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Wolfgang Keller
Carol H. Shiue
Xin Wang

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ABSTRACT

This paper evaluates an approach popularized by McCloskey and Nash (1984) that exploits the fact that grain prices provide information on interest rates. While the grain price approach enables a comparative analysis of capital market development across pre-modern economies and has been applied in various contexts, to date this is the first paper to show how well it captures the actual market development as based on financial data. Using matched data on bank interest rates and grain prices for early 19th century U.S. regions, we show that the grain price approach is useful for capturing differences in capital market development across regions. While estimating particular region-time specific interest rates can be challenging, using both cross-sectional and time-series information the grain price approach accurately reflects differences in capital market development. Furthermore, the approach is robust to employing time series filtering techniques as well as dealing with unavailable information on harvest times, outliers, and a range of other factors.

Wolfgang Keller
Department of Economics
University of Colorado, Boulder
Boulder, CO 80309-0256
and NBER
Wolfgang.Keller@colorado.edu

Carol H. Shiue
Department of Economics
University of Colorado at Boulder
Boulder, CO 80309
and NBER
carol.shiue@colorado.edu

Xin Wang
Institute of New Structural Economics
Peking University
Beijing 100871
China
xin.wang@nsd.pku.edu.cn

1. Introduction

Capital market development is an important step towards modern economic growth because it ensures that surplus is allocated to the project with the highest return (recent contributions include Rousseau 1999 and Mitchener and Ohnuki 2007).[5] Yet, in practice the transition from capital underdevelopment to development is difficult to observe because once systematic data on many comparable transactions and formal financial institutions becomes widely available, the economy has generally moved past the stage of capital underdevelopment.

Even in pre-modern economies, however, farmers trade grain for cash back and forth inter-temporally, a fact insightfully employed by McCloskey and Nash (1984) to assess aspects of capital market development in Medieval England.[6] The approach relies on the notion that in economic equilibrium holding grain and selling it a few months later will be no more or less profitable than selling grain immediately and holding money, so that the rate of grain price appreciation is a good approximation of the interest rate (plus other storage costs). Market prices for grain are among the most-available information for pre-modern economies; in addition, because agriculture is the largest part of the economy with a large number of grain market participants, concerns about idiosyncratic factors and composition effects being the primary drivers are greatly reduced.[7] Although the grain-price approach to assessing interest rates may be well-founded both in terms of asset pricing theory (see Working 1933, 1949, Kaldor 1939) and in the context of equilibrium storage (e.g., Williams and Wright 1991), it has never been established empirically how well the grain price approach to capital markets works, especially with respect to different dimensions of capital markets. This paper fills this gap.

We use matched regional bank interest rates and grain prices for an early period of capital market development: the United States from 1815 to 1855. Due to stochastic shocks and the specifics of each particular grain price series it turns out to be challenging to estimate a particular interest rate level. The grain price approach, however, captures accurately differences in capital

[5] Early work includes Bagehot (1855), Schumpeter (1911), and Gurley and Shaw (1955).
[6] For example, on farmers trading grain back and forth see the memorial from Tang Pin for the case of 18th century China, *Da Qing li chao shilu*, Gaozong reign, 286: 24b-25a (4154-55); Pomeranz (1993), p.32.
[7] Interest rate quotes for pre-modern economies cannot be used for systematic comparisons because they omit information on borrower identity, security, and other determinants, and there are typically too few that are strictly comparable; e.g., Pomeranz (1993), p.32.

market development once economies are compared using both time-series and cross-regional dimensions of the data. We show that used for this purpose, the grain price approach to capital markets works quite well. We also give special emphasis to the robustness of the grain price approach in terms of available information, data generating process, and differences in findings from relatively simple and more sophisticated methods.

We seek to make a number of contributions. First, by evaluating a method to assess capital market development prior to the creation of formal financial institutions, this paper informs the large literature on the importance of capital market development for growth—thus addressing the key question of whether formal financial institutions are a consequence or a cause of modern economic growth. The grain price approach to capital markets has attracted much interest (McCloskey and Nash 1984, Taub 1987, Pomeranz 1993, Brunt and Cannon 1999, 2009, Clark 2001, and Shiue 2002), but without the empirical assessment presented here quantitative capital market studies typically rely on the arrival of high-quality bank interest rate data (e.g. Mitchener and Ohnuki 2007, 2009 on Japan in the late 19th century).[8] The approach has potential in shedding light on capital development in economies before the 19th century, but furthermore, the grain price approach can be applied to those areas in today's less developed countries for which grain price data is available but formal banking institutions are absent.

Second, an important concern is that in a specific historical context the asset-pricing and competitive storage model is misspecified.[9] If in fact farmers do not store grain as an asset, high and randomly changing frictions to intertemporal transactions create abundant noise, or the pre-modern farmer is simply not a *homo oeconomicus,* then we will learn nothing from the grain price approach on capital markets. Whether this is actually the case is hard to know ex-ante, and our paper contributes to our knowledge of how economic behavior has shaped human activity in historical economies.

