time series, consistent with the idea that time series filtering succeeds in removing stochastic trends. According to the filtered series, British carry costs average around 8.2% per year while Chinese carry costs are around 9.6%.

We now turn to breaking down the carry costs into interest rates and storage costs.

4.1.2 From carry costs to interest rates

In this section we show results from implementing equations (6) and (7) in our analysis. We conduct a three-stage adjustment to purge the influence of climate, water access and cropping pattern from our carry cost estimates. In the first step, climate is related to differences in rainfall levels, $rain_{it}$, which varies from 1 (high levels of rain) to 5 (low levels of rain). The effect of climate on storage is allowed to differ across broader areas, namely the provinces in China.[31] We perform OLS regressions separately for each larger geographic area of the carry costs of grain, $\hat{p}_{it}^{g}$, on a weather variable which measures the deviation from normal weather to obtain the mean carry cost for each rain level.

The value of $rain_{it}$ that gives the lowest carry cost on average is defined as the best climate in each region *i*, in the sense of lowest storage costs. We adjust the carry costs $\hat{p}_{it}^{g}$, indexed by grain *g,* region *i,* and time *t,* using the difference of the OLS estimates for the best possible and the actual climate in that region and year. We use $\widetilde{\hat{p}_{1\iota t}^{g}}$ to denote these adjusted, counterfactual carry costs. These would have been the average carry costs had the climate always been the best possible for all regions and years.

The influence of inter-regional trade on carry costs is captured by region *i*'s access to water transport, which was the low-cost mode of transport for grain at the time. We capture this by the following regression:

$$(9) \qquad Trade_{it} = \gamma_0 + \gamma_{1p(i)} river_i + \gamma_{2p(i)} canal_i + \gamma_{3p(i)} coast_i + \varepsilon_{2it}^{g}.$$

where the subscript *p(i)* denotes the geographic area to which region *i* belongs.

To eliminate the downward influence of interregional trade on carry costs, we regress $\widetilde{\hat{p}_{\iota t}^{g1}}$ on the variables on the right hand side of equation (9) for each province, where $river_i$, $canal_i$, and $coast_i$ are indicator variables. The climate-and-waterway access adjusted carry costs, $\widetilde{\hat{p}_{2\iota t}^{g}}$, are equal to $\hat{\gamma}_0 + \hat{\varepsilon}_{2it}^{g}$, where $\hat{\gamma}_0$ and $\hat{\varepsilon}_{2it}^{g}$

[31] We assume that British counties all belong to the same larger geographic area.

are the estimated constant and residuals respectively. This is what average carry costs would have been had the climate always been the best possible and the region had no access to waterway transport.

Harvest patterns might matter because rice was typically harvested twice in Fujian, Guangdong, and Guangxi provinces. This is modeled as follows:

$$(10) \quad Cropping_{it}^{g} = \delta_0 + \delta_{1p(i)} double\_cropping_{p(i)} + \varepsilon_{3it}^{g},$$

where $\delta_{1p(i)}$ captures the influence of double-cropping for rice on carry costs. We run an OLS regression of equation (10) using $\widetilde{\hat{p}_{2it}^{g}}$ when g = rice, and then subtract the estimate of $\delta_{1p(i)}$ from $\widetilde{\hat{p}_{2it}^{g}}$ to obtain our third-stage adjusted estimate $\widetilde{\hat{p}_{3it}^{g}}$. For grains other than rice and regions other than Fujian, Guangdong, and Guangxi, there is no further adjustment so that $\widetilde{\hat{p}_{3it}^{g}} = \widetilde{\hat{p}_{2it}^{g}}$.

To summarize, to eliminate the influence of climate-related storage and other costs, interregional trade, and cropping patterns we adjust the carry costs of Table 4 for these influences. The adjusted figures are estimates of what costs would have been under optimal climate conditions, no waterway access, and no double cropping pattern. These costs are our regional interest rate estimates.

The results of this approach are summarized in Table 5. We perform the analysis separately for carry costs based on the unadjusted and band-pass filtered estimates. Starting from the carry costs of Table 4, the estimate for Britain is 10.2% and 13.7% for China (first column, Panel A). In the first step we adjust for the influence of climate differences on our estimates. In line with other evidence, climate has a substantial influence on the carry costs of grain. Carry costs are around five percentage points higher than if the climate had been the best-possible in every year (column 2, Panel A). Because Britain and China are similarly affected, however, adjusting for climate does not change the earlier findings.

In comparison, the influence of interregional trade on carry cost estimates turns out to be much smaller. If no region had waterway access, we estimate that on average, carry cost estimates would only be higher by about 0.07 percentage points in either Britain or China (column 3, Panel A). Finally, we adjust for harvest patterns that allow multiple crops per year (see column 4). It does not have a major effect, in part presumably because it only affects certain regions and grains in China.

The figures summarized in column 4—carry costs adjusted for the influence of climate, inter-regional trade, and harvest patterns—are our main interest rate estimates. The mean for Britain is about 5.3%, while the mean for China is about 9.2%. Britain's interest rates are roughly 40% lower than China's over the sample period 1770 to 1860.

The results for the band pass filtered data series are shown in Panel B of Table 5. It gives a broadly similar picture. In particular, adjusting for climate differences has a larger effect in the interest rate calculation than inter-regional trade and harvest patterns. The average interest rate for Britain based on the filtered price series is about 5.4%, compared to 7.5% for China. Looking at both sets of results, based on unfiltered and filtered data, Britain had interest rate levels that were about one third lower than those in China.

The final column of Table 5 shows how these conclusions are affected by our assumption on storage months (those with typical grain price increases of 5% per year or more). If instead we assume that storage months are those with *any* price increase in a typical month (0% or more), average interest rates tend to be lower (see column 5, Panel B). This is the consequence of including observations with rather flat price gradients in the calculation, and one might be concerned if the estimation strategy correctly identifies times in which storage took place. However, even expanding the criterion to include implied annual interest rates of 0%, Britain's interest rate is still estimated to be 15% to 20% lower than China's (column 5). This shows that while the assumptions of our approach affect specific estimates, they do not change the finding that Britain had considerably lower interest rates than China in the 18th and early 19th centuries.

We are also interested in changes in the two countries' capital markets over time. The smoothed interest rates between 1770 and 1860 are shown in Figure 10. Interest rates range between 7.5% and 9.8% in China, while for Britain the range is somewhat smaller, between 4.8% and 5.6%. While we do not see major turning points in the British rates, China experienced a period of declining rates from about 1795 until 1835.

We now turn to our analysis of capital market development performance in terms of market integration.

4.2 The integration of capital markets

Main findings

In this section we compare the capital market performance in Britain and China in terms of bilateral correlations between regional interest rates over time. A high level of correlation indicates that the forces that integrate capital markets in the two regions are relatively strong.[32] Furthermore, because early capital market participants typically had to meet in person to trade, given some cost of moving in geographic space, bilateral correlations will tend to fall with distance.

We have computed the bilateral interest rate correlation for each pair of regions in a given country from our interest rates (Table 5, column 4) over all years 1770 to 1860, where the correlation is computed as the coefficient in an OLS regression. We begin by summarizing the degree of capital market integration in the two countries in Figure 11. There are six distance bins in steps of one hundred kilometers, from 0-100 kilometers to 500-600 kilometers.[34] For each country and each of the six distance bins, Figure 11 shows the mean correlation for interest rates based on both filtered and unfiltered price series, with more details given in Table 6.

It is clear from the figure that the integration of British capital markets was considerably higher than that of China's capital markets. Looking at correlations

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[32] Instead of bilateral correlations, more sophisticated time series techniques can be employed to study market integration (see, e.g., Shiue and Keller 2004, Mitchener and Ohnuki 2007). Doing so here does not change our main findings.

[34] The maximum distance between any two British counties in our sample is 638 kilometers.

based on unfiltered interest rates, for distances below 100 kilometers, mean correlations are up to 0.8 in Britain while in China they are less than 0.6. Even more striking is the difference in the decline of capital market integration with geographic distance. While in China the correlation falls from just under 0.6 to around 0.1 as distance increases, in Britain the correlation falls only from 0.8 to 0.7 with the same increase in distance.

Correlations for filtered interest rates are generally somewhat lower, in line with earlier findings that suggest that the filtering removes some (common) shocks. The comparison of results for Britain and China based on the filtered interest rates yields very similar patterns as with the unfiltered series. At short distances, interest rate correlations in Britain are substantially higher than in China: 0.7 compared to 0.4, respectively. Furthermore, the evidence that capital markets were integrated in a larger geographic region is much stronger for Britain than for China. Based on the filtered series, interest rate correlations at distances between 500 and 600 kilometers in Britain were typically above 0.6 while in China they were typically below 0.1.

The following two tables give a more complete picture by separating out individual grains and reporting the number of observations as well as the standard deviation (Table 6 [unfiltered] and 7 [filtered series]). We see that irrespective of which grain price the interest rate is derived from, correlations fall with distance, which is reassuring. Furthermore, the results are not very different across grains. For example, Table 7 reports correlations for the 300-400 kilometer distance bin ranging from 0.12 (millet) to 0.17 (second-grade rice). The highest average interest rate correlation we see in China is 0.65, obtained for first-grade rice at distances below 100 kilometers (Table 6). This type of rice is more prevalent in the traditionally more urban and commercialized central-southern areas of China, which might also help to explain this relatively high level of capital market integration.

There is a substantial amount of variation in interest rate correlations at a given distance, as the standard deviations reported in Tables 6 and 7 show. This parallels our analysis on interest rate levels, both in the U.S. (section 2.2) as well as in Britain and China (section 4.1). While it is possible to observe comparable levels of capital market integration in Britain and China, the typical level, as measured by the average correlation, is always lower in China than in Britain as a cell-by-cell comparison in Tables 6 and 7 shows.

There may be no better way of comparing capital market integration in Britain and China than by visually examining the entire distributions of bilateral interest rate correlations. In Figure 12 we show those distributions plotted against bilateral geographic distance based on the filtered interest rates. The circles are bilateral interest rate correlations in Britain, while the crosses are observations for China. The British circles fill up the upper part of the figure, indicating high levels of capital market integration for a given distance. The figure also shows the smoothed mean correlation for China (dashed line). The observations for Britain are positioned almost entirely above the dashed line for China. The evidence in Figure 12 strongly supports the hypothesis that the degree of integration in British capital markets exceeded the integration in Chinese capital markets over 1770-1860.

Robustness of capital market integration findings

Broad versus narrow interest rate measure

Recall that interest rates are estimated to be lower if we were to include the less steep parts of the price curve over the harvest cycle (Table 5, column 5). It is important to see the influence of this for our comparison of capital market integration. Figure A shows results on bilateral correlations based on filtered grain prices, where the solid lines are for our preferred interest rates while the dashed lines are for the broader interest rates. Generally, the broader interest rates imply a relatively low degree of capital market integration. For China, the difference between the preferred and the broader definition is increasing in distance. The results suggest that the broader price gradient criterion makes the broader interest rate a relatively noisy measure. At the same time, irrespective of whether we adopt the preferred or the broader criterion, we find evidence that the integration of capital markets in Britain was higher than in China at this time.

Region size and the role of spatial aggregation

Chinese prefectures are on average roughly twice as large as British counties. To see the implications of this for our study of capital market performance, we have paired up the 52 British counties into 26 regions of roughly similar size. Taking the same steps as before for these larger British regions, we compare bilateral interest rate correlations resulting from this set of 26 regions with the results from before based on the 52 counties. In Table C, the latter are denoted by "Baseline" (left two columns) while the former are denoted by "Aggregated".

We see that for both interest rates based on the filtered and on the unfiltered data series, aggregation increases somewhat the correlations. Furthermore, it does so for all geographic distance categories. This implies that our findings are not driven by the relatively small size of the regions in Britain. If anything, the difference in average region size appears to have put Britain at a disadvantage relative to China. Our analysis of the effects of spatial aggregation confirms that Britain's capital markets performed better than China's at this time.

Sample composition before and after the year 1820

We have noted above that the overall sample period is characterized by changes in the number of regions for both Britain and China. Such changes might affect our comparison of capital market performance. To see whether there is evidence for this we have conducted the analysis of capital market integration for the period before and after 1820 separately. Results are shown in Table D.

Even though the change in the number of region pairs from one period to the other is at times substantial, we do not see evidence that this systematically affects the results for Britain. For China, there is some evidence for lower levels of integration after the year 1820 for short distances. , This finding, however, is to some extent reversed at higher distances. Overall, we do not find evidence that changes in the sample composition in Britain or China have a major impact on our results.

Capital market integration and time series length

A related concern is that we calculate the bilateral correlations for interest rates that are based on different numbers of annual observations. For some pairs we have interest rates over the entire sample period 1770 to 1860, while for others only for a subset of years. Because the degree of bilateral correlation might be affected by the time series length, if there were differences between China and Britain this could affect our main findings. We analyze this issue by contrasting the results when using all region pairs with results for pairs with information on between 50 and 70 years.

