How does finance generate growth?

Evidence from the first Industrial Revolution

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Abstract

We establish a microeconomic link between the depth of financial intermediation and economic growth. We introduce a new panel of rates of return on capital in each county of England and Wales in each year of the Industrial Revolution (1770-1820). We show that raising the density of bank coverage in a county substantially reduced the interest rate differential with London, so that the explosion in provincial banking significantly reduced regional interest rate differentials across the country. We then show that local interest rates strongly affected the local level of high-technology fixed capital investment.

Keywords: banks, financial integration, industrial revolution.
JEL Classification: O16, N13, G21.

Introduction.

Extensive research has established a strong link between the extent of financial intermediation and rates of economic growth (for a survey, see Levine, 2005). Several dimensions of financial development have been considered, various measures of growth have been used and various settings have been considered. The conclusion is that the link between finance and growth is causal and robust.[1] The weak point in this literature is its failure to illuminate the mechanism at work. Exactly how does finance generate growth? A deeper understanding of the mechanism could help to inform policy and institutional design. The microeconomic linkages between finance and growth are the focus of this paper.

Our setting is England during the Industrial Revolution, which offers an interesting case study because it saw a massive expansion of banking and very few alternative sources of finance (equity markets, in particular, being *de facto* closed).[2] Moreover, the unprecedented take-off in the real economy that occurred concurrently with the expansion of the banking system offers *prima facie* evidence that banking was an important cause of economic growth. The Industrial Revolution occurred in England between 1770 and 1840; it was the first of its kind and is widely regarded as the break point between modern and pre-modern patterns of economic growth. Modern deposit banking was invented at this time and grew extremely rapidly: in 1770 there were a handful of banks; by 1800 there were 300; and by 1815 there were 650.[3]

How might improved financial intermediation promote economic growth? By redirecting capital from projects with a low economic value to those with a higher one. In a spatial context, improvements in financial intermediation should generate credit market integration and interest rate convergence across regions. We document exactly this process using the rate of return in each of the 42 counties of England and Wales, showing that there was interest rate convergence with London (the credit market hub) as the number of local banks rose. Increases in the level of local competition forced banks to price more competitively, passing on to local consumers more

[1] For example, Demirgürç-Kunt and Levine, 2001; Beck, Levine and Loayza, 2000; Rousseau, 1999; Rousseau and Wachtel, 1998; Loayza and Rancière, 2006; Shen and Lee, 2006; Rajan and Zingales, 1998; and Jayaratne and Strahan, 1996.

[2] Following the collapse of the South Sea Bubble in 1720, new firms could be floated on the exchange only by special Act of Parliament; these were granted only to public utilities, such as canals.

[3] Before the Industrial Revolution, banks were focused on financing either long distance trade or bankrupt monarchs. By contrast, the banks analysed in this study functioned essentially as they do today – operating checking and deposit accounts, managing client portfolios, and making loans to individuals and businesses.

of the benefits from arbitraging savings and loans with London. Importantly, our test overcomes the endogeneity problem that plagues many analyses of finance and growth, not merely by using instrumental variables (which we do in addition), but by generating qualitatively different predictions according to which way causality runs. Our hypothesis is that local bank entry pushes down the differential between the local interest rate and London (i.e. banks and interest rate differentials will be negatively related). If causation ran the other way then high interest rate differentials would attract bank entry because there were high profits to be made (i.e. banks and interest rate differentials would be positively related). We find a strong negative relationship, which is unambiguous evidence of the positive effects of banking on spatial interest rate convergence. We then show that lower local interest rates led to increased local investment in high-technology capital goods – namely, steam engines. Thus bank entry into areas with high interest rates caused lower interest rates and thus an increase in technological change.

Our paper is related to that of Beck, Demirgüç-Kunt and Maksimovic (2004, 2005). They use survey data to show: first, that firm financing is more problematic in countries characterized by higher bank concentration; and, second, that obstacles to obtaining finance cause firms to grow more slowly. Together, these results imply that bank concentration harms firm growth. But it does not tell us the mechanism at work. We take the analysis forward by showing that local lending rates are higher in areas with higher bank concentration and these higher rates cause lower fixed capital investment by firms.

Our paper also covers some of the same ground as Demirgüç-Kunt, Laeven and Levine (2004), although our results are somewhat contrasting. They find that bank concentration is positively associated with the margin between borrowing and lending rates – until they control for regulatory environment and institutional arrangements, at which point the relationship weakens and becomes statistically insignificant. We also analyze interest rate margins (although it is the margin between the local market and the London market) and show that increased concentration causes wider margins. But in our setting there are no confounding effects from regulation (banking was unregulated) or institutional arrangements (they were uniform across England). Our results contrast also with those of Claessens and Laeven (2004), who find no relationship between competition and concentration in the banking sector. Instead, they find that contestability is the key factor in ensuring competitive markets. Banking markets in the

Industrial Revolution were fully contestable (indeed there was massive entry) but this was not enough to generate marginal cost pricing (*i.e.* full interest rate convergence with London).

The paper proceeds as follows. Section 1 outlines the unique way in which the banking system operated during the Industrial Revolution. Section 2 describes our data. Section 3 estimates a model linking local banks and local interest rates. Section 4 estimates a model of steam engine adoption using our local interest rates. Section 5 concludes. Appendices discuss our interest rate data in more detail and additional results.

1. The British banking system

The classic analysis of British banking in the eighteenth and nineteenth centuries is that offered by Bagehot (1873), which emphasizes the importance of capital in promoting economic growth:

> In countries where there is little money to lend, and where that little is lent tardily and reluctantly, enterprising traders are long kept back, because they cannot at once borrow the capital, without which skill and knowledge are useless. (p. 14).

Britain was in a fortunate position because:

> We have entirely lost the idea that any undertaking likely to pay, and seen to be likely, can perish for want of money; yet no idea was more familiar to our ancestors, or is more common now in most countries. A citizen of London in Queen Elizabeth's time could not have imagined our state of mind. He would have thought that it was of no use inventing railways (if he could have understood what a railway meant), for you would not have been able to collect the capital with which to make them. (p. 7).