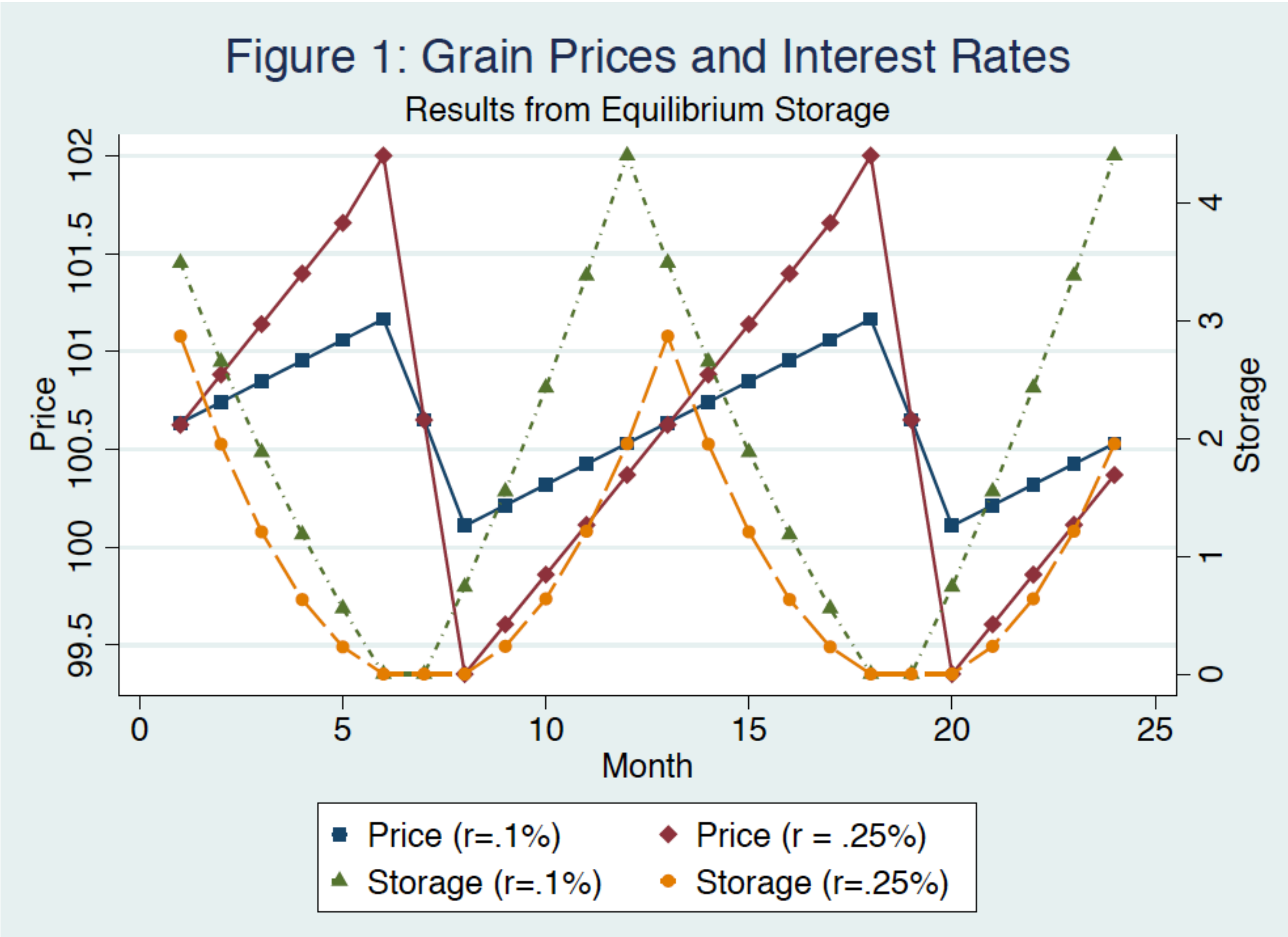
[8] Buchinsky and Polak (1993) employ the quantity of property transactions outside London to study the emergence of a national capital market in England.

[9] Komlos and Landes (1991, p.43), for example, criticize McCloskey and Nash's (1984) application of the grain price approach to Medieval England as anachronistic and forgetting the "social, cultural, intellectual, and institutional realities of the past."

2. Equilibrium prices and the costs of storage: a standard model

To fix ideas, this section shows that in a simple model of optimal commodity storage the commodity's price between harvests is characterized by a 'see-saw' pattern, where the steepness of the 'saw' increases with the interest rate. This approach can, in principle, be applied to any storable asset. Textbook treatment shows that many factors affect equilibrium grain prices (Williams and Wright 1991), including storage capacity, the cost of injection and withdrawal, as well as the implied return holding inventories (so-called convenience yield). We simplify our storage model along the lines of Williams and Wright (1991) by assuming that agents have perfect foresight and the world is deterministic.

Central for our purposes is that in this model, equilibrium grain prices reflect interest rates. This is shown in Figure 1, which depicts the sequences of prices and storage levels for two different interest rate levels, holding all other parameters equal.



Note that prices start to fall when the new harvest comes in (period 6). Also, grain stocks run out (they reach level zero) in the period when grain prices attain their maximum, indicating that the purpose of storage is to dampen price movements. The key feature for the grain price approach, however, is that prices follow a see-saw pattern, and that the price gradient is increasing with the interest rate. The intuition is that between two harvests the value of grain must rise faster per unit of time whenever the interest rate—the opportunity cost of tying up resources—is higher. While interest rate differences are reflected in price changes during any period according to Figure 1, our focus below will be on periods of price increases during times of positive storage.

3. Assessment

Central to our assessment is to see how well the information from monthly grain price data together with the storage model matches up with direct information on capital markets based on regional interest rates. Interest rates charged by banks provide a good measure of prevailing rates against which we assess the interest inferred from the grain-price approach. The earliest episode for which we were able to collect both high-frequency grain prices and regional interest rates is for parts of the U.S. during the years 1815 to 1855.

3.1 U.S. Early Regional Capital Markets Data

We rely on the pioneering work by Bodenhorn (2000) and Bodenhorn-Rokoff (1992), who estimate annual interest rates for a number of U.S. cities and states. Due to constraints on the availability of grain prices, we cannot employ all of Bodenhorn and Rokoff's (1992) data; Table A.1 in the Appendix reproduces the part of their data employed in our analysis.

The series are for the following regions, denoted by *i*: Philadelphia, New York City, Indiana, South Carolina, Virginia, and New Orleans. Note that these bank rates are estimates, obtained using bank balance sheet data with a plausible set of assumptions. Unfortunately, for this relatively early period there is no data on a large number of actual transactions to crosscheck these rates. Given our focus on the grain price approach we will abstract from the implications that uncertainty about the bank rates might have. Moreover, it is apparent that some of these regions are cities and others are U.S. states, which means that there is a mix of regions in terms of size in the sample. This will typically be the case in actual applications. In the following we will typically refer to a series by the name of the city. The length of the time series varies from a maximum of 41 to minimum of 21.[10]

The bottom of Table A.1 shows summary statistics of these interest rate estimates. Overall the interest rate on average in our sample has been equal to 5.81 percent, with a standard deviation of 1.72 percent. The average across all years ranges on the low side from 4.82% and 5.00% (for Alexandria and Philadelphia, respectively), and on the high side from 7.35% and 8.33%

[10] Because interruptions in the time series do not work well with the co-integration methods below we interpolate a handful of missing values with a linear trend for New Orleans and Indianapolis in that case.

(for Indianapolis and New Orleans, respectively).[11] There is also substantial year-to-year variation; for example, the interest rate in New York City moved from 5.32% in year 1848 to 7.17% and then 5.62% in the two following years.

Because these city-level averages are affected by the composition of transactions in a particular location—varying, e.g., with industry, maturity, borrower, and lender—studies of capital market development often analyze the degree to which regional markets co-move with each other, as well as the extent to which one regional market responds to shocks in another. In our assessment of the grain price approach to capital markets we will apply several methods, including the bilateral correlation of interest rates between two given markets, as well as evidence of cointegration and speed of adjustment between series in a error-correction framework.

Table 1: Bilateral correlations between regional U.S. bank interest rates

	PHI	NYC	ALEX	IND	CHA	NO
PHI	1.00					
NYC	**0.65**	1.00				
ALEX	0.24	0.51	1.00			
IND	**0.68**	0.29	0.18	1.00		
CHA	-0.00	0.07	-0.27	-0.04	1.00	
NO	-0.30	-0.30	0.26	0.27	0.02	1.00

Notes: Shown is bilateral correlation between two log series for the period 1835-55 (n=21). PHI is Philadelphia, NYC is New York City, ALEX is Alexandria, IND is Indianapolis, CHA is Charleston, and NO is New Orleans. Bold: OLS coefficient is significant at a 5% level.