The results in Table E show that the time series length has some effects on the estimates of capital market integration. In particular, when focus on pairs with data for 50 to 70 years, the average interest rate correlations for China increase. For example, at distances between 200 and 300 kilometers, the mean correlation increases from 0.25 to 0.36. Based on these figures, China's capital market integration appears to have been not far behind Britain's at distances below 100 kilometers (mean correlation of 0.61 versus 0.68, respectively). At distances above 300 kilometers, however, interest rate correlations between British regions are typically still at least twice as high as those in China.

The previous checks suggest that while the on average shorter time series length may have put China at a disadvantage, the larger region size has tended to favor China in our analysis. Overall, we are unable to find evidence that would overturn the finding of a British lead in capital market performance over China.

We now turn to the implications of our findings for the Great Divergence.

4.3 Capital markets and the Great Divergence

While our result that Britain was ahead of China in terms of capital market integration seems to be clear, for this to matter for the question of why Britain and Western Europe as a whole pulled ahead of China, a number of issues remain to be discussed. The first is China's size compared to Britain's, and the regional heterogeneity that comes with China's size. To be specific, we do not want to make the mistake of comparing some relatively underdeveloped region in China's southwestern Yunnan province with Lancashire, where the world's first factory-based textile industry emerged.

In order to examine the influence of regional differences we have computed bilateral interest rate correlations separately for the prefectures of China's relatively highly developed Yangzi Delta.[35] This area is well known to be one of China's most advanced areas (Pomeranz 2000, Li and van Zanden 2013). Furthermore, research has shown that China's Yangzi Delta had levels of commodity market integration that were, while lower, not totally unlike the levels of commodity market integration that prevailed in England. The mean grain price correlation at distances below 150 kilometers in the Yangzi Delta was 0.83, compared to 0.87 in England, while for distances of 150 to 300 kilometers the Yangzi Delta figure was 0.81 while England's mean correlation was 0.77.[36]

In the light of this we are interested in two questions. First, does our analysis of capital market integration bear out the generally prevailing view that the Yangzi Delta is a relatively highly developed area of China, compared to other parts of China? Second, how does capital market integration in the Yangzi Delta compare with that in Britain? As a corollary, the answer to the second question tells us whether Britain's advantage over China in terms of capital market integration was comparable to its advantage in terms of commodity market integration. Results are shown in Table 8.

We begin with the last row in this table. Based on all grains, the average bilateral interest rate correlation of China outside of the Yangzi Delta at distances below 100 kilometers was 0.42 (last row), while it was 0.47 inside of the Yangzi

[35] The seven prefectures in our data set are marked in Table A of the Appendix.
[36] Shiue and Keller (2004, Table 2a); figures are for years 1770 to 1794.

Delta (third row). Typical interest rate correlations in the Delta were also higher than outside of the Delta at higher distances, by varying amounts. This shows that our analysis of capital market integration is in line with other evidence that the Yangzi Delta was relatively developed compared to other parts of China.

Although the sample size shrinks, we may want to focus on interest rates based exclusively on rice prices, both because rice was the Yangzi Delta's most important grain and because it might be that rice price quotations are more reliable than those for other grains. Bilateral correlations with rice-based interest rates show figures of around 0.6 for distances below 200 kilometers (row 2). It is interesting to note that a correlation of 0.6 is similar to the values for Britain, which range from 0.59 to 0.62 (row 1). Beyond 200 kilometers, however, correlations in Britain are almost twice as high as in the Yangzi Delta (0.55 versus 0.30). This shows that while the Yangzi Delta's capital market integration over short distances was high by most standards, medium and longer-distance market integration was still to come.[37]

These results show that capital market integration in Britain exceeded that of even the most developed areas of China. Further, Britain's advantage over China in terms of capital market performance was higher than in the area of commodity market integration.

Timing of capital market performance differences

Another important question is whether our findings hold already for the late 18th century, or only for the entire sample period of 1770 to 1860. The concerns to which this speaks are simultaneity and reverse causation. If capital market development is an outcome of industrialization, it should not come as a surprise that Britain was ahead of China in the 19th century, because after all, Britain industrialized first. It would still be impossible to establish a causal effect from capital market development on modern economic growth using only data for the

[37] The analysis of spatial interaction in 18th China by Keller and Shiue (2007) shows that larger geographic distance is an important margin of increases in market integration.

19th century if capital market development and the take-off into modern economic growth went hand in hand.

While this paper does not establish a causal link between capital market development and industrialization, we can shed some light on this issue by focusing on the 18th century. In particular, we consider the period 1770 to 1794, for which it has been shown earlier that China and England were not too far apart in their levels of commodity market integration (Shiue and Keller 2007). In contrast, our evidence on capital market integration indicates that by the late 18th century, Britain was already well ahead of China. Figure 13 shows the entire distributions of bilateral interest rate correlations in China and Britain for the years 1770 to 1794. Figure 13 can be compared with Figure 12, which shows the correlations for the entire sample period of 1770 to 1860. While the advantage of Britain grew somewhat over time, the most striking finding from comparing Figures 12 and 13 is how large Britain's advantage over China already was by the late 18th century. If we were to follow convention and use 1770 as the start date of British industrialization, the findings are consistent with capital market development being an important factor in explaining why Britain industrialized first. Britain had a lead in capital market efficiency not only in comparison to China, but also at a date well before the onset of its own technological change.

We can also use our analysis to date the emergence of the divergence in capital market performance between Britain and China. To do so we calculate the *change* in interest rate correlations during the sample period 1770-1860 in either country, and then extrapolate this trend out-of-sample to see at which time bilateral interest rate correlations in Britain and China were roughly equal to each other. Figure 14 shows the picture that emerges.

On the right side of the figure we have both the levels and the trends that were found in our analysis of capital market integration. The upper line is for Britain, the lower for China. Going backwards in time, our sample period ends in the year 1770. Backcasting the trends in capital market performance for China and Britain to times before 1770, we estimate that capital market performance in the two countries was the same around the year 1690. While clearly there is a good amount of uncertainty surrounding this date, the year 1690 emerges as our best estimate; alternative estimates range from the year 1630 on the early side, to 1720 on the late side. Summing up, we estimate that the great divergence in capital market performance between China and Britain began in the late 17th century.

We now turn to some concluding remarks.

5. Conclusions

We find evidence that Britain's capital market performed considerably better than China's over the period from 1770 to 1860. First, we estimated interest rates for Britain and China using grain price data from each country after showing that the grain-price based approach captures some of the major features in early capital markets in U.S. data. We find annual interest rates in Britain of about 5.4% on average, while China's were more than one third higher (about 7.5%). These estimates net out the potential influence of storage costs and interregional trade by waterway. Without netting out storage costs our estimates would be about 40% higher.

Using these estimated interest rates, we find that the regional integration of British capital markets was far greater than the regional integration of Chinese capital markets. The Yangzi Delta, a relatively developed region in China, shows higher capital market integration than other areas in China, and comes close to the British average at distances below 200 kilometers. However, at larger distances the interest rate correlations in Britain are twice those in the Delta, and three or more times higher than elsewhere in China. Although Britain increased its advantage over China during the period of 1770 to 1860, already by the end of the 18th century there was a substantial gap in capital market integration between the two countries. Overall, the results in this paper show that Britain had a lead in capital market development not only in comparison to most areas of China, but also at a date well before the onset of technological change in Britain (ca. 1770). This suggests that capital market development might be an important factor in explaining the Great Divergence.

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Table 1. United States Regional Interest Rates, 1815 – 1859

Year	New York City	Philadelphia	Richmond	New Orleans	Indianapolis
1815		4.62			
1816		5.70			
1817		3.69			
1818		5.55			
1819		3.84			
1820		5.60			
1821		4.78			
1822		5.65	4.08		
1823		3.42	3.81		
1824		5.21	4.14		
1825		4.24	4.61		
1826		5.86	3.97		
1827		4.95	4.97		
1828		5.82	3.97		
1829		4.58	4.23		
1830		4.97	4.45		
1831		5.15	4.84		
1832		4.48	6.28		
1833	5.03	6.54	8.02		
1834	5.69	3.41	3.75	6.82	
1835	5.11	6.12	4.43	7.54	7.97
1836	6.82	5.74	7.22	7.16	7.60
1837	5.91	4.75	5.70	11.28	8.50
1838	5.33	5.47	4.41	7.68	8.35
1839	4.24	3.44	6.78	10.15	
1840	5.57	5.73	5.43	9.01	
1841	5.27	4.41	4.21	8.86	7.65
1842	3.95	2.50	4.20	8.85	5.05
1843	5.37	3.72	4.12		2.85
1844	5.80	5.18	4.15		5.74
1845	5.21	4.20	5.10		7.86
1846	4.69	6.39	3.95		
1847	5.04	5.21	4.99		6.32
1848	5.32	4.83	4.43	7.73	8.36
1849	7.17	6.35	4.19	4.84	7.77
1850	5.62	6.47	4.53	7.42	9.45
1851	6.32	4.69	4.72	7.79	5.95
1852	7.23	5.56	5.53	7.91	6.81
1853	4.99	5.10	4.46	7.38	6.37
1854	4.98	5.31	5.04	8.50	7.70
1855	5.87	5.70	5.18	12.81	10.89
1856	6.09	4.45	4.29		9.25
1857	5.45	3.16	3.88		
1858	4.95	6.46	2.92		
1859	4.62	4.32	5.96		

Source: Bodenhorn and Rokoff (1992)

Table 2. Calibration

	Observed	Asset-pricing grain storage model				
		Unfiltered	Moving Average	Baxter-King	Christiano-Fitzgerald	Butterworth
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Interest rate levels						
Mean	0.058	0.074	0.269	0.197	0.127	0.029
	(0.018)	(0.507)	(1.802)	(1.113)	(0.337)	(0.241)
Panel B: Interest rates over time						
T-statistic of regression on observed interest rate						
Mean		1.63	1.05	1.98	1.91	2.17
		(1.40)	(1.52)	(0.65)	(0.46)	(0.57)
Panel C: Capital market integration						
Bilateral interest rate correlations						
Mean	0.25	0.73	0.80	0.72	0.54	0.46
	(0.33)	(0.16)	(0.09)	(0.15)	(0.28)	(0.30)
Correlation w/ column (1)		0.72	0.61	0.75	0.69	0.72

Notes: Observed are interest rates from Bodenhorn and Rokoff (1992); all other are based on grain price changes, computed as the average of log month-to-month changes from August to December. Unfiltered: no adjustment to grain prices; Moving average (MA) using 2 lags, the month itself, and 2 leads; Baxter-King (BK) filters below 4 months, above 12 months, moving average of order 10; Cristiano-Fitzgerald (CF) filters below 3 months, above 12 months; Butterworth (BW) filters below 3 months (order 8), and above 12 months (order 2). Standard deviation in parentheses.

Table 3. Summary statistics for grain prices

	n	Mean	Std. Dev.	Coeff. Var.	One-month Δ non-zero Mean
Britain					
Wheat	48,314	7.732	2.696	0.349	0.994
Bandpass filtered					
Wheat	48,314	1.001	0.049	0.048	0.994
China					
Wheat	107,069	1.466	0.521	0.355	0.344
Millet	52,947	1.601	0.558	0.348	0.456
Rice 1st quality	74,282	1.798	0.603	0.336	0.517
Rice 2nd quality	84,458	1.694	0.572	0.338	0.464
Bandpass filtered					
Wheat	107,069	1.000	0.020	0.020	0.344
Millet	52,947	1.000	0.022	0.022	0.456
Rice 1st quality	74,231	1.000	0.018	0.018	0.517
Rice 2nd quality	84,374	1.000	0.020	0.020	0.464

Notes: Source of data, see text.