By contrast,

> Taking the world as a whole – either now or in the past – it is certain that in poor states there is no spare money for new and great undertakings, and that in most rich states the money is too scattered, and clings too close to the hands of the owners, to be often obtainable in large quantities for new purposes. (p. 7-8).

Bagehot argues that this ready availability of capital in Britain was due to her unique banking system:

> Concentration of money in banks, though not the sole cause, is the principal cause which has made the Money Market of England so exceedingly rich, so much beyond that of other countries. (p. 6).

Even the other advanced economies were then laboring under a rudimentary banking system and a shortage of capital:

> If you take a country town in France, even now, you will not find any such system of banking as ours. Cheque-books are unknown, and money kept on running account by bankers is rare. People store their money in a *caisse* at their houses. (p. 76).

So how exactly did the British banking system work? Joint stock banking was outlawed in England and Wales until 1826:[4] up to this time the banking system outside London was based on the country banks. These were private partnerships, restricted to a maximum of six partners who each had to endure unlimited liability. Banks therefore had a very restricted capital base and almost always possessed only one outlet (*i.e.* they were unit banks). To overcome their extremely limited geographic reach, the country banks developed correspondent relationships with a bank in London. In this way, they could send excess deposits to London and still earn a reasonable return on them; or they could borrow from London when they needed more funds locally. Hence the local country banks played a crucial role in recycling capital from surplus to deficit regions via London. As Bagehot put it:

> [T]here are whole districts in England which cannot and do not employ their own money. No purely agricultural county does so. The savings of a county with good land but no manufactures and no trade much exceed what can be safely lent in the county. These savings are first lodged in the local banks, are by them sent to London, and are deposited with London bankers, or with the bill brokers. In either case the result is the same. The money thus sent up from the accumulating districts is employed in discounting the bills of the industrial districts. Deposits are made with the bankers and brokers in Lombard Street by the bankers of such counties as Somersetshire and Hampshire, and those bill brokers and bankers employ them in the discount of bills from Yorkshire and Lancashire. (p. 12).

Moreover, the country bankers were heavily engaged in this pursuit:

> All country bankers keep their reserve in London. They only retain in each country town the minimum of cash necessary to the transaction of the current business of that country town. Long experience has told them to a nicety how much this is, and they do not waste capital and lose profit by keeping more idle. They send the money to London, invest part of it in securities, and keep the rest with the London bankers and bill brokers. (p. 30-31).

[4] The only exception to this was the Bank of England, which enjoyed privileged joint stock status in return for being the Government's banker, but did not provide banking services outside London in this period.

In this way, the banks linked each of their localities directly to the London money market. It is interesting to note that there was little or no interaction *between* local banks. Instead there was a sophisticated network of bilateral relationships with London, and an almost complete absence of regional networks.

The number of banks grew extremely rapidly between 1800 and 1815, from around 300 to around 650 banks. Therefore if improvements in financial intermediation have a measurable effect on financial market integration then we would expect to be able to measure it in our setting.[5] Notice also that the initial distribution of banks across counties was very uneven, and that the growth over time in the number of banks in each county also varied enormously. This is extremely useful for our empirical strategy because it means that there was a lot of variation in the explanatory variable. Note, in particular, that in some counties the number of banks was actually falling over time, so our results are not driven simply by the presence of an upward trend in all the variables.

2. Measures of banking, interest rates and other explanatory variables

In this section we discuss the data that we have collected to analyse the effect of banking on interest rates.

2.1 Measuring banking services.

Modern analyses of banking (such as Demirgüç-Kunt and Levine, 2001) use the size of the money supply relative to GDP, private credit or bank assets to measure financial intermediation. Apart from the fact that these variables are themselves endogenous, such data are not available for the period that we are studying.

Instead we have collected the number of banks and the number of bank outlets operating in each town in each year, as reported in the *Post Office Directory* annually from 1801 onwards.

[5] There were very few non-bank financial intermediaries in England in this period and the main source of business finance was the savings of the entrepreneur, his family and, increasingly, the banks (Mathias, 1983, pp. 134-6).

Since very few banks had more than one outlet, these two variables are almost the same and it makes little difference which one we use.[6]

Either of these two measures almost certainly reflects the local supply of banking services, since there is very good reason to believe that the size of each bank was fairly constant across the sample. We do not have direct evidence on this because very few bank balance sheets have survived. However, the asset bases of all country banks were circumscribed by the requirement that banks take the legal form of an unlimited liability partnership with a maximum of six partners. In a random sample of 30 banks for which we do know the number of partners, the minimum was 1 partner and the maximum 5; the mean was 3.0 and the standard deviation was 1.3. It may seem surprising that we only ever observe partnerships that were smaller than the legal maximum. But this almost certainly stems from the unlimited liability requirement: a banker would want only partners whom he could really trust, and he would lend only to borrowers about whom he had good information. This is reflected in the fact that the partners in a bank were very often related to one another, either by blood or marriage. Clearly, if modern banks in the US were limited to a maximum of six shareholders – and each of those shareholders had to have unlimited liability – then bank sizes would become much more homogeneous than they are currently. It would simply no longer be feasible to have Bank of America and so on.

Furthermore, to the extent that the number of banking outlets is an imperfect measure of the supply of local banking services, we merely face a classic errors-in-variables problem, which will bias parameter estimates towards zero. Hence our OLS estimates provide a lower bound on the effectiveness of banks. And we can obtain better estimates by using IV rather than OLS estimation.[7]

One further problem that we need to address is that banks might be linked together. Some individuals and some families were involved in more than one bank, so one might wonder whether two banks were really independent, even though they were legally distinct entities. So we constructed a third measure of banking services based on these identifiable "banking combinations": in our analysis below this variable yielded empirical results almost identical to our first two measures, so we do not report them here.

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[6] Although the ratio of banking outlets to banks was steadily growing over the period 1801 to 1815, it never exceeded 1.065. Dorset, the county with the highest ratio of outlets to banks, had only 15 outlets from 11 banks in the peak year of 1815 and over the entire period only five banks ever operated more than three outlets.