Table 1 shows the matrix of bilateral correlations between the six markets. We see evidence for a significant positive correlation between some markets, especially when Philadelphia is involved. Overall, these results are consistent with a national U.S. capital market

[11] One might be concerned that the coverage in terms of years varies across cities, but in fact the correlation of the average rates for all years and for common years is high (99.5%).

that is still emerging. Typically, the correlation of interest rates between two regions is only around 0.13 and not significant in our sample. Importantly, the sample combines areas where regional capital markets appear to be more developed, such as in the Philadelphia-New York area, with other regions of the U.S. that have less developed capital markets. A key question is whether the grain-price approach to capital markets is able to detect that.

3.2 Grain-price Data

We have obtained observations on monthly grain prices for six U.S. markets during the sample period: Philadelphia, New York City, Alexandria, New Orleans, Indianapolis and Charleston. The sources are Jacks (2005, 2006) for the former five and Shiue and Keller (2007) for the Charleston prices. All of the series are considered market prices for grain. The grain is wheat except for Charleston for which rice prices are employed. Recall that in principle the approach should work with any storable commodity.[12] Due to lack of detailed information, we assume that all non-interest factors influencing storage decisions were the same for wheat and rice.

The grain-price approach suggests that we can exploit information on the within-harvest year price gradient to estimate regional interest rates. To do so, we aggregate monthly price changes to get an annual grain-price based interest rate. For a given region, our benchmark interest rate estimate in year *t* is the average of all price changes during August to December of year *t*.

3.3 A Framework for Comparison

Let the bank interest rate in region *i* and year *t* be denoted by r_{it}, with *i* = 1,…,6, and *t* = 1815,…,1855. We will estimate grain-price based interest rates using a number of different methods, *m*, and consequently these corresponding rates are denoted by ρ_{it}^{m}. The average region-specific grain rate across all years is denoted by $\bar{\rho}_{i}^{m}$ while the average bank rate is $\bar{r}_{i}$ (the latter is given at the bottom of Table 1). We will use six different criteria, as described below.

Our first interest rate criterion is simply the average of all interest rates, denoted by $\bar{\bar{r}}$ for the bank rates and $\bar{\bar{\rho}}^{m}$ for the grain rates. From above, $\bar{\bar{r}}$ is equal to 5.7% in our sample of bank rates, with a standard deviation of 1.68%. We will compare the average of grain-price interest rates to the bank rates in the empirical results.

[12] E.g., McCloskey and Nash (1984) consider sheep, and also Taub (1987) discusses multiple commodities.

Our second interest rate criterion is the t-statistic of a regression of ρ_{it}^{m} on r_{it}; this criterion evaluates the extent to which the grain price approach captures year-to-year variation in the bank rates. Our third interest rate criterion examines the *pattern* of interest rates across regions. We have seen, for example, that interest rates in Philadelphia were on average lower than in New Orleans (Table A.1, bottom), that is, $\bar{r}_{PHI} < \bar{r}_{NO}$, and a natural question is whether $\bar{\rho}_{PHI}^{m} < \bar{\rho}_{NO}^{m}$ as well. More generally, our third criterion is the correlation between the six bank-rate and the six grain-rate averages.

Turning to the capital market integration criteria, let $c_{ii'}$ be the correlation between any two regions' *i* and *i'* bank rates r_{it} and $r_{i't}$, with $-1 \leq c_{ii'} \leq 1$. These bilateral correlations are given in Table 1. Further, let $\gamma_{ii'}^{m}$ be the corresponding bilateral correlation between the grain-price based rates ρ_{it}^{m} and $\rho_{i't}^{m}$, with $-1 \leq \gamma_{ii'}^{m} \leq 1$. Our first market integration criterion is to compare the average bilateral correlation for bank rates over all pairs with the corresponding average bilateral correlation of the grain rates using method *m*.

The second market integration criterion compares the *pattern* of bilateral bank rate correlations with the pattern of bilateral grain rate correlations. Formally, let C be the set of bilateral bank rate correlations, $C = \{c_{12}, c_{13}, \ldots, c_{56}\}$, and let Γ^{m} be the set of corresponding bilateral correlations based on method *m*, $\Gamma^{m} = \{\gamma_{12}^{m}, \gamma_{13}^{m}, \ldots, \gamma_{56}^{m}\}$. The correlation between C and Γ^{m} provides evidence on the extent to which *differences* in the strength of capital market integration that are implied by the bank rates are captured by the method-*m* based grain rates. Denoting this correlation as CC^{m}, it captures the extent to which the grain price approach succeeds to distinguish between high- and low-integration areas.

Finally, our third capital market integration criterion is whether bank rates and grain rates deliver similar evidence in terms of co-integration using the autoregressive, distributed lag (ARDL) error-correction framework introduced by Pesaran and co-authors. We choose Pesaran et al.'s (1999, 2001) method and the associated bounds test for co-integration in part because it can be applied to variables regardless of their underlying stationary properties, that is, they could be either *I* (0) or *I* (1). We prefer this to other co-integration approaches in which only *I* (1) variables are allowed because when conducting unit root tests for a several variables it is common that the evidence is mixed, with some variables stationary while others are non-stationary.

For space reasons, given that the Pesaran et al. approach requires several steps, checks, and parameters as well as lag lengths to be set, we focus on two bilateral relations, namely Philadelphia-New Orleans (PHI-NO) and New Orleans-Charleston (NO-CHA); as we will see below, there is much stronger evidence for cointegration for the former than the latter according to bank rates.[13] In addition, the analysis below explores the robustness of our findings in a number of dimensions, including the influence of (i) outliers; (ii) different storage months; (iii) stochastic trends and cycles; and (iv) measurement error.

4. Empirical Results

This section covers the main results of the paper. Two sets of indicators of capital market development are considered. The first set is based on the level of regional interest rates while the second concerns various aspects of co-movements of regional interest rates, that is, capital market integration. Our empirical assessment of the grain-price approach is a comparison of the conclusions on capital market development in terms of these criteria based on Bodenhorn-Rokoff's bank interest rates with the conclusions that we arrive at with the grain price approach.

4.1 Benchmark Results

First, we apply the six criteria laid out in section 3.3 above to the bank interest rates. Next, we compare them with analogous statistics for our benchmark grain price method, employing the average of all first-differences of log grain price between August and December. The results are in Table 2.

[13] Our analysis of cointegration employs STATA's implementation of the Pesaran et al. ARDL framework and associated bounds co-integration test. We use default settings for all parameter and lag length choices.