Table 4. Carry costs of grain, 1770 to 1860

			Monthly rate		Annualized
		n	Mean (%)	Std. dev.	(%)
Britain	Wheat	4,074	0.854	2.577	10.248
China	All grains	15,152	1.144	2.446	13.732
Britain	Wheat	4,074	0.854	2.577	10.248
China	Wheat	4,930	1.124	2.577	13.488
China	Millet	3,973	1.020	2.598	12.242
	Rice 1st quality	5,135	1.071	1.978	12.854
	Rice 2nd quality	5,384	1.074	2.133	12.883
Band-pass filtered					
Britain	Wheat	4,102	0.684	2.239	8.209
China	All grains	13,403	0.801	2.172	9.612
Britain	Wheat	4,102	0.684	2.239	8.209
China	Wheat	4,221	0.774	1.886	9.284
China	Millet	3,314	0.684	2.000	8.210
	Rice 1st quality	4,366	0.761	2.048	9.131
	Rice 2nd quality	4,794	0.781	2.054	9.376

Table 5. From carry costs to interest rates: the role of storage, trade, and harvest patterns

		Carry costs			Interest rate	Interest rate broad
Adjustments			Climate	Climate & Waterway	Climate & Waterway & Harvest Patterns	Climate & Waterway & Harvest Patterns
		(1)	(2)	(3)	(4)	(5)
Panel A. Unfiltered data						
Britain	Mean in %	10.248 (30.924)	5.271 (30.804)	5.348 (30.795)	5.348 (30.795)	5.348 (30.795)
	n	4,074	4,074	4,074	4,074	4,074
China	Mean in %	13.732 (29.350)	9.374 (29.040)	9.440 (29.088)	9.200 (29.077)	6.258 (24.544)
	n	15,152	15,152	15,152	15,152	18,586
Panel B. Bandpass-filtered data						
Britain	Mean in %	8.209 (26.868)	4.891 (26.808)	5.415 (26.772)	5.415 (26.772)	3.204 (15.684)
	n	4,102	4,102	4,102	4,102	4,115
China	Mean in %	9.612 (26.064)	7.616 (25.800)	7.482 (25.934)	7.501 (25.814)	4.023 (15.946)
	n	13,403	13,403	13,403	13,403	19,736

Notes: Standard deviation in parentheses

Table 6. Bilateral interest rate correlations and geographic distance I
Based on unfiltered price data

	Britain	China			
	Wheat	Wheat	Rice 1st quality	Rice 2nd quality	Millet
0-100km	0.80 (0.16) [n = 350]	0.53 (0.38) [n = 186]	0.65 (1.18) [n=196]	0.56 (0.62) [n=202]	0.54 (0.36) [n=152]
100-200km	0.77 (0.16) [n = 788]	0.41 (0.55) [n = 566]	0.45 (1.37) [n=602]	0.40 (0.69) [n=628]	0.44 (0.38) [n=484]
200-300km	0.74 (0.17) [n = 720]	0.30 (0.43) [n=730]	0.39 (1.43) [n=758]	0.36 (0.72) [n=840]	0.35 (0.45) [n=616]
300-400km	0.73 (0.18) [n = 476]	0.21 (0.39) [n=786]	0.20 (0.80) [n=802]	0.22 (1.01) [n=902]	0.25 (0.43) [n=684]
400-500km	0.70 (0.18) [n = 246]	0.11 (0.49) [n = 886]	0.20 (2.07) [n=908]	0.14 (0.88) [n=1,108]	0.17 (0.38) [n=568]
500-600km	0.70 (0.19) [n = 64]	0.07 (0.48) [n=1,002]	0.11 (2.04) [n=1,018]	0.11 (1.22) (n=1,184)	0.12 (0.27) [n=548]

Notes: Entries are average correlations over period 1770 to 1860. Interest rates as underlying Table 5, Panel A, column 4. Standard deviations in parentheses.

Table 7. Bilateral interest rate correlations and geographic distance II
Based on filtered price data

	Britain	China			
	Wheat	Wheat	Rice 1st quality	Rice 2nd quality	Millet
0-100km	0.71 (0.17) [n = 350]	0.35 (0.28) [n = 138]	0.44 (0.50) [n=166]	0.51 (0.46) [n=158]	0.29 (0.34) [n=134]
100-200km	0.68 (0.18) [n = 788]	0.26 (0.30) [n = 424]	0.34 (0.56) [n=500]	0.35 (0.54) [n=494]	0.24 (0.35) [n=390]
200-300km	0.66 (0.17) [n = 720]	0.21 (0.33) [n=556]	0.23 (0.62) [n=620]	0.25 (0.58) [n=612]	0.16 (0.35) [n=482]
300-400km	0.65 (0.16) [n = 476]	0.13 (0.31) [n=560]	0.16 (0.73) [n=628]	0.17 (0.56) [n=660]	0.12 (0.34) [n=514]
400-500km	0.63 (0.19) [n = 246]	0.10 (0.34) [n = 630]	0.15 (0.78) [n=658]	0.10 (0.55) [n=804]	0.07 (0.33) [n=398]
500-600km	0.62 (0.23) [n = 64]	0.07 (0.34) [n=706]	0.07 (0.75) [n=682]	0.08 (0.62) (n=802)	0.03 (0.29) [n=374]

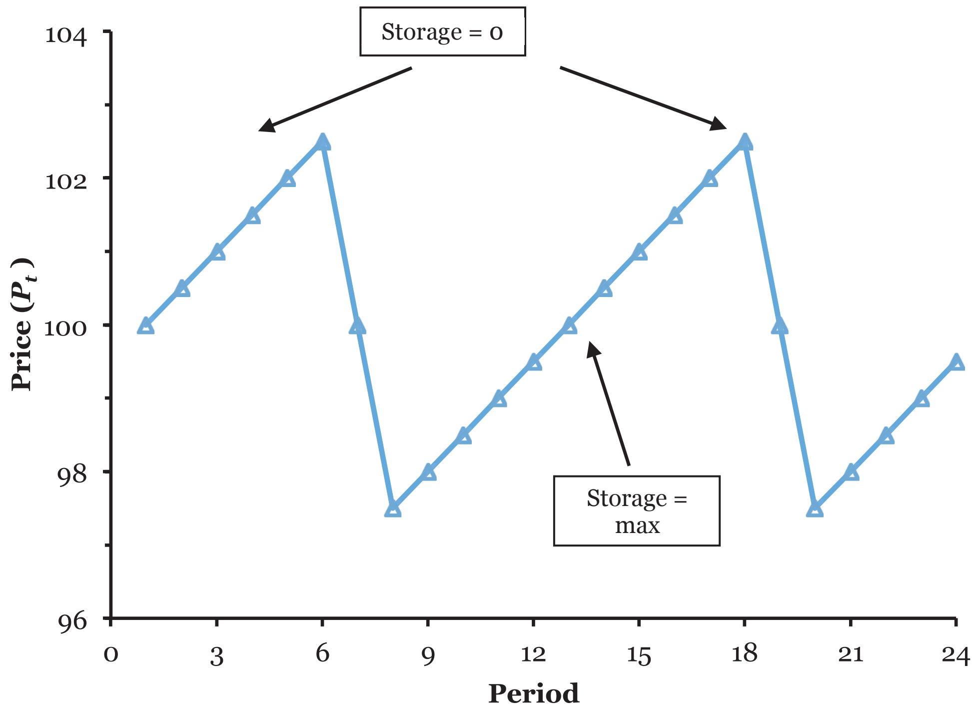
Notes: Entries are average correlations over period 1770 to 1860. Interest rates as underlying Table 5, Panel A, column 4. Standard deviations in parentheses.

Table 8. Interest Rate Correlations: Inside the Yangzi Delta and beyond

		Distance		
		0-100km	100-200km	200-300km
Britain	Mean	0.621	0.592	0.552
	n	350	788	720
Yangzi Delta Rice	Mean	0.598	0.618	0.300
	n	36	28	20
Yangzi Delta All Grains	Mean	0.468	0.242	0.115
	n	66	68	36
China outside Yangzi Delta,	Mean	0.416	0.238	0.086
All Grains	n	704	2,364	3,194

Notes: Interest rates based on time-series filtered data (Table 5, Panel B, column 5). Yangzi Delta are bilateral correlations between nine particular prefectures located in Zhejiang and Jiangsu province, see the appendix. Rice is first-grade and second-grade rice. All Grains is rice plus wheat.

Figure 1. Price behavior in a model with storage

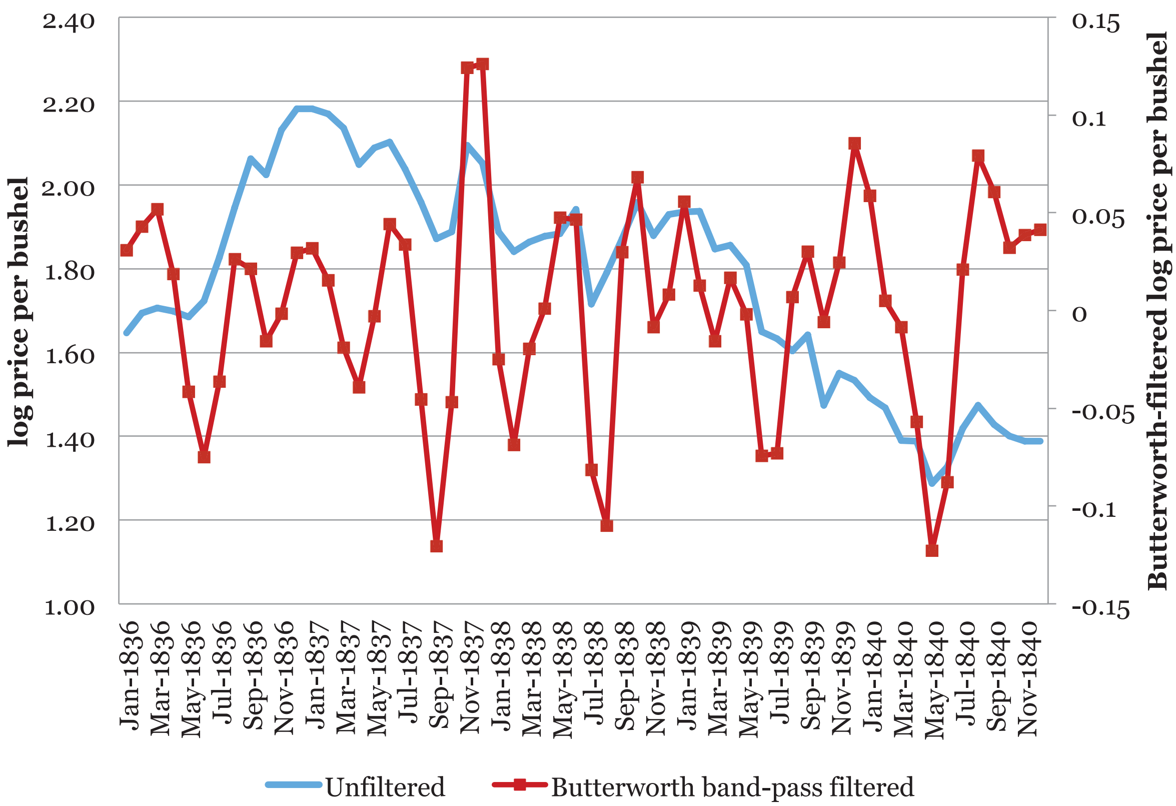


Source: Based on Williams and Wright (1991).

Figure 2. Philadelphia Wheat Price, 1836 to 1840

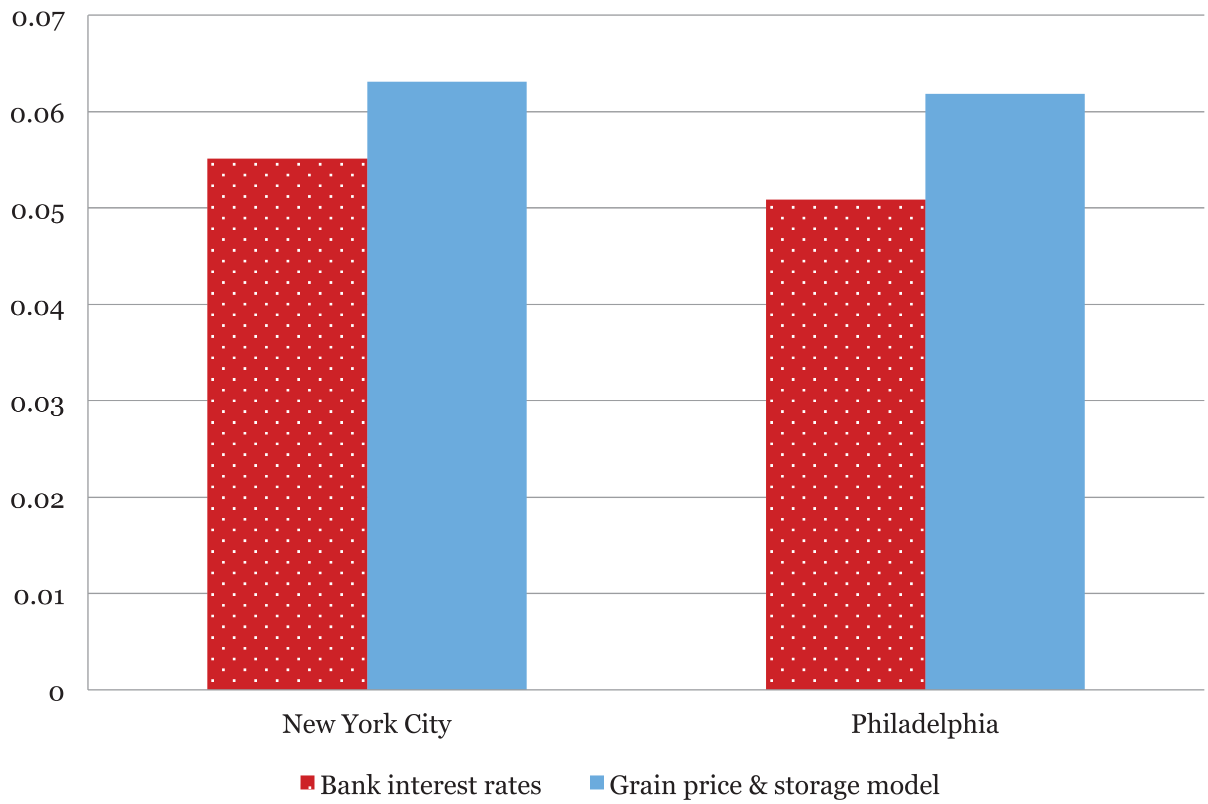
Source: Jacks (2006).