[7] A further cause of measurement error might be that some London correspondents were bigger or better than others. But this problem will also be resolved by IV estimation.

Regardless of whether we look at banking outlets, banks or banking combinations, we need to adjust the data to take account of the fact that our units of observation of interest rates vary greatly in size: the largest county (Yorkshire) is 40 times the area of the smallest county (Rutland) so it is unsurprising that it has more banks. Perhaps an ideal solution to this issue would be to divide the number of banks (or outlets or combinations) by GDP. But such data are not available, so instead we divide by the local population total. These data are taken from the 1801, 1811 and 1821 censuses, from which we create annual data by interpolating with a cubic spline.[8] Although the overall supply of banking services rose considerably through the period, by this measure our data show considerable variation both between and within counties.

2.2. Inferring the interest rate from grain prices.

In the absence of regional interest rates we need to infer rates of return from other data sources and we use the seasonal fluctuation in grain prices. This choice is based on data availability and is justified in detail in Appendix A. The data that we use for grain prices are based on official *London Gazette* average prices of wheat in the 39 counties of England, together with Welsh prices averaged for South Wales and North Wales, giving us 41 observations for each week for the whole period. Official data for London prices are only available before 1793 and hence do not overlap with the period for which we have data on banks, but we have been able to construct a weekly London wheat price series for 1801-1815 from contemporary newspapers.

The idea of using grain prices to infer the interest rate was introduced by McCloskey and Nash (1984), who used it to estimate interest rates in the middle ages; formal demonstrations of the underlying model are provided by Taub (1987) and Deaton and Laroque (1992). Since grain was harvested once per annum (generally in August in England) it had to be stored for the rest of the year as stocks were gradually consumed. In between harvests, the grain price had to appreciate enough to offset the cost of storage and physical depreciation, δ, and the rate of return on the capital invested in the purchase of the grain, r_t, otherwise rational economic agents would not have stored the grain and would instead have found some other investment opportunity for their savings. So long as there were storage, prices would obey the no-arbitrage condition

[8] The 1801 Censal data are adjusted for parishes known to be omitted following the suggestion of Wrigley and Schofield (1981). Linear interpolation of the data produces almost identical results. The simpler alternative of dividing banks by county area led to similar results in our analysis below.

(1) $$p_t = \frac{1-\delta}{1+r_t} \mathrm{E}_t\left[p_{t+1}\right] \quad \Rightarrow \quad \ln p_{t+1} \approx \ln p_t + r_t + \delta + e_t$$

where e_t is a white noise error. This means that prices rise steadily throughout the year at rate $r_t + \delta$, except at the point of harvest; at that point, stocks are either zero or minimal (being held only for insurance reasons) and prices typically fall. If equation (1) is correct then we should be able to estimate the gross rate of return from weekly grain prices.

Empirical tests by Deaton and Laroque (1992) of the no-arbitrage condition suggest that the model is only partially successful. But their implementation of the model uses annual data and assumes that the interest rate is constant over a long period. Since our point is that the interest rate is changing over time, their results, together with subsequent papers (Deaton and Laroque, 1995; Chambers and Bailey, 1996), are not really very helpful in our context.

A more direct test involves checking that the seasonal pattern of grain prices is as suggested by McCloskey and Nash (1984): namely, that the no-arbitrage condition determines behaviour between harvests and that there is a price fall at the time of the harvest. Figure 1 presents graphically our estimates of the *average* seasonal pattern of wheat prices over the entire period 1770-1820 in England and Wales.[9]

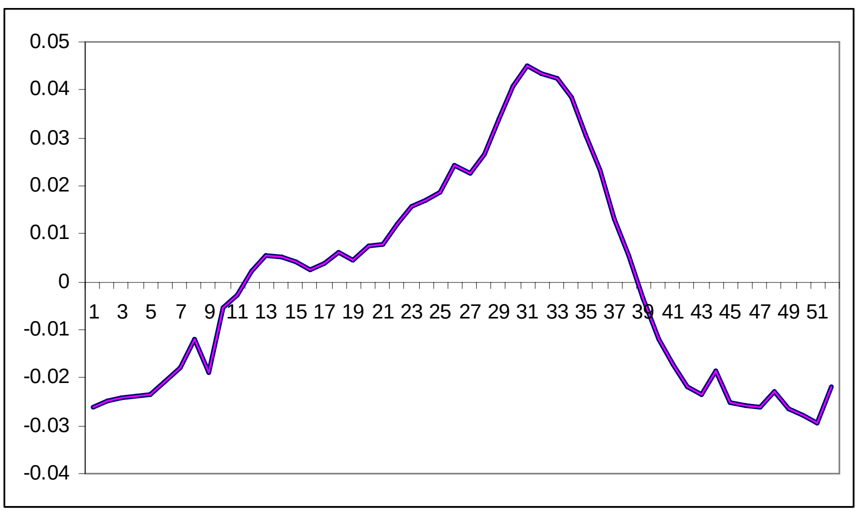

Figure 1: Average Seasonal Pattern of Grain Prices

[9]The graph shows $\hat{a}_{week}$ from the regression $\ln P_{year,week} = a_0 + \sum_{week=1}^{52} a_{week} + e_{year,week}$

Figure 1 does provide support for the McCloskey and Nash hypothesis: the log of the price of threshed wheat rises gradually throughout the year until harvest time, at which point stocks were low. Prices were then falling for a relatively short period after the harvest. Arguably we should expect prices to fall much more quickly after the harvest: taken at face value, wheat prices were falling from weeks 32 to 47, whereas the theory is inconsistent with stocks of wheat being held while prices were falling for such a long period. But figure 1 is estimated over a fifty year period and the timing of the harvest would have varied considerably from year to year. Furthermore, the prices reported are for threshed wheat and hence include not only the value of the wheat but also the labour input of threshing. We know that labour costs would have been falling at this time of year as demand for labour went from very high (ploughing and sowing) to very low (little else to do during winter); so it would have made sense to hold unthreshed grain immediately after the harvest, even while the price of threshed grain were falling.