Table 2: Grain Prices and Capital Markets – Benchmark Results

	Interest Rates				Market Integration				
	(1) Overall $\bar{\bar{r}}$; $\bar{\bar{\rho}}^m$	(2) T-stat ρ_{it}^m on r_{it}	(3) Corr $(\bar{\rho}_i^m, \bar{r}_i)$ across regions	(4) Bilat Corr $(r_{it}, r_{i' t})$, Bilat Corr $(\rho_{it}^m, \rho_{i' t}^m)$	(5) Pattern of Bilateral Correlations	(6) ARDL Cointegration Pesaran/Shin/Smith			
						PHI-CHA		NO-CHA	
	Average [s.d.]			Average [s.d.]	CC^m	F-stat	Coint p-val < 1%	F-stat	Coint p-val < 1%
Bank Rates	5.70 [1.68]			0.13 [0.28]		27.2	Yes	4.1	No
Grain Rates Benchmark	7.25 [46.12]	1.86	0.79	0.51 [0.35]	0.64	22.4	Yes	5.0	No
Years 1835-1855	9.77 [48.46]	1.64	0.77	0.51 [0.43]	0.64	12.7	Yes	8.4	Yes
Years 1835-55, Wheat	12.19 [48.83]	1.75	0.80	0.77 [0.16]	0.69	12.7	Yes	8.4	Yes

Notes: *Grain Rates Benchmark* is based on the average of first-differences of log grain prices from August to December in the years 1815-1855, for six markets (PHI, NYC, ALEX, IND, NO, and CHA; n=181); *Years 1835-55* is the benchmark specification using only data for 1835-55 (n=109). *Years 1835-55, Wheat* employs data for the five wheat series (PHI, NYC, ALEX, IND, and NO; n = 88). See text for details. For the co-integration tests of column (6) bank rates are linearly intrapolated.

The set of results for interest rates are seen on the left in Table 2, while the capital market integration results are on the right. The overall mean bank rate is 5.70%, compared with 7.25% for the grain price benchmark.[14] Grain rates are about 12% higher than bank rates on average. There is a substantially greater difference in the degree to which bank and grain-based interest rates vary, as seen from the standard variations in brackets. One reason for that may be shocks

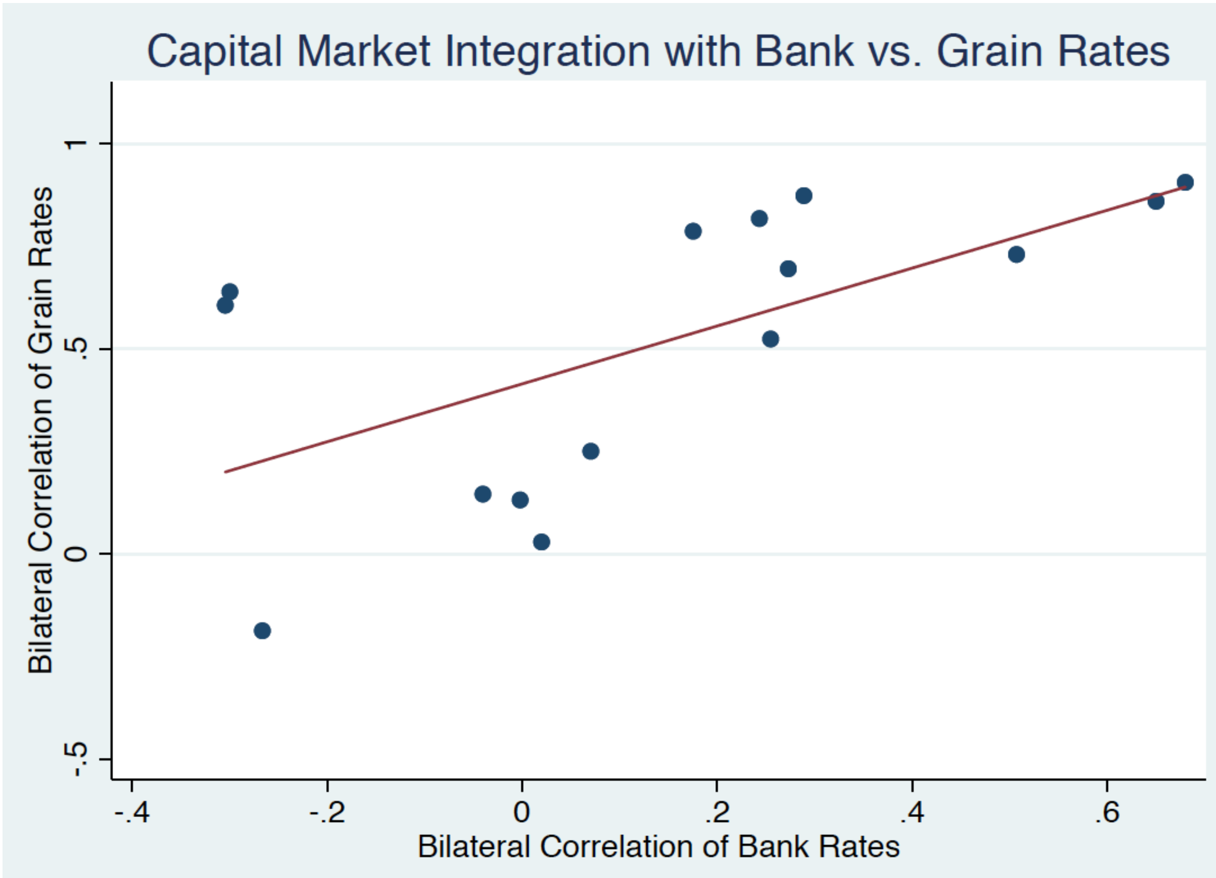
[14] We compute the grain-based rates as 12 times the average monthly rate.

and stochastic trends in relatively volatile grain prices. Bank rates, in contrast, are computed bank balance sheet information (not individual transactions), which appears to be relatively stable from year to year. Next, we examine the year-to-year time series behavior of the grain rates. The second column shows that the t-statistic from the pooled regression of the grain-based on the bank interest rates (and a constant) is 1.86 (n = 181). The following result examines the cross-sectional pattern of mean interest rates across regions. Recall that the average rate in Philadelphia, e.g., was about 5%, compared to 8% in New Orleans. Do the grain rates pick up this difference? We find that across the six regions, the correlation between mean bank and mean grain rates is 0.79.

Turning to the right side of Table 2, we present a number of results on pair-wise market integration.[15] First, the average bilateral correlation of bank rates is 0.13 while the average for grain-based rates is with about 0.5 higher. One reason for this may be the presence of common shocks (such as weather) on grain prices. Our second market integration criterion is the correlation of the patterns of grain rate correlation with the pattern of bank rate correlation. This correlation is equal to 0.64, see column (5). With n = 6 regions, there are fifteen (= n(n-1)/2) bilateral correlations. Figure 2 gives a scatter plot of the relationship between bank rate correlations and grain rate correlations. Note that the relationship is tighter for higher than for lower levels of bank rate integration. Thus, although results get noisy when integration levels are low, the grain-based approach captures differences in integration when markets are relatively well integrated, which is what we should expect if the approach has successfully picked up relevant information.