Figure 3. Filtered versus unfiltered Philadelphia wheat prices, 1836-40



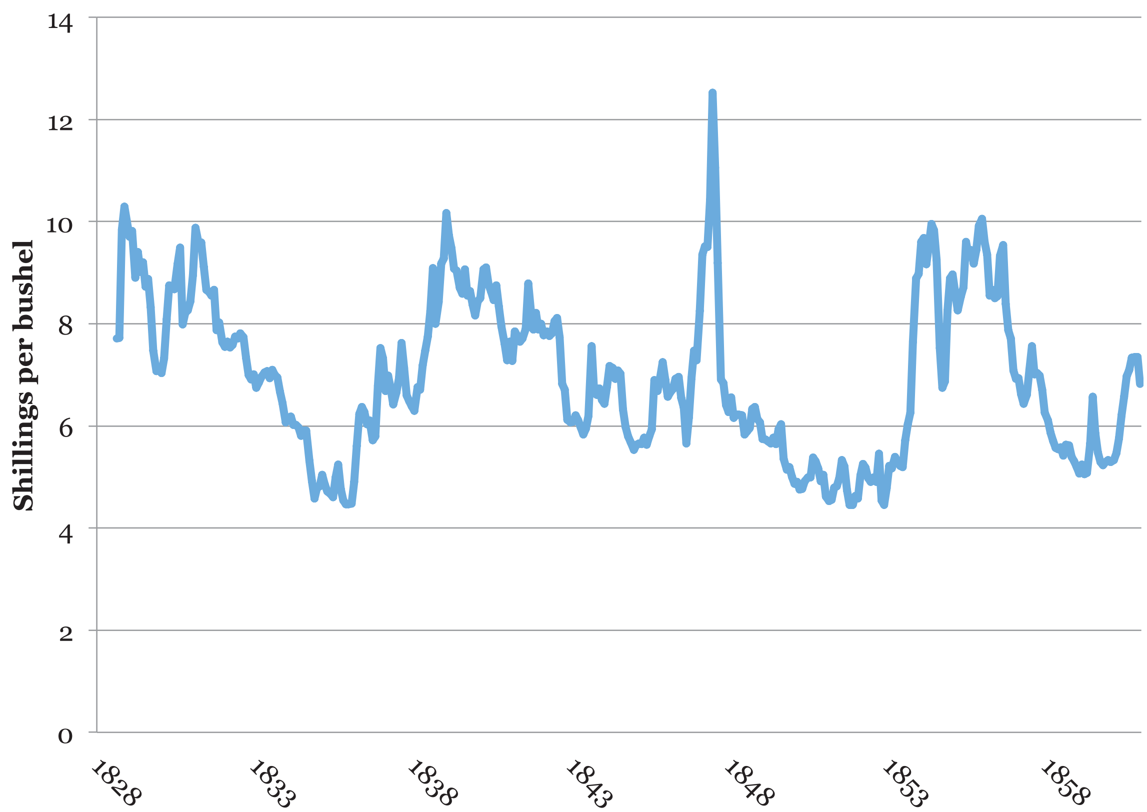
Source: Jacks (2006) and own calculations

Figure 4. Interest rate estimates in 19th Century United States
Average per year, 1835 to 1855



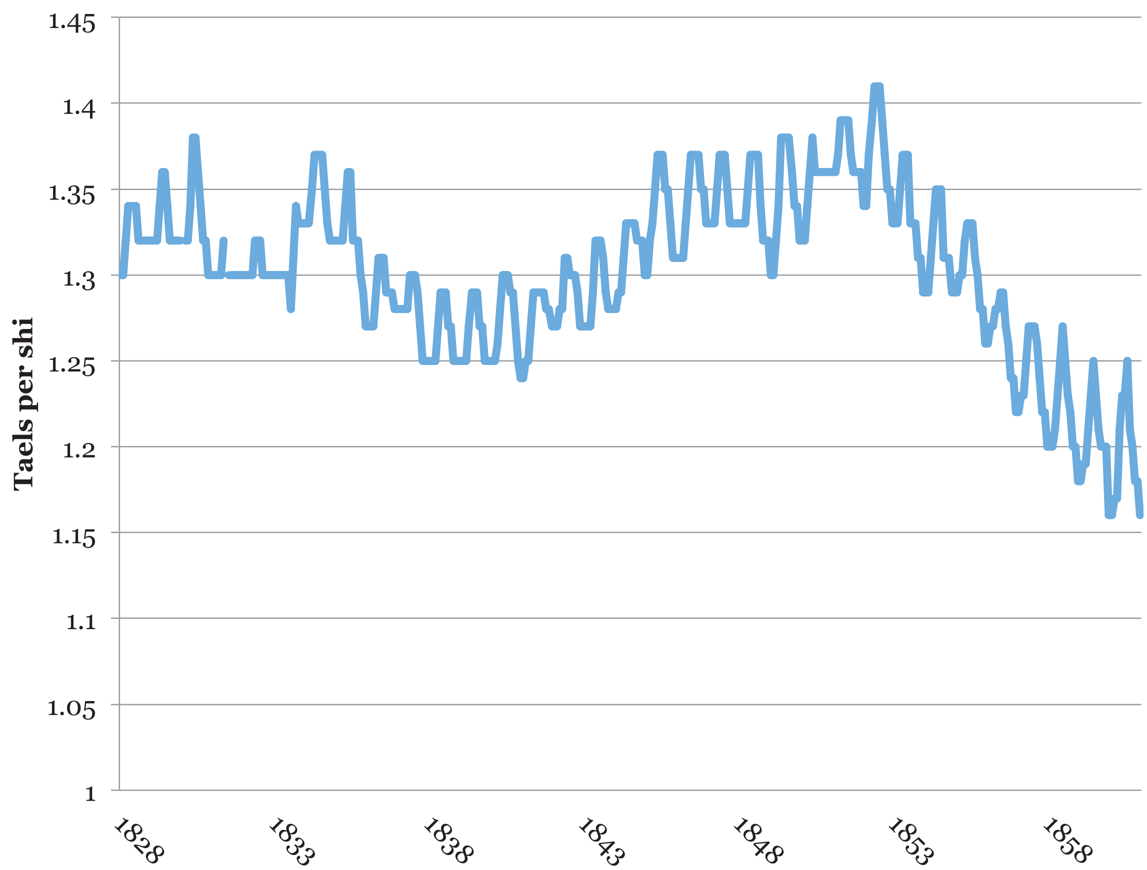
Source: Own calculations (Table 2), and Bodenhorn and Rokoff (1992).

Figure 5. Monthly wheat price in Bedfordshire county, 1828 – 1860



Source: Data from the *London Gazette*.

Figure 6. Monthly price of first-grade rice, Guilin prefecture, 1828 - 1860



Source: Chinese Academy of Social Sciences (2009)