A possible objection to our model is that equation (1) assumes temporal arbitrage but not spatial arbitrage: would prices also be equalised across regions (in which case all regions would have the same rate of return)? There are three pieces of evidence against this. First, data on the quantity of wheat traded, which are available for the single year of 1818, confirm that wheat was widely traded (and hence grown) in all areas, even if the climate were unsuitable. This is *prima facie* evidence that the cost of moving wheat from one area to another was high.

Second, figure 2 reports the average and extreme values of wheat prices. Clearly prices are correlated, but we should expect significant correlation even with no spatial arbitrage because different regions experience similar weather and also much of the price variation is due to the underlying price movements (*i.e.* inflation) of the Napoleonic Wars. Moreover, the spread of prices is also very high and a more detailed analysis of the data shows that there were large differences even between adjacent areas.

Third, we have direct evidence that transport costs were sufficiently high to ensure substantial divergence in wheat prices in individual markets. Jackman (1916, p. 723) suggests that costs of carriage by road were about 0.75d per hundredweight per mile in 1810, corresponding to about 0.365d per bushel per mile. Since the price of wheat ranged from about 50d to 150d per bushel, the cost of transporting wheat 50 miles (19d) was in the range of 13 to 38 per cent of the value of the wheat. However, it is certainly the case that there were improvements in transportation in this period and we control for this with data on turnpikes, discussed in section 2.3

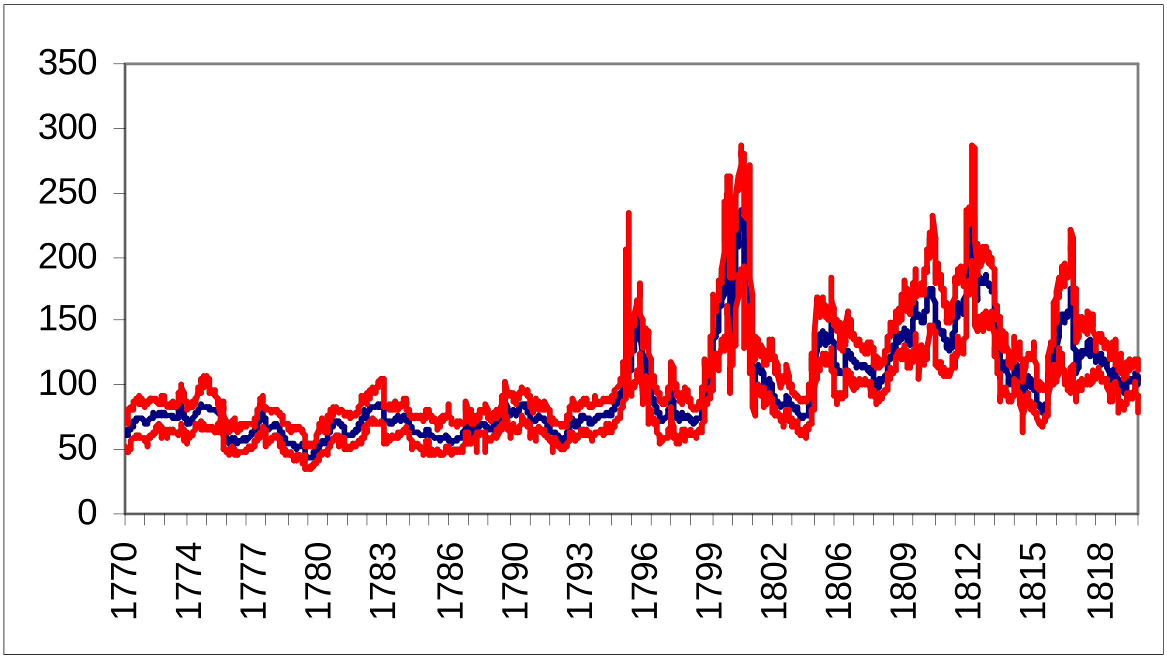

Figure 2: Weekly wheat prices (Mean, Minimum and Maximum, pence per Quarter)

The data appear to fit the theoretical model sufficiently closely that we can proceed to estimate interest rates using rates of return. Since wheat prices in the early winter and early summer have high variance, our preferred measure is the rate of return on wheat for each county and London using the price change from January to April (i.e. the first 14 weeks of the year):

(2) $$\hat{\alpha}_{year,\,county} = \frac{52 \times \ln\left(P_{week=14,year,county} / P_{week=1,year,county}\right)}{13}$$

Similar results were obtained by using the price change from January to July. The average interest rates thus estimated for each county are reported in table 1.

Table 1. County average rates of return, 1771-1820 (%).

Dorsetshire	3.8	**AVERAGE**	**9.8**
Gloucestershire	4.2	Staffordshire	10.1
Somersetshire	4.5	Warwickshire	10.1
LONDON	**4.7**	Cambridgeshire	10.5

Worcestershire	5.9	Devonshire	10.5
Leicestershire	6.0	Lincolnshire	10.8
Derbyshire	6.6	South Wales	11.0
Wiltshire	6.6	Shropshire	11.2
Rutlandshire	6.7	Norfolk	11.4
Hampshire	7.7	Yorkshire	11.5
Northamptonshire	7.7	Essex	11.6
Oxfordshire	7.8	Surrey	11.7
Huntingdonshire	8.0	Cumberland	12.0
Buckinghamshire	8.5	Lancashire	12.2
Bedfordshire	8.6	Suffolk	12.9
Hertfordshire	8.7	Cheshire	14.1
Nottinghamshire	8.7	Westmorland	14.5
Kent	8.9	Herefordshire	14.9
Berkshire	9.3	Cornwall	15.3
North Wales	9.5	Northumberland	15.7
Middlesex	9.6	Durham	18.2
Sussex	9.7		

These results are consistent with the narrative from Bagehot: rates of return on capital were low in agricultural counties, where there were limited investment opportunities, and high in the industrial counties such as Staffordshire (pottery), Warwickshire (metal goods), South Wales (coalmining), Yorkshire (coalmining, iron and woolen production), Lancashire (cotton spinning and weaving), Cornwall (copper mining and smelting), Durham and Northumberland (coalmining). We calculate that the rates of return in table 1 are negatively correlated with the proportion of families engaged in agriculture (-0.22, p = 0.02) and positively correlated with the proportion of families engaged in trade (+0.32, p = 0.22).[10] Of course, the local rate of return was not determined solely by the local supply and demand for loanable funds and this brings us to the issue of banks and financial intermediation.