[15] While pair-wise analysis does not impose all restrictions of an n-region economic system, it has the advantage of being relatively simple, leading to robust results.

Figure 2: Capital Market Integration with Bank vs. Grain Rates



Finally, we assess capital market integration employing Pesaran et al.'s (1999, 2001) Autoregressive Distributed Lag ((ARDL) bounds test for cointegration. Table 2 reports ARDL bounds test results for two bilateral relationships, Philadelphia-New Orleans (PHI-NO) and New Orleans-Charleston (NO-CHA). Note that the distance, a likely determinant of capital market integration, between the cities in the two pairs is comparable.

For the Philadelphia-New Orleans bank rates, the cointegration F-statistic is about 27. The critical value of Pesaran et al.'s bounds test is highest if both series were integrated of order 1, at 7.84, and the critical value is at its lowest if both series were integrated of order 0, at 6.84.[16] In this case we can be confident that there is a long-run cointegration relationship for bank rates between Philadelphia and New Orleans because the F-statistic of about 27 exceeds even the higher

[16] As noted above, one advance of this test is that it can be applied whether or not one or both series are integrated of order I. We report bounds test critical values for relatively short time series tabulated Narayan (2005); note that the F-statistic of 27 is also larger than the comparable original critical value by Pesaran et al. (2001) for longer time series, which is 8.26.

critical value of 7.84. In contrast, for the New Orleans-Charleston bank rates the F-statistic is 4.1 and we cannot reject the null hypothesis that there is no co-integration relationship between bank rates in New Orleans and Charleston.

Given that the evidence for capital market integration between Philadelphia and New Orleans using the co-integration criterion in an ECM framework is much stronger than between New Orleans and Charleston, what are the corresponding results using the grain interest rates? We find an F-statistic of 22.4 for the Philadelphia-New Orleans pair, while the F-statistic for New Orleans-Charleston is 5.0 in the benchmark grain price approach. This means that using bank rates or grain rates, the researcher arrives at the same differences in capital market integration using the ARDL co-integration test in the ECM framework in this case. Although there can be some differences, we have found that simple bilateral correlations and the ARDL co-integration evidence generally paint a similar picture in terms of differences in market integration across regions.

We turn now to two extensions. First, it is clear from the fact that only two bank series are available in the year 1815 (see Table A.1) that the U.S. banking system at this time was still emerging. One might be concerned that early data availability for some markets in itself induces a bias in our analysis. To address that, note that by the year 1835 there is data on all six markets in most of the years. We therefore perform an analogous analysis as in the benchmark case but focus on the years 1835 to 1855. The advantage is that the analysis gives more uniform weight across regions. The cost is a lower number of observations, which is now n = 109, down from n = 181.

Table 2 shows that the overall mean grain interest rate for 1835 to 1855 is about 9.8%, which is higher than the average bank rate for 1835 to 1855 now (6.1%; not shown). The correlation of the average bank and average grain rates across cities does not change much (see column (3)). Furthermore, the focus on the period 1835 to 1855 leaves unchanged the ability of the grain price approach to explain the pattern of capital market integration (correlation remains at 0.64, see column (5)).[17] These results show that the main results are not driven by the fact that bank rates are available in some regions earlier than in others.

[17] Note that the ability of the ARDL bounds test (column (6)) to discriminate between co-integrated and not co-integrated series weakens, as does the time series fit (see column (2)); this is likely a consequence of the on average shorter time series employed now.

Second, we drop Charleston (South Carolina) from the analysis. Recall that the grain rate for Charleston is based on rice, not wheat prices, and the relationship between storage costs and price changes may be different for those grains. We see that dropping the rice series strengthens somewhat our ability to explain cross-regional differences in average interest rates, where the correlation between bank rates and grain rates is now equal to 0.80 (column (3)). In addition, the correlation between bilateral bank rate correlations and bilateral grain rate correlations is with 0.69 also higher than before (column (5)). This indicates, as one would expect, that the grain price approach benefits from employing the same type of grain instead of a mix of different grain types.

To summarize, this analysis of the benchmark suggests that the grain price approach works quite well. While it can be challenging to estimate region-by-year specific interest rates, capital development differences across regions are captured fairly accurately, both in terms of mean interest rates and in terms of capital market integration. In the next section we extend the analysis in a number of important dimensions.

4.3 Robustness of the Grain Price Approach

First, grain prices are often subject to stochastic shocks, trends, or cycles other than the gradient shown in Figure 1. We will apply several alternative time series filtering techniques such as the Butterworth (1930) filter to separate trend from cycle.[18] Second, there are likely to be unobserved factors affecting the price gradient in a given harvest year and region, such as variation in the timing of the harvest or changes in the per-month price of storage. We will thus analyze the influence of adding months (beyond August to December) or shifting the period for which the price gradient is computed. Third, we will examine robustness by adopting various sample restrictions, including dropping particularly high and low price changes, and incorporating price change thresholds. These approaches are in part motivated by the desire to eliminate noise, thereby reducing measurement error.

In all these cases, we are interested to see first, how well capital market performance as implied by our regional bank rates is captured by the grain price approach. Second, to the extent that the grain price approach captures some aspects of capital market performance better than

[18] See Hamilton (1994) and Wei (2006) for general discussions. We employ these techniques as implemented in STATA using the *tsfilter* and *tssmooth* commands.

others, as captured by the six criteria shown above (see Table 2), we focus on whether there are key differences to our benchmark findings.

We begin by eliminating stochastic shocks and trends that may overlap the see-saw pattern of Figure 1 by applying a number of standard time series filtering techniques, namely the following: (i) Christiano-Fitzgerald (2003), (ii) Butterworth (1930), (iii) Baxter-King (1999), and (iv) Moving average filters. In each case, we feed the log monthly grain prices through one of the filters before calculating the within-harvest year price gradient, as before. As an extension we will also show results based on (a) Hodrik-Prescott, (b) Exponential, and (c) Nonlinear time series filtering techniques. The filters (i) to (iv) have the advantage that the degree of smoothing depends on one (or a small number) of parameters that substantially change the time series properties of the series, which allows for an expanded robustness analysis. This is not the case for the filters (a) to (c).

Table 3 shows the average results for each filtering technique, together results based on the benchmark grain rates as well as the bank rates.