Figure 7. Sample size in terms of numbers of regions

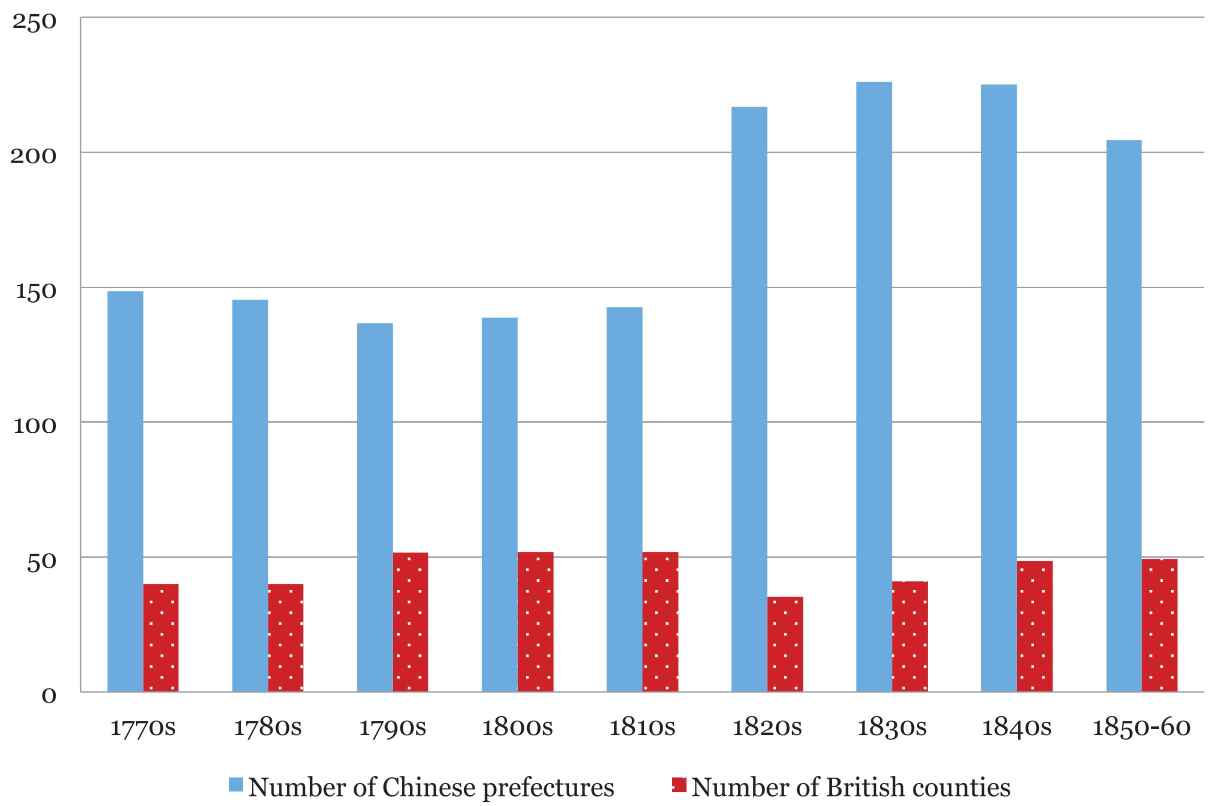
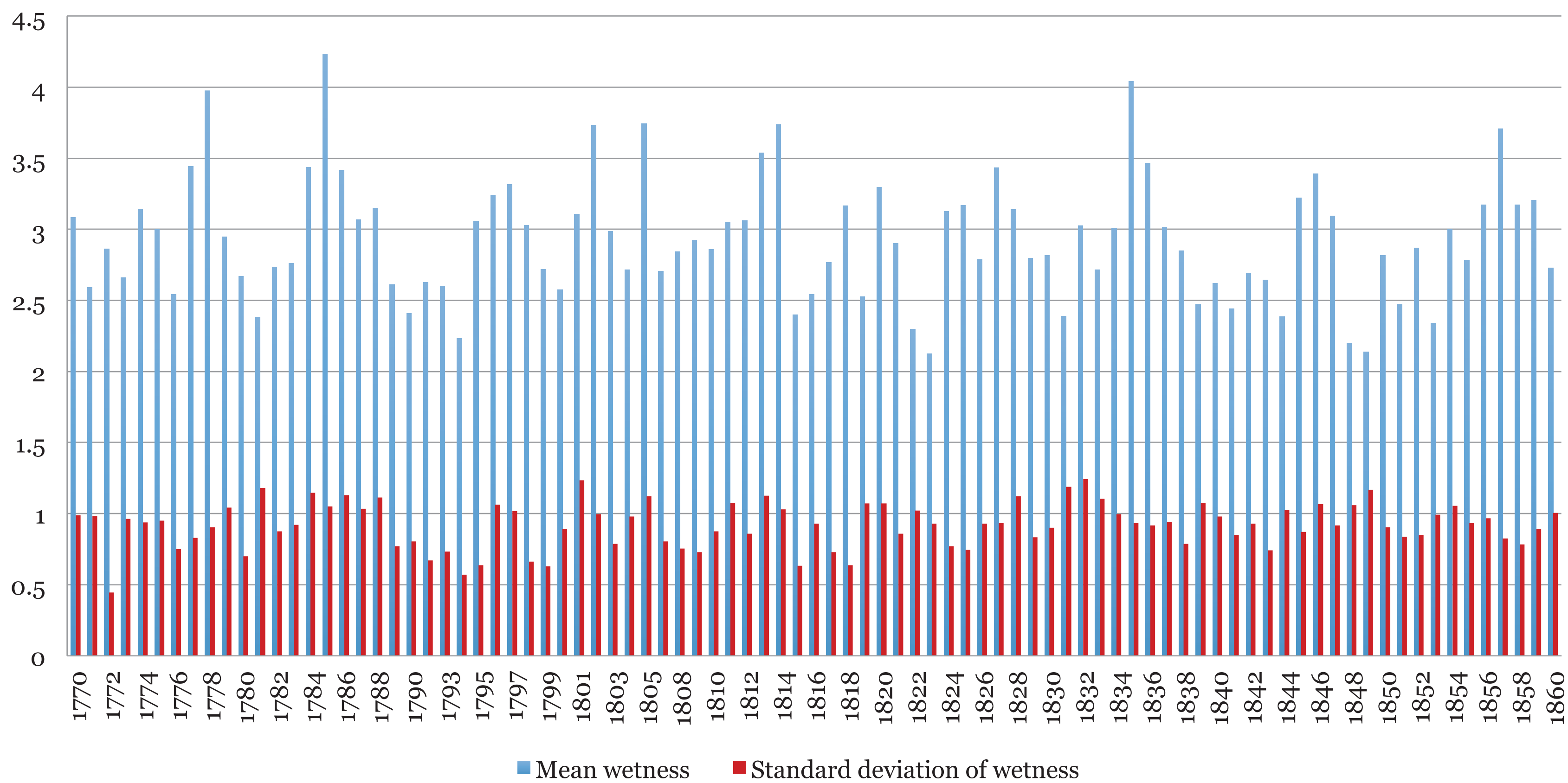
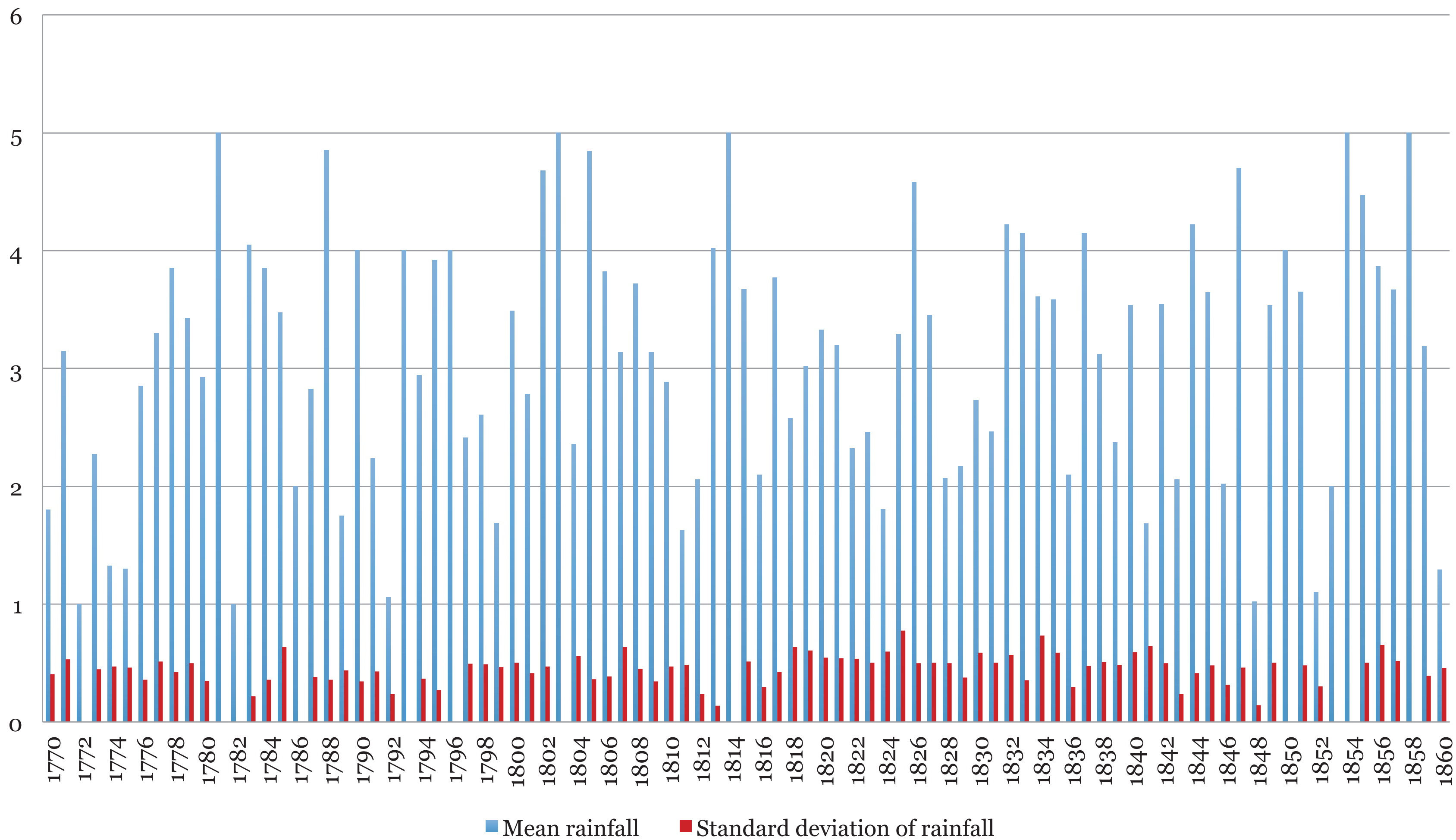


Figure 8. Climate in China: Annual wetness, 1770 - 1860



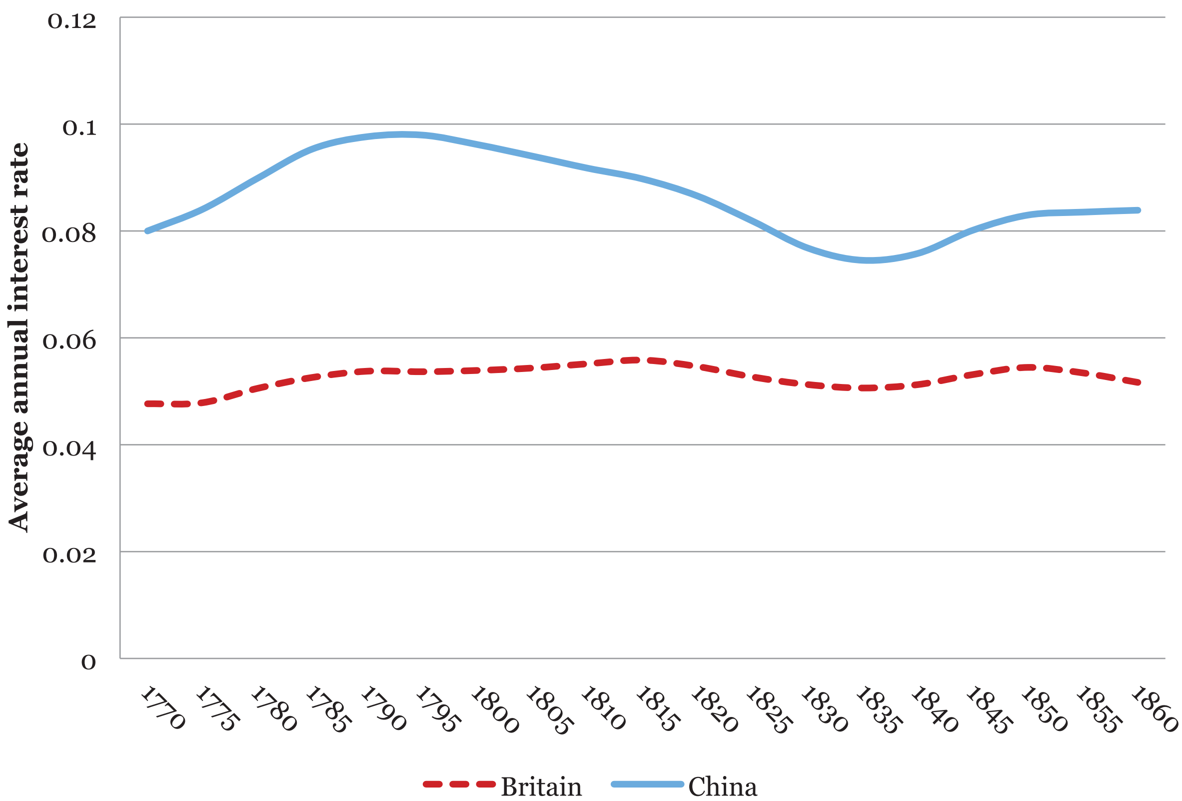
Source: State Meteorological Society (1981)

Figure 9. Climate in Britain: Annual rainfall, 1770 to 1860



Source: Pauling, Luterbacher, Casty, and Wanner (2006)

Figure 10. Interest rates over time, 1770 to 1860



Source: Own calculations (Table 5, Panel B, column 4)