2.3 Additional explanatory variables

In order to provide an adequate test of the effect of banking on the rate of return on grain, we need to consider the effect of transport costs. Since these were falling over the period, increased arbitrage in grain markets could have reduced the wheat price differentials across markets. Price

[10] The data on the proportion of families engaged in agriculture or trade are taken from the 1811 census.

differentials put a bound on the local interest rate. Take the extreme case where wheat markets were perfectly integrated; then there would be no scope for prices to differ and no differences in rates of return. Financial markets would effectively be integrated through the physical movement of commodities across counties.

We discussed in the previous section that transport costs were very high. However, it is certainly the case that there were improvements in transportation in this period. For example, the mileage of turnpikes increased from 15,833 miles in 1801 to 16,945 miles in 1815,[11] which might have been sufficient to narrow wheat price differentials enough to simultaneously erode rates of return on grain.[12]

Accordingly, we consider the role of transport costs by looking at the density of turnpikes (miles of turnpike divided by area of county). When we consider town level data it is less obvious how to scale the mileage of turnpike, so we consider average mileage linked to a town and also a turnpike dummy.[13]

2.4 Endogeneity and measurement error.

As discussed above, our explanatory variables could suffer both from measurement error and endogeneity. The supply of banking services and the supply of roads is endogenous because we know that these were provided by the private sector in order to respond to arbitrage opportunities. Measurement error exists because our banks variable is only an imperfect measure of the supply of banking services and deflating by population does not fully take into account the potential demand for banking services. Similarly, the density of turnpikes does not fully capture the ease of transport. For both these reasons we should ideally use instrumental variable techniques.

There are relatively few variables available on an annual basis for each county for the period 1801 to 1815. One variable that we use is the density of population in the locality (census district) immediately surrounding the towns for which we have data. But this is available only by interpolating between the censal years of 1801, 1811 and 1821.

[11] These data were collected from Albert (1972), Pawson (1977) and British Parliamentary Papers 1821, vol. 4.

[12] Virtually none of the towns from which grain prices were collected had a canal built in the period 1801 to 1815, so any fall in transport costs is likely to have arisen entirely through roads.

[13] Alternative measures of road supply, such as turnpike mileage divided by population, had no effect in our analysis.

The other data that we have are information on newspaper circulation, both at county and town level. These are potentially good instruments because they would be correlated with the degree of development of each town while being unlikely to be correlated with either any measurement error or differences in rates of return. It is also extremely unlikely that such newspapers would have a direct effect on rates of return, since they did not contain information on interest rates nor on prices of wheat (except insofar as it was already available in the *London Gazette*).[14] So these are good candidates for excluded instruments. They are also available annually for each county for the period with which we are concerned.

3. The effect of banking on interest rates

Our empirical test of the relationship between the local level of financial intermediation and the degree of capital market integration can be summarized by the equation

$$(3) \qquad \left|\hat{\alpha}_{year,\,county} - \hat{\alpha}_{year,\,London}\right| = \beta_{county} + \lambda \times \text{Banking}_{year,county} + \mu \times \text{Roads}_{year,county} + e_{year,county}$$

where $\hat{\alpha}$ is the estimated rate of return obtained from equation (4) above and the variables “Banking” and “Roads” are our measures of banking services and transport as described above. Alternative specifications to allow for non-linearities or more sophisticated dynamics suggested that (3) adequately fits the data.

We are able to conduct this analysis in two sets of regressions. In the first we relate county-level data on banks and turnpikes to the absolute difference in the rate of return that we have estimated for each county and London. However, as we discuss in the appendix, the towns from which grain prices were collected within each county were not completely representative of all the towns in that county: in particular, they tended to be larger and more involved in the grain trade. So the rates of return in these wheat towns could be systematically different to the rates of return in the other towns in each county and we could be introducing measurement error by

[14] The exception would be those London newspapers that contained information on the price of wheat in London during the period when the *London Gazette* did not publish London prices. However, they contained no information on provincial wheat prices, only the London price. Interestingly, after 1815 even the London newspapers contained no information on London prices: all of the published data that we have found is simply for the national average price. Notice also that the *London Gazette* published the official prices one to two weeks in arrears, so that by the time they found their way into a local newspaper the data would have been well out of date.

relating rates of return in the wheat towns to the level of financial intermediation in the county as a whole. To address this potential problem, we performed a second set of regressions using the same dependent variable but with explanatory variables collected at the town level. Since this duplicate analysis produced results which were qualitatively and quantitatively similar we do not report them here (see Appendix 3).

Summary statistics for our data are reported in table 2 below. It can be seen that the average absolute difference in rates of return between London and any given county was substantial, but that there was a large fall over the period from about 30 percentage points to 18 percentage points. This was accompanied by a substantial rise in the number of banks and banking outlets per head of population. There was a much more modest rise in the mileage of turnpiked road. From the analysis of the standard deviations we can see that the variation in the absolute differences in rates of return is due rather more to within-group variation (*i.e.* arising from changes over time) than between-group variation (*i.e.* arising from the variation across counties). By contrast, the variation in mileages of turnpiked road is due mostly to the variation across counties; and the variation in banks per capita is split roughly equally between the within-group variation and the between-group variation.

Table 2. Summary statistics of the main variables.