Table 3: The Grain Price Approach and Time Series Filtering

	N	Interest Rates				Market Integration				
		(1) Overall $\bar{\bar{r}}; \bar{\bar{\rho}}^m$	(2) T-stat ρ_{it}^m on r_{it}	(3) Corr $(\bar{\rho}_i^m, \bar{r}_i)$ across regions	(4) Bilat Corr $(r_{it}, r_{i'\,t})$, Bilat Corr $(\rho_{it}^m, \rho_{i'\,t}^m)$	(5) Pattern of Bilateral Correlations	(6) ARDL Cointegration Pesaran/Shin/Smith			
							PHI-CHA		NO-CHA	
		Average			Average	CC^m	F-stat	Coint p-val < 1%	F-stat	Coint p-val < 1%
Bank Rates		5.70			0.13		27.2	Yes	4.1	No
Benchmark		7.25	1.86	0.66	0.52	0.63	22.4	Yes	5.0	No
Christiano-Fitzgerald	100	5.74	1.88	0.23	0.48	0.60	14.2		12.8	5.74
Butterworth	96	5.08	1.77	0.48	0.46	0.65	14.3		12.4	
Baxter-King	144	5.56	1.53	0.61	0.52	0.57	14.5		10.8	
Moving-Average	72	0.94	0.58	0.24	0.68	0.44	26.2		12.2	
Hodrik-Prescott	4	6.27	1.61	0.70	0.45	0.65	11.2		9.6	
Exponential	18	-0.36	0.78	-0.36	0.64	0.41	40.2		9.9	
Nonlinear	5	5.03	1.33	0.65	0.53	0.58	22.8		10.0	

Notes: PHI-CHA is Philadelphia-Charleston, NO-CHA is New Orleans-Charleston.

The column N in Table 3 shows, for each filter, the number of methods (corresponding to parameter settings) for which the reported means are based (for Bank rates and Benchmark, N = 1). From these results we conclude, first, that across the board, filtering typically lowers the grain-price based interest rate estimate; the means in column (1) are all below those for both the bank rates and the benchmark method (unfiltered first-difference).

Second, exponential and moving-average smoothed data does not do well capturing year-to-year changes in interest rates, as indicated in column (2), in contrast to some of the filters which have a mean t-statistics of closer to 2. We also see that cross-regional interest rate differences are often not captured very well using exponential and moving-average smoothers (column 3), however it should be noted that Table 3 reports averages; below we will see that filtering techniques can 'work' when the appropriate degree of smoothing is applied.

Column (4) confirms that bilateral correlations of grain-price based interest rates are higher than among bank rates on average, likely the result of common high-frequency shocks that affect grain-based rates but not bank rates. Compared to the mean level of bilateral correlation, the pattern of bilateral correlations is picked up better using some filtering techniques, with mean correlations as high as 0.65 for the Hodrick-Prescott and Butterworth filters (see column 5), except for moving average and exponential filters. Finally, columns (6) and (7) show the mean results for the ARDL cointegration analysis. The (mean) F-statistic is higher for NO-CHA for all filtering techniques than for the bank rates or the benchmark grain price approach. This suggests that employing ARDL cointegration tests in an ECM framework using filtered grain price series might make it challenging to detect differences in capital market integration.

We now turn to the range of outcomes for a subset of filtering techniques, those with a N (the number of different smoothing parameter combinations) higher than 50. Results are shown in Table 4.

Table 4: Extended Results for Filtered Grain Price Data

	Interest Rates			Market Integration					
	(1) Overall $\bar{\bar{r}}; \bar{\bar{\rho}}^m$	(2) T-stat ρ_{it}^m on r_{it}	(3) Corr $(\bar{\rho}_i^m, \bar{r}_i)$ across regions	(4) Bilat Corr $(r_{it}, r_{i'\,t})$, Bilat Corr $(\rho_{it}^m, \rho_{i'\,t}^m)$	(5) Pattern of Bilateral Correlations	(6) ARDL Cointegration Pesaran/Shin/Smith			
						PHI-CHA		NO-CHA	
	Average			Average	CC^m	F-stat	Coint p-val < 1%	F-stat	Coint p-val < 1%
Bank Rates	5.70			0.13		27.2	Yes	4.1	No
Benchmark	7.25	1.86	0.66	0.52	0.63	22.4	Yes	5.0	No
Christiano-Fitzgerald	2.23-8.34	1.26-2.53	-0.67-0.80	0.26-0.60	0.56-0.67	9.9-20.5		2.23-8.34	
Butterworth	2.79-6.72	1.08-2.55	0.22-0.70	0.27-0.58	0.57-0.70	10.6-19.3		8.3-17.6	
Baxter-King	3.06-7.56	0.78-2.88	0.28-0.80	0.25-0.67	0.25-0.67	10.0-20.5		5.5-17.6	
Moving-Average	-1.21-4.09	-0.65-2.19	-0.57-0.82	0.59-0.77	0.30-0.59	15.6-36.2		3.2-24.6	

Notes: For each filtering technique, reported is the range of the central 90% of the results for different smoothing parameter combinations. The different combinations of smoothing parameters are: N = 100 for Christiano-Fitzgerald, N = 96 for Butterworth, N = 144 for Baxter-King, and N = 72 for Moving Average filter.

First, consider the three interest rate criteria (columns (1) to (3)). Looking at the central 90% of the results (between the 5th and the 95th percentile of parameter combinations), it is clear that the grain price approach has sometimes difficulties hitting interest rate levels (column 1). The grain price approach can do better than the unfiltered first-difference price series--the benchmark--in terms of year-to-year variation, see column 2. The picture for cross-regional variation in the mean interest rate varies: the Christiano-Fitzgerald and Moving-Average techniques can do very well (maximum correlations of about 0.8) but they do poorly for other smoothing parameter choices

(low correlations of around -0.6, see column 3). In contrast, the Butterworth and Baxter-King methods are, with highs of around 0.75 and low correlations around 0.25 more robust.
We now turn to our measures of capital market integration. While the ARDL cointegration evidence with the benchmark grain price approach is closely in line with the evidence from bank rates (namely, PHI-CHA is more integrated than NO-CHA), for almost all filtering techniques the difference in the ARDL F-statistic between the high- and the low-integrated pairs is now lower than for the unfiltered benchmark series. For example, while with bank rates the F-stat is about 27 versus 4, the mean for the Christiano-Fitzgerald smoother, e.g., is about 14 versus 13, and in fact the 95th percentile of the not cointegrated NO-CHA pair is *higher* than the 95th percentile of the cointegrated PHI-NO. The median of the difference in F-statistics between the pairs PHI-NO and NO-CHA is only 2.

In contrast, using the filtering techniques the pattern of bilateral interest rate correlations can be quite similar to that among the bank rates, with correlations that go as high as around 0.7 for the Butterworth and Baxter-King methods, see column (5). Turning to the ARDL co-integration ranges, it appears that while they are in line to the bilateral correlation results of column (5), the latter seem to be more robust, perhaps because of their simplicity.

Of course, the optimal setting of smoothing parameters for a filtering technique is unknown in a specific empirical application. Given that, it is useful to examine the worst-case scenario, when the researcher errs in setting the smoothing parameters. We see that both the Butterworth and the Christiano-Fitzgerald filters never go much below a correlation of 0.6 in accounting for the pattern of bilateral interest rate correlations (see column (5)), and of the two filters, the Butterworth filter performs considerably better in terms of accounting for cross-regional variation in mean interest rates (see column 3)).