Figure 11. Capital market integration in Britain and China, 1770 - 1860

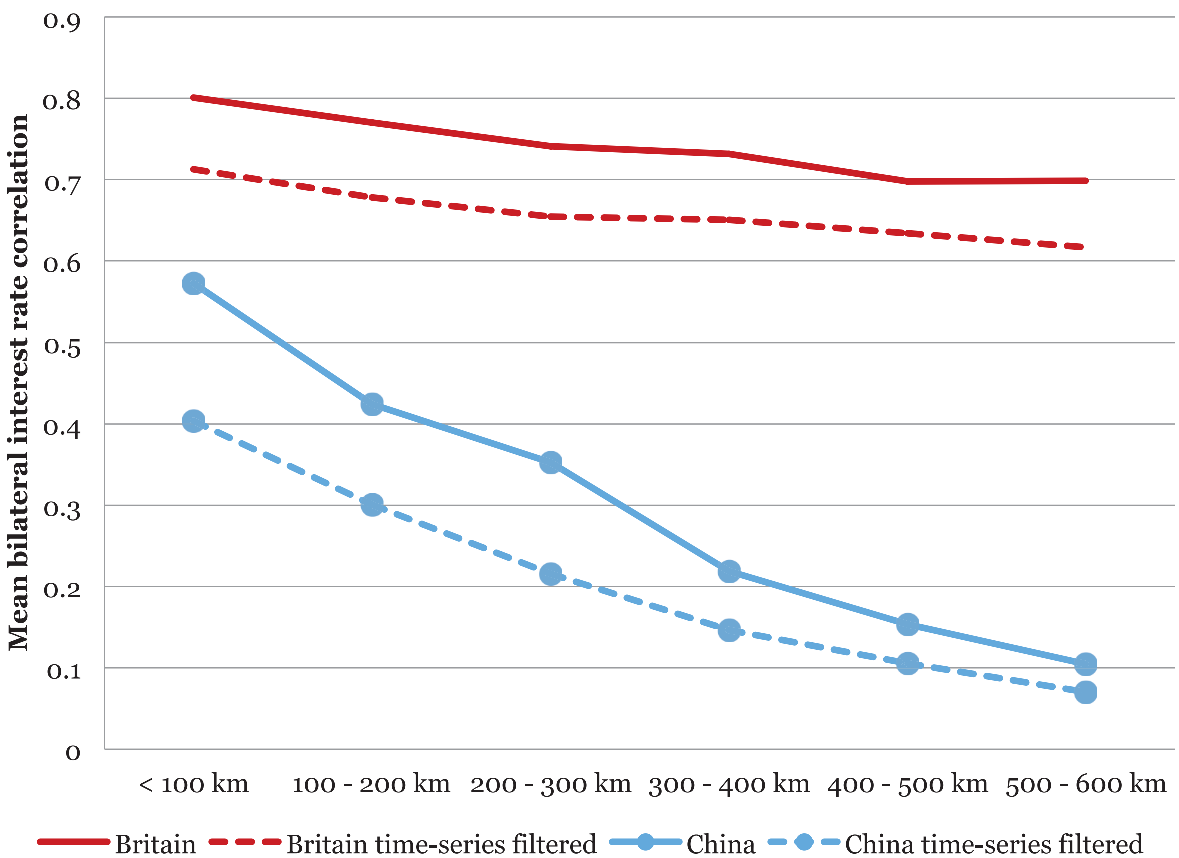


Figure 12. Bilateral interest rate correlations for years 1770 to 1860

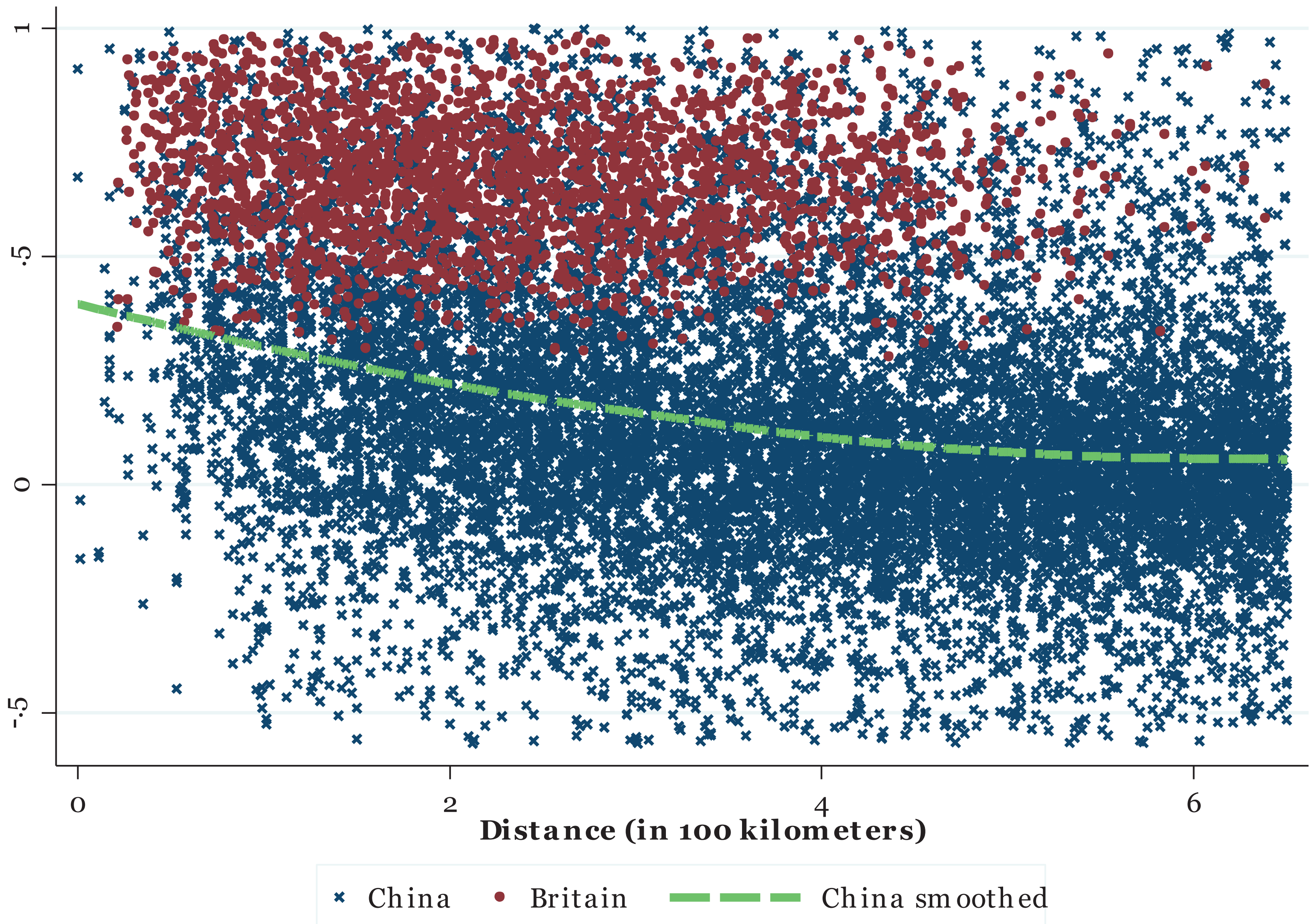


Figure 13. Bilateral interest rate correlations for years 1770 to 1794

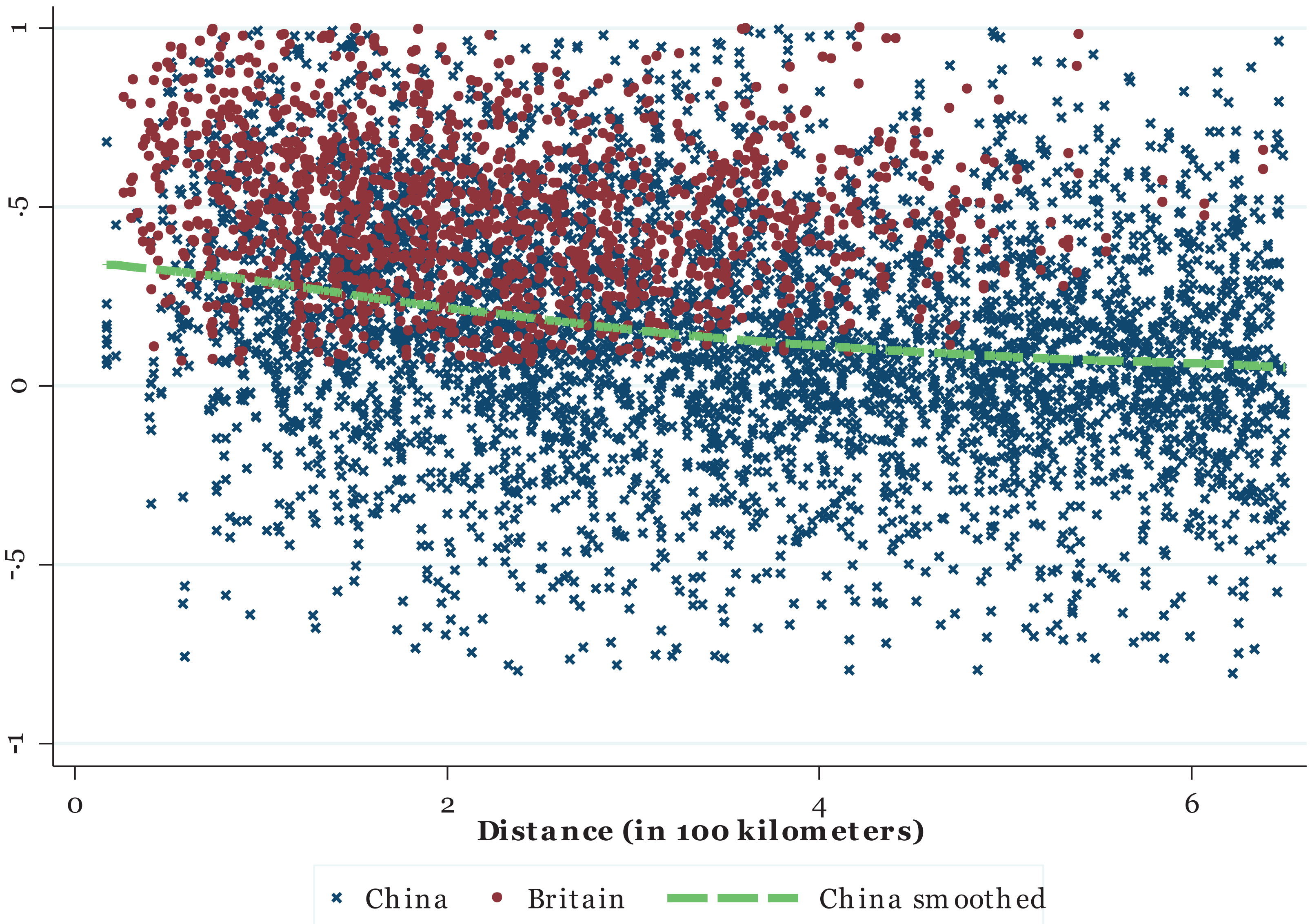
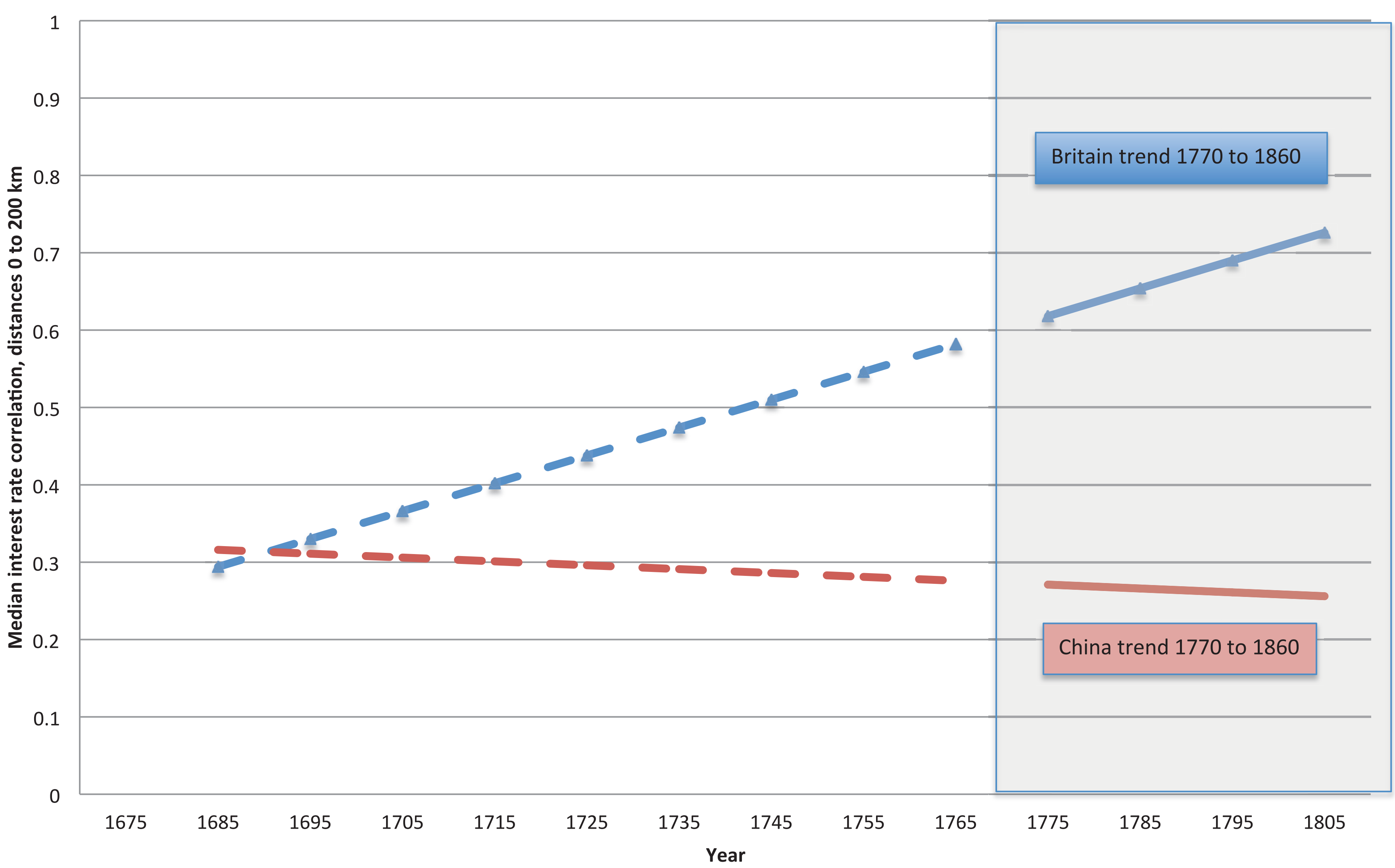


Figure 14. The Great Divergence in Capital Market Performance



Appendix

Chinese grain price data

The price reports are originally from the *Gongzhong zhupi zouzhe, nongye lei, liangjia qingdan* [Grain Price Lists in the Agricultural Section of the Vermilion Rescripts in the Palace Archives], which records monthly prices on the lunar calendar. These data exist on microfilm (Yishiguan 1990) and in published volumes from the Daoguang reign onwards (Chinese Academy of Social Sciences 2009). Original price reports were made at the county level. However, these records no longer exist. What we have today are prices for a higher administrative unit, the prefecture. A prefectural high price and a low price are given at lunar month intervals. The high price is the highest county price within the prefecture, and the low price is the lowest county price for that period. We use the mid-point price, and map that to the location of the prefectural capital. Quantity units are in units of "shi", where 1 shi = 103 liters. The original monetary units are in "liang", or the Chinese silver *tael*.

Chinese weather data

The Chinese rainfall data comes from the compilation published by the State Meteorological Administration (1981) from a variety of historical sources, including local histories and gazetteers. Weather for each year for 120 "stations" throughout China, a regional designation that is equal to one or two prefectures, is tabulated in this source. A ranking of one to five is used to summarize the impact of the "wetness and dryness" of weather changes from floods, droughts, monsoons, or rainfall, as opposed to other weather phenomenon such as windstorms or temperature changes. The ranking of weather for all regions in China, however, can be seen in the annual contour maps of weather provided, and all prefectural locations were filled in by examining the weather in the closest nearby stations.