	Mean		
	1801-1815	1801-1805	1811-1815
Absolute difference in returns	0.233	0.303	0.180
County bank outlets per capita	0.063	0.048	0.074
County turnpike density	0.509	0.497	0.522
	Standard Deviation		
	Overall	Between group	Within group
Absolute difference in returns	0.188	0.058	0.179
County bank outlets per capita	0.030	0.025	0.017
County turnpike density	0.235	0.237	0.019

The results of our analysis using the county-level data are reported in table 3 below. Using OLS estimation, in which the coefficients are likely to be biased downwards due to measurement error and endogeneity, it appears that improved financial intermediation and transportation both reduced the differentials in the rates of return across England. IV and GMM estimates strengthen these results, with larger coefficients on both variables. There is some evidence that the instruments are slightly weak, but weak-instrument robust tests suggest that banks and turnpikes are jointly highly significant.

The GMM parameter estimates suggest that the increase in the supply of banks between 1801-1805 and 1811-1815 resulted in a fall in the rate of return differentials of 6.3 percentage points, compared to an overall fall of about 12 percentage points. This is an economically very substantial fall. If we take the parameter estimate at face value, then the increase in road density over the period resulted in a somewhat smaller fall in the rate of return differential of 4.6 per cent, although the statistical imprecision of our estimates means that we cannot place any real weight on this conclusion.

Table 3. Regression results from county-level data.

	OLS	IV	GMM
County bank outlets per capita	-1.040*** (0.368)	-2.222** (1.102)	-2.438** (1.053)
County density of turnpikes	-1.182*** (0.320)	-1.898 (1.289)	-1.822 (1.250)
Centered R^2	0.125	0.101	0.097
Uncentered R^2	0.654	0.645	0.643
Number of obs.	615	615	615
Kleibergen-Paap statistic		6.952	
Hansen J-test $\chi^2(3)$		0.841 [p = 0.840]	0.841 [p = 0.840]
Anderson-Rubin Wald test		F(5,569)= 5.52 [p = 0.000]	

Notes to table: Dependent variable is the absolute difference in the return on wheat in London and each county (measured from January to April) from 1801 to 1815 for 41 counties, where North Wales and South Wales / Monmouth are each treated as a "county". Heteroskedasticity-consistent standard errors are in parentheses and p-values in square brackets. *** denotes significance at the 1% level; ** at the 5% level and * at the 10% level. Estimation includes county fixed effects (not reported in the table), since Hausman tests suggested that these were necessary. The Kleibergen-Paap statistic is the robust equivalent of the Stock-Yogo statistic for weak instruments: the critical value for the IV bias to be less than 20% of the OLS bias is 5.91. The Hansen test is the test for overidentification of the excluded instruments (i.e. that the instruments be valid). The Anderson-Rubin Wald test is the weak-instrument robust test for joint significance of the two explanatory variables. Instruments used are county population; the number of newspapers both in production and circulation in a county; the mean and total circulation of newspapers in the wheat towns.

We turn now to analysis of sub-samples of the data. Partly, this acts as a robustness check on our estimates. And, partly, it takes us back to the issue of finance and growth. One obvious question is how the magnitude of the effect of banks was related to the local rate of economic growth. Since county-level GDP data are not available, we use the population growth rate as the nearest possible indicator of economic growth.[15] However, since this is the period of the Industrial Revolution, we might well expect per capita GDP to be rising faster in industrial areas than agricultural areas. This could make population growth *per se* a rather inaccurate measure of local variations in GDP growth. A better measure might be population growth in only the industrial areas of each county but extracting such data from the census would be difficult and open to considerable interpretation about which parishes were industrial. For this reason we simply use the growth rate of the population in the geographical area including and immediately adjacent to our wheat towns and we calculate for each of these areas the annual growth rate between the censal years of 1801, 1811 and 1821. The distribution of growth rates is almost uniform, so any division of counties into "fast" and "slow" counties must be rather arbitrary and we simply divide our data into those counties above and beneath the median growth rate of 0.283 per cent per year.

The censuses also contain information on the sectoral composition of the labor force in each county, with the proportions of agriculture, trade and "other" occupations recorded and we can again use this to get at the issue of economic growth. Contemporary documentation suggests the question on individuals' occupations in the 1801 census was widely misunderstood. This is confirmed by the fact that in only two counties do the proportions of employment in the three sectors add up to 100 per cent, and in six counties they add up to less than 90 per cent. Hence we opt to use the 1811 census information, which reports occupation by family rather than individual. The proportions of families in agriculture and trade are quite strongly negatively correlated, with a correlation coefficient of -0.86, and our results here are based on the proportion in agriculture. This variable is fairly uniformly distributed across the counties, with a slight "step" between the twentieth county (Dorset, 48.4 per cent) and the twenty-first county (Somerset, 43.6 per cent) and so we split the sample at this point. The correspondence between agricultural counties and slow-growing population is fairly high but substantial differences remain: 14 out of 20 fast growing counties are non-agricultural and 14 out of 21 agricultural counties are slow-growing.

[15] Why would we expect population growth to be correlated with economic growth? First, there was substantial internal migration in Britain in this period and we would expect migrants to head for areas where economic growth was fastest. Second, if economic growth resulted in higher incomes then we would expect to see a rise in the gross rate of reproduction (this is certainly the pattern that we observe in England later in the nineteenth century).

The results for these sub-samples are reported in table 4 below. In counties with fast population growth or low shares in agriculture the effect of banks appears to be considerably larger, although it is less well specified. For slow-growing or agricultural counties the size of the effect is similar to that which we obtained for the whole sample. This dichotomy is what we would expect. Technological innovations and changing economic conditions were promoting industrialization and economic growth in some counties. For example, the invention of Watt's steam engine enabled miners to pump the Cornish copper mines dry and increase production. This lead to a very large increase in the local demand for capital in Cornwall: first, because mining was capital-intensive; and, second, because it now required new, additional forms of capital (steam engines and coal to run them – see Brunt, 2005). This would have pushed up the local interest rate, *ceteris paribus*. But the existence of local banks allowed an inflow of capital and put downward pressure on local interest rates. Clearly, this downward pressure would be higher in counties where the demand for capital was higher and rising faster over time (*i.e.* industrializing counties). So we would expect the coefficient on banks to be larger in industrializing counties, as characterized by fast population growth and low percentages of the workforce in agriculture. Notice further that the downward pressure on local interest rates caused by the presence of banks would have led to more capital investment and hence faster economic growth.