We also note that the benchmark grain price approach, without any filtering, appears to work quite well. This is encouraging because it shows that the results are not predominantly driven by common shocks that are left in the unfiltered data series. Therefore, we employ the benchmark grain price approach to explore a number of other dimensions. Table 5 examines the robustness of the method to outliers, unknown information, and measurement error.

The results in Table 5 show that employing the median instead of the mean (= Benchmark) of the monthly price changes raises the mean interest rate somewhat (row I, column 1) while at the same time one captures the year-to-year interest rate changes somewhat less well (row I, column 2). The median instead of the mean turns out to be quite robust in terms of cross-regional mean correlation (0.77 instead of 0.79), while the pattern of market integration differences is captured somewhat less well (0.54, compard to 0.64).

Adding January to the months from which the price gradient is computed leads to a slightly better capturing of the pattern of regional capital market integration patterns (row II, column 5) while the ARDL F-statistic difference between PHI-NO and NO-CHA shrinks (row II, columns 6, 7).

Winsorizing the price changes at the 1st and 99th percentile does not lead to qualitative changes (row III), which is important because it shows that the results are not driven by extreme outliers (row III). Eliminating 10% of extreme price changes leads to similar results, except that we find also (counter-factually) evidence for cointegration for the NO-CHA pair (row IV). Notice that with winsorizing, the grain price approach yields a correlation of almost 0.9 in terms of cross-regional mean interest rate variation (column (3)).

Given that the see-saw pattern in Figure 1 results from increasing prices until right before the harvest, one may be tempted to discard all negative price changes (row V). While this naturally raises mean interest rate levels (column 1), it also drastically lowers the extent to which the grain price approach captures the pattern of capital market integration (column 5). Actual grain prices move not only up but also down, and not only around harvest time. It is clear that discarding nearly half of the distribution of price changes—those that are negative--is not compatible with estimating the patterns of capital market integration. Related to this, row VI shows results for utilizing a subset of months for the price gradient calculation. Because the months of harvest and storage are often unknown in historical settings, the selection of months with typically relatively high price increases can be seen as a strategy to deal with measurement error. We see that selecting months that have typically price increases above some threshold captures the patterns of regional capital market integration quite well, as long as we use all price changes (positive and negative) for this subset of months (column 5).

Overall, the analysis has shown that the grain price approach to capital market development is quite robust. Among the best-performing methods across several indicators are the unfiltered and the Butterworth-filtered grain price series.

Table 5: Robustness to Outliers, Unknown Information, and Measurement Error

		Interest Rates				Market Integration				
		(1) Overall Average $\bar{\bar{r}}; \bar{\bar{\rho}}^m$	(2) T-stat ρ^m_{it} on r_{it}	(3) Corr $(\bar{\rho}^m_i, \bar{r}_i)$ across regions	(4) Bilat Corr $(r_{it}, r_{i't})$, Bilat Corr $(\rho^m_{it}, \rho^m_{i't})$	(5) Pattern of Bilateral Correlations	(6) ARDL Co-integration Pesaran/Shin/ Smith			
							PHI-CHA		NO-CHA	
					Average	CC^m	F-stat	Coint p-val < 1%	F-stat	Coint p-val < 1%
	Bank Rates	5.70			0.13		27.2	Yes	4.1	No
	Benchmark	7.25	1.86	0.66	0.52	0.63	22.4	Yes	5.0	No
I	*Median*	10.12	0.98	0.77	0.33	0.54	21.9	Yes	7.2	No
II	*Storage Months*	7.67	1.29	0.62	0.56	0.65	9.4	Yes	6.3	No
III	*Winsorize 1/99*	7.40	1.96	0.86	0.50	0.62	21.9	Yes	6.0	No
IV	*Winsorize 5/95*	7.43	1.46	0.89	0.52	0.53	23.6	Yes	10.0	Yes
V	*Positive*	60.86	0.71	0.53	0.23	0.06	15.0	Yes	5.5	No
VI	*Exceeds 5%*	25.02	0.65	0.77	0.45	0.62	15.2	Yes	5.7	No

Notes: *Median* computes price gradient as median instead of mean of Aug-Dec one-period log price differences; *Storage Months* changes period from which price gradient is computed from Aug-Dec to Aug-Jan; *Winsorize 1/99* price changes below 1st percentile are replaced by 1st percentile, price changes above 99th percentile are replaced by 99th percentile; *Winsorize 5/95* price changes below 5th percentile are replaced by 5th percentile, price changes above 95th percentile are replaced by 95th percentile; *Positive* drops negative price changes in gradient calculation; *Exceeds 5%* uses only price changes for months that on average imply an annual rate of > 4.8%.

5. Conclusions

This paper has employed regional bank rates and matching grain prices for the early 19th century in the United States to investigate how well the grain price approach captures actual capital market development using a number of methods and different criteria. The analysis has shown that it can be challenging to employ the grain price approach to study capital market development in a particular region and year in isolation. In contrast, we have shown that the grain price approach to capital markets works quite well, and is also robust, when researchers are interested in differences across regions.

There is a quite a bit of variation in the determinants of the recorded price of grain in a specific region and year, such as storage technology, consumer preferences, and data collection. While in historical contexts, due to unavailability of data, these factors may be hard to model explicitly, if is also often the case that many of the relevant factors are changing slowly over time and are also common to a greater area. Therefore, spurious influences can often be eliminated by a comparison across regions, and as a consequence the grain price to capital markets works well when taking a comparative approach. We conclude that the grain price approach to capital markets is a useful tool in historical contexts and when other reliable capital market information is not available.

References

Baxter, M., and R. G. King (1999), "Measuring business cycles: Approximate band-pass filters for economic time series", *Review of Economics and Statistics* 81: 575-593.

Bodenhorn, H. (2000), *A History of Banking in Antebellum America: Financial Markets and Economic Development in an Era of Nation-Building*, Cambridge: Cambridge University Press.

Bodenhorn, H., and H. Rokoff (1992), "Regional Interest Rates in Antebellum America." In *Strategic Factors in American Economic History: A Volume to Honor Robert W. Fogel,* 159-187. Edited by Claudia Goldin and Hugh Rockoff. Chicago: University of Chicago Press, 1992.

Brunt, L., and E. Cannon (2009), "How does finance generate growth? Evidence from the first Industrial Revolution", working paper, NHH Bergen and University of Bristol, February.

Brunt, L, and E. Cannon (1999), "A Grain of Truth in Medieval Interest Rates? Re-examining the McCloskey-Nash Hypothesis", Oxford working paper, February.

Buchinsky, M., and B. Polak (1993), "The Emergence of a National Capital Market in England, 1710 – 1880", *Journal of Economic History* Vol. 53, No. 1: 1-24.