The scale of rainfall is defined as follows by the compilers as follows: "Level 1 represents years in which there have been exceptional rainfall, leading to major floods, typhoons, water related disasters, and the destruction of all crops. Level 2 encompasses cases where there is heavy rainfall, but limited in scope and/or resulting in only minor flooding. Level 3 should be interpreted as normal weather, neither very wet nor very dry, and therefore the most favorable weather for that locality. Level 4 indicates minor droughts of limited consequences, while level 5 denotes the years of greatest drought, lasting two or more seasons of the year, and leading to major harvest failures." Over all years (1470-1979) and all regions (mainland China, Taiwan, excluding Mongolia) considered, the five categories are classified by the authors such that years and regions ranking level 1 and 5 in severity each appear with a frequency of 10 percent, ranks of level 2 and 4 each appear with a frequency between 20-30 percent, and the rank of level 3 accounts for 30-40 percent of the total distribution. In particular, the scale of rainfall is classified as follows:

Level 1: $R_i > (\overline{R} + 1.17\widetilde{\sigma})$

Level 2: $(\overline{R} + 0.33\widetilde{\sigma}) < R_i \leq (\overline{R} + 1.17\widetilde{\sigma})$

Level 3: $(\overline{R} - 0.33\widetilde{\sigma}) < R_i \leq (\overline{R} + 0.33\widetilde{\sigma})$

Level 4: $(\overline{R} - 1.17\widetilde{\sigma}) < R_i \leq (\overline{R} - 0.33\widetilde{\sigma})$

Level 5: $R_i \leq (\overline{R} - 1.17\widetilde{\sigma})$

where,
R_i = relative wetness of year *i,* between the months of 5-9.
$\overline{R}$ = average wetness between the months 5-9 over all years.
$\widetilde{\sigma}$ = standard deviation.

The weather variable used in the first stage adjustment of carry costs is the absolute value of the actual rainfall level's deviation from the weather that gives on average the lowest carry costs.

Distance

Distance calculations employ Playfair's (1965) listing of latitude and longitude measurements of prefectural cities based on their historical locations for China. The distance calculation between two points uses the Haversine Formula.

British wheat price data

We created the county-month wheat prices for British between 1770 and 1860 with the British government's Corn Returns published weekly in the *London Gazette*. Before 1820, only county weighted averages of grain prices were reported. From October 1820, however, the weekly Corn Returns include prices in all market towns within each county, as well as information on quantities sold (Adrian 1977). Hence, for the period 1821-1860, we construct the monthly prices as the weighted averages of prices across market towns, using quantities as weights.

British weather data

We use the precipitation reconstructions from Pauling et al. (2006) to obtain our rainfall data used for the British carry cost adjustment. Pauling et al. (2006) present seasonal precipitation reconstructions for European land areas on a 0.5 by 0.5 resolved grid between 1500 and 1900. We use the nearest data point to each county as the county precipitation, and aggregate the seasonal data to get the total annual precipitation. To make it comparable to the Chinese data, we normalize the British data according to the above Chinese official methodology to a 1-5 scale.

Table A: Regions in China

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
1	奉天府	Fengtian Fu	奉天	Fengtian	
2	錦州府	Jingzhou Fu	奉天	Fengtian	
3	承德府	Chengde Fu	热河	Rehe	
4	济南府	Jinan Fu	山东	Shandong	
5	兖州府	Yanzhou Fu	山东	Shandong	
6	东昌府	Dongchang Fu	山东	Shandong	
7	青州府	Qingzhou Fu	山东	Shandong	
8	登州府	Dengzhou Fu	山东	Shandong	
9	莱州府	Laizhou Fu	山东	Shandong	
10	泰安府	Taian Fu	山东	Shandong	
11	武定府	Wuding Fu	山东	Shandong	
12	曹州府	Caozhou Fu	山东	Shandong	
13	济宁直隶州	Jining Zhilizhou	山东	Shandong	
14	沂州府	Yizhou Fu	山东	Shandong	
15	临清直隶州	Linqing Zhilizhou	山东	Shandong	
16	顺天府	Shuntian Fu	直隶	Zhili	
17	保定府	Baoding Fu	直隶	Zhili	
18	永平府	Yongping Fu	直隶	Zhili	
19	河间府	Hejian Fu	直隶	Zhili	
20	正定府	Zhengding Fu	直隶	Zhili	
21	顺德府	Shunde Fu	直隶	Zhili	
22	广平府	Guangping Fu	直隶	Zhili	
23	大名府	Daming Fu	直隶	Zhili	
24	冀州直隶州	Jizhou Zhilizhou	直隶	Zhili	
25	赵州直隶州	Zhaozhou Zhilizhou	直隶	Zhili	
26	深州直隶州	Shenzhou Zhilizhou	直隶	Zhili	
27	定州直隶州	Dingzhou Zhilizhou	直隶	Zhili	
28	天津府	Tianjin Fu	直隶	Zhili	
29	易州直隶州	Yizhou Zhilizhou	直隶	Zhili	
30	遵化州直隶州	Zunhua Zhilizhou	直隶	Zhili	
31	宣化府	Xuanhua Fu	直隶	Zhili	
32	太原府	Taiyuan Fu	山西	Shanxi	
33	平阳府	Pingyang Fu	山西	Shanxi	
34	大同府	Datong Fu	山西	Shanxi	
35	潞安府	Luan Fu	山西	Shanxi	
36	汾州府	Fenzhou Fu	山西	Shanxi	
37	辽州直隶州	Liaozhou Zhilizhou	山西	Shanxi	
38	沁州直隶州	Qinzhou Zhilizhou	山西	Shanxi	
39	泽州府	Zezhou Fu	山西	Shanxi	
40	平定州	Pingding Zhilizhou	山西	Shanxi	
41	忻州直隶州	Xinzhou Zhilizhou	山西	Shanxi	
42	代州直隶州	Daizhou Zhilizhou	山西	Shanxi	
43	保德州	Baode Zhilizhou	山西	Shanxi	
44	蒲州府	Puzhou Fu	山西	Shanxi	
45	解州	Jiezhou Zhilizhou	山西	Shanxi	

46	绛州	Jiangzhou Zhilizhou	山西	Shanxi	
47	隰州直隶州	Xizhou Zhilizhou	山西	Shanxi	
48	朔平府	Shuoping Fu	山西	Shanxi	
49	宁武府	Ningwu Fu	山西	Shanxi	
50	霍州直隶州	Huozhou Zhilizhou	山西	Shanxi	
51	归绥道	Guisui Dao	山西	Shanxi	
52	开封府	Kaifeng Fu	河南	Henan	
53	归德府	Guide Fu	河南	Henan	
54	彰德府	Zhangde Fu	河南	Henan	
55	卫辉府	Weihui Fu	河南	Henan	
56	怀庆府	Huaiqing Fu	河南	Henan	
57	河南府	Henan Fu	河南	Henan	
58	南阳府	Nanyang Fu	河南	Henan	
59	汝宁府	Runing Fu	河南	Henan	
60	汝州	Ruzhou Zhilizhou	河南	Henan	
61	陈州府	Chenzhou Fu	河南	Henan	
62	许州直隶州	Xuzhou Zhilizhou	河南	Henan	
63	陕州直隶州	Shaanzhou Zhilizhou	河南	Henan	
64	光州直隶州	Guangzhou Zhilizhou	河南	Henan	
65	西安府	Xi'an Fu	陕西	Shaanxi	
66	延安府	Yan'an Fu	陕西	Shaanxi	
67	凤翔府	Fengxiang Fu	陕西	Shaanxi	
68	汉中府	Hanzhong Fu	陕西	Shaanxi	
69	兴安府	Xing'an Fu	陕西	Shaanxi	
70	商州	Shangzhou Zhilizhou	陕西	Shaanxi	
71	同州府	Tongzhou Fu	陕西	Shaanxi	
72	乾州厅	Qianzhou Zhilizhou	陕西	Shaanxi	
73	州	Binzhou Zhilizhou	陕西	Shaanxi	
74	州	Fuzhou Zhilizhou	陕西	Shaanxi	
75	绥德州	Suide Zhilizhou	陕西	Shaanxi	
76	榆林府	Yulin Fu	陕西	Shaanxi	
77	兰州府	Lanzhou Fu	甘肃	Gansu	
78	平凉府	Pingliang Fu	甘肃	Gansu	
79	巩昌府	Gongchang Fu	甘肃	Gansu	
80	庆阳府	Qingyang Fu	甘肃	Gansu	
81	宁夏府	Ningxia Fu	甘肃	Gansu	
82	西宁府	Xining Fu	甘肃	Gansu	
83	安西直隶州	Anxi Zhilizhou	甘肃	Gansu	
84	凉州府	Liangzhou Fu	甘肃	Gansu	
85	甘州府	Ganzhou Fu	甘肃	Gansu	
86	秦州直隶州	Qinzhou Zhilizhou	甘肃	Gansu	
87	阶州直隶州	Jiezhou Zhilizhou	甘肃	Gansu	
88	肃州直隶州	Suzhou Zhilizhou	甘肃	Gansu	
89	泾州直隶州	Jingzhou Zhilizhou	甘肃	Gansu	
90	江宁府	Jiangning Fu	江苏	Jiangsu	1
91	苏州府	Suzhou Fu	江苏	Jiangsu	1
92	松江府	Songjiang Fu	江苏	Jiangsu	1
93	常州府	Changzhou Fu	江苏	Jiangsu	1

94	镇江府	Zhenjiang Fu	江苏	Jiangsu	1
95	淮安府	Huaian Fu	江苏	Jiangsu	
96	扬州府	Yangzhou Fu	江苏	Jiangsu	
97	徐州府	Xuzhou Fu	江苏	Jiangsu	
98	太仓直隶州	Taicang Zhilizhou	江苏	Jiangsu	1
99	海州直隶州	Haizhou Zhilizhou	江苏	Jiangsu	
100	通州直隶州	Tongzhou Zhilizhou	江苏	Jiangsu	1
101	安庆府	Anqing Fu	安徽	Anhui	
102	徽州府	Huizhou Fu	安徽	Anhui	
103	宁国府	Ningguo Fu	安徽	Anhui	
104	池州府	Chizhou Fu	安徽	Anhui	
105	太平府	Taiping Fu	安徽	Anhui	
106	庐州府	Luzhou Fu	安徽	Anhui	
107	凤阳府	Fengyang Fu	安徽	Anhui	
108	广德直隶州	Guangde Zhilizhou	安徽	Anhui	
109	和州直隶州	Hezhou Zhilizhou	安徽	Anhui	
110	滁州直隶州	Chuzhou Zhilizhou	安徽	Anhui	
111	六安州直隶州	Liu'an Zhilizhou	安徽	Anhui	
112	泗州直隶州	Sizhou Zhilizhou	安徽	Anhui	
113	颍州府	Yingzhou Fu	安徽	Anhui	
114	南昌府	Nanchang Fu	江西	Jiangxi	
115	饶州府	Raozhou Fu	江西	Jiangxi	
116	广信府	Guangxin Fu	江西	Jiangxi	
117	南康府	Nankang Fu	江西	Jiangxi	
118	九江府	Jiujiang Fu	江西	Jiangxi	
119	建昌府	Jianchang Fu	江西	Jiangxi	
120	抚州府	Fuzhou Fu	江西	Jiangxi	
121	临江府	Linjiang Fu	江西	Jiangxi	
122	吉安府	Ji'an Fu	江西	Jiangxi	
123	瑞州府	Ruizhou Fu	江西	Jiangxi	
124	袁州府	Yuanzhou Fu	江西	Jiangxi	
125	赣州府	Ganzhou Fu	江西	Jiangxi	
126	南安府	Nan'an Fu	江西	Jiangxi	
127	宁都直隶州	Ningdu Zhilizhou	江西	Jiangxi	
128	福州府	Fuzhou Fu	福建	Fujian	
129	泉州府	Quanzhou Fu	福建	Fujian	
130	建宁府	Jianning Fu	福建	Fujian	
131	延平府	Yanping Fu	福建	Fujian	
132	汀州府	Tingzhou Fu	福建	Fujian	
133	兴化府	Xinghua Fu	福建	Fujian	
134	邵武府	Shaowu Fu	福建	Fujian	
135	漳州府	Zhangzhou Fu	福建	Fujian	
136	福宁府	Funing Fu	福建	Fujian	
137	永春州	Yongchun Zhilizhou	福建	Fujian	
138	龙岩州	Longyan Zhilizhou	福建	Fujian	
139	台湾府	Taiwan Fu	福建	Fujian	
140	武昌府	Wuchang Fu	湖北	Hubei	
141	汉阳府	Hanyang Fu	湖北	Hubei	