Table 4. Regression results from county-level data: sub-samples.

Sub-samples	Population growth		Sectoral composition	
	Fast (20 counties)	Slow (21 counties)	Agricultural (20 counties)	Non-agricultural (21 counties)
County bank outlets per capita	-3.369* (1.723)	-2.637*** (0.955)	-3.336 (2.506)	-2.205** (1.100)
County density of turnpikes	-0.943 (0.997)	-0.083 (1.502)	2.195 (3.805)	-2.717** (1.145)
Centered R^2	0.091	0.096	0.063	0.046
Uncentered R^2	0.631	0.656	0.643	0.612
Number of obs.	300	315	300	315
Hansen J-test $\chi^2(3)$	0.605 [p = 0.895]	3.058 [p = 0.383]	0.488 [p = 0.922]	1.267 [p = 0.737]

Notes to table: Details of the regressions are the same as in the previous table: all the regressions are estimated using GMM with fixed effects. The counties assigned as having fast population growth (greater than 0.283 per cent annually) are Cambridgeshire, Cheshire, Cornwall, Cumberland, Devon, Kent, Lancashire, Leicestershire, Lincolnshire, Middlesex, Northamptonshire, Nottinghamshire, Somerset, Staffordshire, Surrey, Sussex, Warwickshire, Westmorland, Yorkshire and South Wales; the counties assigned as *not* being agricultural (fewer than 44 per cent of families in agriculture in the 1811 census) are Cheshire, Cornwall, Cumberland, Derbyshire, Devon, Durham, Gloucestershire, Hampshire, Kent, Lancashire, Leicestershire, Middlesex, Northumberland, Nottinghamshire, Shropshire, Somerset, Staffordshire, Surrey, Warwickshire, Worcestershire and Yorkshire.

4. The effect of interest rates on investment.

We now turn to the effect of interest rates on fixed investment. Again we are constrained by data availability: we do not have total fixed investment and we have no data at all for the period 1801-1815. However, we do have sufficient data for 1780-1800 to analyse the relationship between interest rates and steam engine investment for the period just before the increase in bank services.

Our focus on steam engines has the corresponding advantage of analysing one of the most distinctive drivers of the Industrial Revolution. The steam engine was the most technologically advanced piece of capital equipment then available, comparable to information technology systems or biotech today. Steam engines were also extremely expensive, typically costing £2,000 to £3,000 to purchase in an age when the average annual salary for a laborer was £20. It is precisely this importance that has made them the focus of a huge amount of historical research and one output of this agenda has been to record every single steam engine produced up to 1800, all 2,191 of them (Kanefsky and Robey, 1980). The published data tell us for each county the total number of steam engines installed in the period 1780 to 1800.[16] If our hypothesis about financial intermediation and growth is correct then we would expect the cross-sectional variation in steam engines to be explained partly by the cross-sectional variation in interest rates over the same period. In this section we test directly this hypothesis.

Most industrial output in the late eighteenth century was not factory-based and thus only a few industries were able to utilize such large power sources as a steam engine. Demand for steam engines was thus largely confined to the cotton and woolen textile industries, the iron industry and mining (Nuvolari, 2004).[17] To control for these local demand effects we include

[16] Ideally we could use these data in a full panel analysis. We are confined to a between-group analysis (cross section regression) due to limitations in other potential explanatory variables.

[17] Notice that the geographical location of these industries was largely exogenous to the presence of steam engines because mines had to be situated in places where coal or ore was to be found, iron foundries had to be situated where coal was available cheaply. Corroboratory evidence for this is that 11 out of the 42 counties for which we have data did not purchase a single steam engine over the whole period.

information on cotton and woolen production and the share of industrial employment[18] and also the local coal price.[19]

This leaves the cost of capital – the interest rate – as the proximate cause for any remaining variation in the demand for steam engines, but this variable may be endogenous. Since steam engines were very expensive, installing more of them might have pushed up the local interest rate. Also, demand for steam engines is likely to be indicative of demand for investment goods more generally. So we estimate the model using instrumental variables.

Parsimonious specifications of our regression analysis are presented in table 7 below. Overall, the results show a strong, negative effect of interest rates on steam engine investment, with a reduction of one percentage point in the interest rate generating an additional 58 steam engines in the county. Hence a one standard deviation reduction in the interest rate (0.46 percentage points) is associated with an increase of 27 steam engines. This compares to a median of 24 steam engines in counties that had more than zero and a maximum of 242 steam engines in a single county. Similarly, a one standard deviation increase in the industrial employment share (15.25 percentage points) is associated with an increase of 33 steam engines.

Since the sample size is relatively small, and our estimators are consistent at best, we report not only the IV Tobit analysis but regression results using either IV or Tobit alone as a robustness check. These regressions suggest that the endogeneity of the interest rate is more of a problem for identifying the effect of interest rates than the censoring issue. The correlation between the instrumental variables and the interest rate is not very strong, with a Cragg-Donald minimal eigenvalue statistic of only 6.76 (compared to the Stock-Yogo critical value for a maximal IV relative bias of 20%, which is 6.46). Since the parameter estimate changes so much when we instrument the interest rate, we can arguably set this result aside. However, we also compute a weak-instrument-robust test for the significance of the interest rate along the lines suggested by Moreira (2003) – but this procedure is not available for the IV Tobit estimate, so we are able to implement it only for the IV estimates. Given our previous results suggesting that banks determined interest rates, it might seem surprising that the instruments appear weak. However, our analysis in section 3.4 used fixed effects and therefore the bank variable was

[18] Most steam engines came from the same source, Birmingham, and the delivery cost of an engine was only a tiny percentage of total cost. Thus the supply of steam engines can be treated as the same for all counties.
[19] Other explanatory variables were considered but were insignificant.

predominantly explaining the within-group variation: but because our data here limit us to a between-group analysis, it is to be expected that the correlation will be lower.

The parameter estimates on the control variables are statistically insignificant or of the expected sign. The parameter estimate on the interest rate appears to be in excess of unity. Since the interest rate is expressed as a fraction, rather than a percentage, this means that a reduction of interest rates of 1 percentage point would lead to a county buying a further hundred steam engines or more.