Butterworth, S. (1930), "On the Theory of Filter Amplifiers", *Experimental wireless and the wireless engineer*, October 1930, pp. 536 – 541.

Clark, G. (2001), "Markets and Economic Growth: The Grain Market of Medieval England", working paper, UC Davis.

Christiano, L. J., and T. J. Fitzgerald (2003), "The band pass filter", *International Economic Review* 44: 435-465.

Davis, L. (1965), "The Investment Market, 1870 – 1914: The Evolution of a National Market", *Journal of Economic History*, Vol. 25, No. 3: 355-399.

Good, D. F. (1977), "Financial Integration in Late-Nineteenth-Century Austria", *Journal of Economic History* 37(4): 890-910.

Gurley, J. G. and E. S. Shaw (1955), "Financial Aspects of Economic Development." *American Economic Review* 45(4): 515-38.

Hamilton, J. D. (1994), *Time Series Analysis*. Princeton: Princeton University Press.

Jacks, D. (2006), "What Drove Nineteenth Century Commodity Market Integration?" *Explorations in Economic History* 43(3): 383-412.

Jacks, D. (2005), "Intra- and International Commodity Market Integration in the Atlantic Economy, 1800-1913", *Explorations in Economic History* 42(3): 381-413.

Komlos, J., and R. Landes (1991), "Anachronistic economics: grain storage in medieval England", *Economic History Review* XLIV, 1: 36 – 45.

Kaldor, N. (1939), "Speculation and Economic Theory", *Review of Economic Studies* Vol. 7, pp.1-27.

McCloskey, D., and J. Nash (1984), "Corn at Interest: The Extent and Cost of Grain Storage in Medieval England", *American Economic Review* 74: 174-187.

Mitchener, K. J., and M. Ohnuki (2009), "Institutions, Competition, and Capital Market Integration in Japan", *Journal of Economic History* 69(1): 138-171.

Mitchener, K. J., and M. Ohnuki (2007), "Capital Market Integration in Japan", *Monetary and Economic Studies* 25(2): 129-153.

Narayan, P.K. (2005), "The Saving and Investment Nexus for China: Evidence from Cointegration Tests", *Applied Economics*, 37 (17), 1979-1990.

Pesaran, M.H. and Y. Shin (1999): An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis. In: Strom, S. (Ed.): *Econometrics and Economic Theory in the 20th Century*: The Ragnar Frisch Centennial Symposium. Cambridge, UK: Cambridge University Press.

Pesaran, M.H., Shin, Y. and R.J. Smith (2001), "Bounds Testing Approaches to the Analysis of Level Relationships", *Journal of Applied Econometrics*, 16 (3), 289-326.

Pomeranz, K. (1993), *The Making of a Hinterland: State, Society, and Economy in Inland North China, 1853-1937*, University of California Press.

Rousseau, P. L. (1999), "Finance, investment, and growth in Meiji-era Japan", *Japan and the World Economy* 11: 185-198.

Rousseau, P. L. , and P. Wachtel (1998), "Financial Intermediation and Economic Performance: Historical Evidence from Five Industrialized Countries", *Journal of Money, Credit, and Banking*, Vol. 30(4): 657-678.

Shiue, C. H., and W. Keller (2007), "Markets in China and Europe on the Eve of the Industrial Revolution", *American Economic Review* 97.

Shiue, C. H. (2002), "Transport Costs and the Geography of Arbitrage in Eighteenth-Century China", *American Economic Review* 92(5): 1406-1419.

Sylla, R. (1969), "Federal Policy, Banking Market Structure, and Capital Mobilization in the United States, 1863-1913", *Journal of Economic History* 29(4): 657-686.

Taub, B. (1987), “A Model of Medieval Grain Prices: Comment”, *American Economic Review* Vol. 77, 5: 1048 – 1053.

Wei, W. W. S. (2006), *Time Series Analysis: Univariate and Multivariate Methods*. 2nd ed. Boston: Pearson.

Williams, J. C. and B. D. Wright (1991), *Storage and Commodity Markets*, Cambridge University Press.

Working, H. (1949), “Theory of Price of Storage”, *American Economic Review* 39(6): 1254-62.

Working, H. (1933), “Price Relations between July and September Wheat Futures at Chicago since 1885”, Wheat Studies of the Food Research Institute 9(6): 187-274.

Appendix

Table A.1: Regional U.S. bank interest rates, 1815-1855

Year	New York City	Philadelphia	New Orleans	Indiana	South Carolina	Virginia
1815		4.62			8.55	
1816		5.70			5.55	
1817		3.69			5.45	
1818		5.55			8.35	
1819		3.84			4.23	
1820		5.60			4.36	
1821		4.78			4.34	
1822		5.65			5.77	4.08
1823		3.42			4.86	3.81
1824		5.21			4.62	4.14
1825		4.24			4.15	4.61
1826		5.86			2.53	3.97
1827		4.95			7.81	4.97
1828		5.82			4.50	3.97
1829		4.58			4.09	4.23
1830		4.97			4.14	4.45
1831		5.15			4.49	4.84
1832		4.48			4.24	6.28
1833	5.03	6.54			4.37	8.02
1834	5.69	3.41	6.82		3.54	3.75
1835	5.11	6.12	7.54	7.97	4.12	4.43
1836	6.82	5.74	7.16	7.60	4.37	7.22
1837	5.91	4.75	11.28	8.50	6.11	5.70
1838	5.33	5.47	7.68	8.35	6.00	4.41
1839	4.24	3.44	10.15		5.11	6.78
1840	5.57	5.73	9.01		3.10	5.43

1841	5.27	4.41	8.86	7.65	5.75	4.21
1842	3.95	2.50	8.85	5.05	5.97	4.20
1843	5.37	3.72		2.85	6.2	4.12
1844	5.80	5.18		5.74	6.03	4.15
1845	5.21	4.20		7.86	5.76	5.10
1846	4.69	6.39			5.42	3.95
1847	5.04	5.21		6.32	7.11	4.99
1848	5.32	4.83	7.73	8.36	5.07	4.43
1849	7.17	6.35	4.84	7.77	6.03	4.19
1850	5.62	6.47	7.42	9.45	9.28	4.53
1851	6.32	4.69	7.79	5.95	7.67	4.72
1852	7.23	5.56	7.91	6.81	6.38	5.53
1853	4.99	5.10	7.38	6.37	6.71	4.46
1854	4.98	5.31	8.50	7.70	5.57	5.04
1855	5.87	5.70	12.81	10.89	6.03	5.18
Mean	5.50	5.00	8.34	7.29	5.46	4.82
Std.Dev.	0.82	0.94	1.81	1.78	1.47	0.99

Notes: Source is Bodenhorn-Rokoff (1992). For the co-integration analysis, values for New Orleans and Indiana during the years 1835 to 1855 are linearly interpolated.