142	安陆府	Anlu Fu	湖北	Hubei
143	襄阳府	Xiangyang Fu	湖北	Hubei
144	郧阳府	Yunyang Fu	湖北	Hubei
145	德安府	De'an Fu	湖北	Hubei
146	黄州府	Huangzhou Fu	湖北	Hubei
147	荆州府	Jingzhou Fu	湖北	Hubei
148	宜昌府	Yichang Fu	湖北	Hubei
149	施南府	Shinan Fu	湖北	Hubei
150	荆门直隶州	Jingmen Zhilizhou	湖北	Hubei
151	长沙府	Changsha Fu	湖南	Hunan
152	岳州府	Yuezhou Fu	湖南	Hunan
153	宝庆府	Baoqing Fu	湖南	Hunan
154	衡州府	Hengzhou Fu	湖南	Hunan
155	常德府	Changde Fu	湖南	Hunan
156	辰州府	Chenzhou Fu	湖南	Hunan
157	永州府	Yongzhou Fu	湖南	Hunan
158	靖州	Jingzhou Zhilizhou	湖南	Hunan
159	郴州直隶州	Chenzhou Zhilizhou	湖南	Hunan
160	永顺府	Yongshun Fu	湖南	Hunan
161	澧州直隶州	Lizhou Zhilizhou	湖南	Hunan
162	沅州府	Yuanzhou Fu	湖南	Hunan
163	桂阳州	Guiyang Zhilizhou	湖南	Hunan
164	广州府	Guangzhou Fu	广东	Guangdong
165	韶州府	Shaozhou Fu	广东	Guangdong
166	南雄直隶州	Nanxiong Zhilizhou	广东	Guangdong
167	惠州府	Huizhou Fu	广东	Guangdong
168	潮州府	Chaozhou Fu	广东	Guangdong
169	肇庆府	Zhaoqing Fu	广东	Guangdong
170	高州府	Gaozhou Fu	广东	Guangdong
171	廉州府	Lianzhou Fu	广东	Guangdong
172	雷州府	Leizhou Fu	广东	Guangdong
173	琼州府	Qiongzhou Fu	广东	Guangdong
174	罗定直隶州	Luoding Zhilizhou	广东	Guangdong
175	连州直隶州	Lianzhou Zhilizhou	广东	Guangdong
176	嘉应直隶州	Jiaying Zhilizhou	广东	Guangdong
177	佛冈直隶厅	Fogang Zhiliting	广东	Guangdong
178	连山直隶厅	Lianshan Zhiliting	广东	Guangdong
179	桂林府	Guilin Fu	广西	Guangxi
180	柳州府	Liuzhou Fu	广西	Guangxi
181	庆远府	Qingyuan Fu	广西	Guangxi
182	思恩府	Si'en Fu	广西	Guangxi
183	平乐府	Pingle Fu	广西	Guangxi
184	梧州府	Wuzhou Fu	广西	Guangxi
185	浔州府	Xunzhou Fu	广西	Guangxi
186	南宁府	Nanning Fu	广西	Guangxi
187	太平府	Taiping Fu	广西	Guangxi
188	郁林直隶州	Yulin Zhilizhou	广西	Guangxi
189	泗城府	Sicheng Fu	广西	Guangxi

190	镇安府	Zhenan Fu	广西	Guangxi
191	成都府	Chengdu Fu	四川	Sichuan
192	保宁府	Baoning Fu	四川	Sichuan
193	顺庆府	Shunqing Fu	四川	Sichuan
194	叙州府	Xuzhou Fu	四川	Sichuan
195	重庆府	Zhongqing Fu	四川	Sichuan
196	夔州府	Kuizhou Fu	四川	Sichuan
197	龙安府	Longan Fu	四川	Sichuan
198	潼川府	Tongchuan Fu	四川	Sichuan
199	嘉定府	Jiading Fu	四川	Sichuan
200	雅州府	Yazhou Fu	四川	Sichuan
201	眉州	Meizhou Zhilizhou	四川	Sichuan
202	邛州	Qiongzhou Zhilizhou	四川	Sichuan
203	泸州直隶州	Luzhou Zhilizhou	四川	Sichuan
204	资州	Zizhou Zhilizhou	四川	Sichuan
205	绵州	Mianzhou Zhilizhou	四川	Sichuan
206	茂州	Maozhou Zhilizhou	四川	Sichuan
207	叙永厅	Xuyong Zhilizhou	四川	Sichuan
208	绥定府	Suiding Fu	四川	Sichuan
209	宁远府	Ningyuan Fu	四川	Sichuan
210	酉阳州	Youyang Zhilizhou	四川	Sichuan
211	忠州	Zhongzhou Zhilizhou	四川	Sichuan
212	松潘厅	Songpan Zhiliting	四川	Sichuan
213	石砫厅	Shizhu Zhiliting	四川	Sichuan
214	太平厅	Taiping Zhiliting	四川	Sichuan
215	云南府	Yunnan Fu	云南	Yunan
216	大理府	Dali Fu	云南	Yunan
217	临安府	Lin'an Fu	云南	Yunan
218	楚雄府	Chuxiong Fu	云南	Yunan
219	澂江府	Chengjiang Fu	云南	Yunan
220	广西直隶州	Guangxi Zhilizhou	云南	Yunan
221	顺宁府	Shunning Fu	云南	Yunan
222	曲靖府	Qujing Fu	云南	Yunan
223	武定直隶州	Wuding Zhilizhou	云南	Yunan
224	永昌府	Yongchang Fu	云南	Yunan
225	永北直隶厅	Yongbei Zhiliting	云南	Yunan
226	元江直隶州	Yuanjiang Zhilizhou	云南	Yunan
227	广南府	Guangnan Fu	云南	Yunan
228	蒙化直隶厅	Menghua Zhiliting	云南	Yunan
229	景东直隶厅	Jingdong Zhiliting	云南	Yunan
230	开化府	Kaihua Fu	云南	Yunan
231	丽江府	Lijiang Fu	云南	Yunan
232	东川府	Dongchuan Fu	云南	Yunan
233	镇沅直隶州	Zhenyuan Zhiliting	云南	Yunan
234	昭通府	Zhaotong Fu	云南	Yunan
235	普洱府	Puer Fu	云南	Yunan
236	镇雄直隶州	Zhenxiong Zhilizhou	云南	Yunan
237	贵阳府	Guiyang Fu	贵州	Guizhou

238	思州府	Sizhou Fu	贵州	Guizhou
239	思南府	Sinan Fu	贵州	Guizhou
240	镇远府	Zhenyuan Fu	贵州	Guizhou
241	石阡府	Shiqian Fu	贵州	Guizhou
242	铜仁府	Tongren Fu	贵州	Guizhou
243	黎平府	Liping Fu	贵州	Guizhou
244	安顺府	Anshun Fu	贵州	Guizhou
245	都匀府	Duyun Fu	贵州	Guizhou
246	平越直隶州	Pingyue Zhilizhou	贵州	Guizhou
247	大定府	Dading Fu	贵州	Guizhou
248	兴义府	Xingyi Fu	贵州	Guizhou
249	遵义府	Zunyi Fu	贵州	Guizhou
250	仁怀直隶厅	Renhuai Zhiliting	贵州	Guizhou
251	松桃直隶厅	Songtao Zhiliting	贵州	Guizhou
252	普安直隶厅	Pu'an Zhiliting	贵州	Guizhou

Table B: British regions

Region No.	County name
1	Anglesey
2	Bedfordshire
3	Berkshire
4	Brecknockshire
5	Buckinghamshire
9	Caernarfonshire
6	Cambridgeshire
7	Cardiganshire
8	Carmarthenshire
10	Cheshire
11	Cornwall
12	Cumberland
13	Denbighshire
14	Derbyshire
15	Devon
16	Dorset
17	Durham
18	Essex
19	Flintshire
20	Glamorgan
21	Gloucestershire
22	Hampshire
23	Herefordshire
24	Hertfordshire
25	Huntingdonshire
26	Kent
27	Lancashire
28	Leicestershire
29	Lincolnshire
30	Merionethshire
31	Middlesex
32	Monmouthshire
33	Montgomeryshire
34	Norfolk
35	Northamptonshire
36	Northumberland
37	Nottinghamshire
38	Oxfordshire
39	Pembrokeshire
40	Radnorshire
41	Rutland
42	Shropshire
43	Somerset
44	Staffordshire

45	Suffolk
46	Surrey
47	Sussex
48	Warwickshire
49	Westmorland
50	Wiltshire
51	Worcestershire
52	Yorkshire

Table C. Spatial Aggregation and interest rate correlations in Britain

	Baseline		Aggregated	
	Unfiltered	Filtered	Unfiltered	Filtered
0-100 km	0.80 (0.16) [n = 350]	0.71 (0.17) [n = 350]	0.85 (0.10) [n = 42]	0.81 (0.11) [n = 42]
100-200km	0.77 (0.16) [n = 788]	0.68 (0.18) [n = 788]	0.82 (0.13) [n = 162]	0.74 (0.13) [n = 162]
200-300km	0.74 (0.17) [n = 720]	0.66 (0.17) [n = 720]	0.81 (0.12) [n = 170]	0.71 (0.11) [n = 170]
300-400km	0.73 (0.18) [n = 476]	0.65 (0.16) [n = 476]	0.80 (0.12) [n = 132]	0.70 (0.11) [n = 132]
400-500km	0.70 (0.18) [n = 246]	0.63 (0.19) [n = 246]	0.78 (0.13) [n = 74]	0.69 (0.11) [n = 74]
500-600km	0.70 (0.19) [n = 64]	0.62 (0.23) [n = 64]	0.79 (0.19) [n = 20]	0.67 (0.15) [n = 20]

Notes: All results are for Britain. Shown in the Baseline columns are results for 52 counties. In the Aggregated columns, the 52 counties are aggregated to 26 regions that on average closely resemble the size of a Chinese prefecture.

Table D: The role of sample composition before and after 1820

	Britain		China	
	Before 1820	After 1820	Before 1820	After 1820
0-100 km	0.73 (0.20) [n = 350]	0.72 (0.23) [n = 314]	0.38 (0.32) [n = 116]	0.29 (0.32) [n = 108]
100-200km	0.69 (0.22) [n = 788]	0.71 (0.23) [n = 724]	0.28 (0.40) [n = 380]	0.23 (0.30) [n = 274]
200-300km	0.66 (0.21) [n = 720]	0.69 (0.26) [n = 660]	0.21 (0.42) [n = 472]	0.22 (0.35) [n = 380]
300-400km	0.66 (0.22) [n = 476]	0.68 (0.24) [n = 430]	0.15 (0.36) [n = 474]	0.14 (0.36) [n = 288]
400-500km	0.64 (0.28) [n = 246]	0.66 (0.21) [n = 216]	0.10 (0.33) [n = 478]	0.09 (0.43) [n = 276]
500-600km	0.56 (0.42) [n = 64]	0.67 (0.24) [n = 58]	0.06 (0.34) [n = 530]	0.09 (0.39) [n = 278]

Notes: Results for mean bilateral correlations of interest rates based on filtered wheat prices. Standard deviation in parentheses, and number of observations in brackets.

Table E: Capital market integration and time series length

	Britain		China	
	All	50 < x < 70	All	50 < x < 70
0-100 km	0.71 (0.17) [n = 350]	0.68 (0.18) [n = 92]	0.51 (0.46) [n = 158]	0.61 (0.50) [n = 56]
100-200km	0.68 (0.18) [n = 788]	0.67 (0.18) [n = 222]	0.35 (0.54) [n = 494]	0.46 (0.61) [n = 164]
200-300km	0.66 (0.17) [n = 720]	0.67 (0.16) [n = 224]	0.25 (0.58) [n = 612]	0.36 (0.49) [n = 118]
300-400km	0.65 (0.16) [n = 476]	0.65 (0.13) [n = 136]	0.17 (0.56) [n = 660]	0.33 (0.23) [n = 66]
400-500km	0.63 (0.19) [n = 246]	0.65 (0.14) [n = 80]	0.10 (0.55) [n = 804]	0.22 (0.29) [n = 48]
500-600km	0.62 (0.23) [n = 64]	0.66 (0.12) [n = 28]	0.08 (0.62) [n = 802]	0.19 (0.55) [n = 108]

Notes: Results for mean bilateral correlations of interest rates based on filtered wheat prices for Britain and based on filtered second-grade rice prices for China. Results for columns "All" are for interest rate correlations using all data, from Table 7. Results for columns "50 < x < 70" are for pairs of regions with 50 to 70 years of data in the period 1770 to 1860. Standard deviation in parentheses, and number of observations in brackets.

Figure A. Capital market integration with preferred vs. broad interest rates