Table 7. Explaining investment in steam engines, 1780-1800.

	IV	Tobit	IV Tobit
Interest rate (measured as a fraction)	-1.02** (0.43)	-0.26* (0.14)	-1.58** (0.79)
Woolen textile mills	0.66*** (0.23)	0.76 (1.46)	0.59*** (0.16)
Cotton textile mills	0.0004 (0.0002)	0.0001 (0.0004)	0.0005* (0.0003)
Price of coal	0.13 (0.09)	0.006 (0.05)	0.21 (0.13)
Industrial employment share	2.09*** (0.64)	2.12*** (0.73)	2.71*** (0.86)
Number of observations	42	42	42
R^2 or pseudo R^2	0.32	0.11	
Test of the over-identifying restrictions	$\chi^2(2) = 1.38$ [p = 0.50]		$\chi^2(2) = 1.76$ [p = 0.42]
Test for exogeneity of the interest rate	$\chi^2(1) = 11.59$ [p = 0.001]		$\chi^2(1) = 4.45$ [p = 0.04]
Weak-instrument-robust test for significance of interest rate	$\chi^2(3) = 114$ [p = 0.00]		

Notes to table: A constant is included in each regression but not reported. The interest rate variable is the mean for each county of the annual interest rate over the period 1780-1800. The industrial employment share is the percentage of the workforce recorded as being employed in "Trade" (rather than "Agriculture" or "Other") in the 1811 census (this variable being notoriously poorly measured in the 1801 census). Data on county totals of woolen textile mills are taken from Jenkins and Ponting (1975). Excluded instruments are: percentage of the county population living in urban areas larger than 20 000 people, county population and banks per member of population in 180l. Robust standard errors are in parentheses. The over-identification tests are respectively the Hansen-Sargan test and the Amemiya-Lee-Newey test taken from an analogous IV Tobit regression estimated using the Heckman two-step procedure, rather than the ML procedure reported in the table (the results from the two methods are similar but we know of no test for the ML procedure). The tests for exogeneity of the interest rate are respectively the Durbin-Wu-Hausman and the Smith and Blundell (1986) Wald tests. The weak-instrument-robust test for significance of the interest rate is the Anderson-Rubin Wald test: Moreira's (2003) conditional likelihood ratio test yields the same p-value.

5. Conclusion.

We started our analysis by examining weekly wheat prices for each county for the period 1770-1820. Since the seasonal pattern of wheat prices is consistent with the model of intra-year storage posited by McCloskey and Nash, and since markets were weakly efficient, we used the intra-year appreciation to infer rates of return on capital in each county in each year. Rates of return varied enormously across England and Wales and differed considerably from the rate of return on wheat in London. The fact that rates of returns were not fully arbitraged shows that regional capital markets were not well-integrated in 1770, either with London or with each other.

We then showed that the differentials between the rates of return in each county and London were driven down by the increasing density of banks in each county. This is what we would expect, since more entry into local financial markets would have led to more competition and a narrowing of margins for local bankers. Consequently, the massive increase over time in the number of country banks – even though it was spread unevenly across the country – substantially reduced the average interest rate differential between London and the counties, probably by around seven percentage points. This demonstrates indirectly that banks were providing conduits for excess funds to be invested in London and enabling areas where credit was short to benefit from the London market. This is true even when controlling for alternative mechanisms that might have impacted on local wheat prices, such as transport costs.

Finally, we showed that local levels of investment in fixed capital responded to local interest rates. In particular, the purchase of steam engines – which were the most expensive and the most technologically advanced capital good of the period – was very sensitive to the local interest rate. This is an important mechanism by which we would expect interest rates to affect economic growth

Overall, our analysis provides strong microeconomic evidence supporting the link between finance and growth. We do this by employing new data sources and a new empirical approach. It is founded on the use of asset prices to infer local rates of return and the use of bank densities to proxy the local depth of financial intermediation.

Appendix 1.

Using grain prices to infer interest rates has been controversial for some economic historians. Here we examine their criticisms in detail and rebut them by presenting evidence both that the underlying model is indeed an appropriate characterization of agents' behavior in the late eighteenth and early nineteenth centuries and that the intra-year variation of prices is consistent with the theory.

A1.1 Options for measuring the cost of capital. The usual approach to measuring the interest rate is to look at the rate of return on a riskless asset, such as treasury bills or government bonds. However, this is not an option when looking at regions within a country because, for example, counties within England did not issue their own bills or bonds.

Since our primary interest is in the effect of banks, an obvious potential source is the interest rate offered on bank loans and John James (1978) has used this approach for the United States in the late nineteenth century. Implementing this strategy is somewhat problematic because banks face heterogeneous borrowers and we would need to account for varying default rates in order to estimate the risk-free rate (or, at least, an equally risky rate across the country). Such data are not available for England in the early nineteenth century due to a scarcity of archival information. But there is also a conceptual problem with this approach, since the bank interest rate would not be observed when no banks were in existence. In the period that we consider, 1800 to 1820, half of the 40 English counties each had fewer than five banks at the beginning of the period, so the supply of banking services for most of the county was effectively zero: two of the counties had zero banks for at least some of the period of analysis (rising to three counties when we consider town-level grain data).[20] If we want to examine the effect of banks entering a local capital market *ab initio*, then we need to observe the interest rate both before and after the banks exist, which is logically impossible if we rely on bank interest rate data.

The second potential source of data on the rate of return on capital is mortgages on land, which are both widely traded and relatively low risk, and Robert Allen (1988) has used this source for England in the early modern period. But this approach suffers from uneven

[20] Another five counties had only one bank for at least some of the period of analysis, and another four counties had only two banks.

geographical coverage and potentially severe sample selection problems because most extant mortgage documents come from the largest landowners, who may have had peculiar risk characteristics or had direct access to London's financial markets. So the mortgage rate recorded for a piece of land in the north of England may actually reflect the rate of return in London for a rich landowner rather than the interest rate face by a more typical borrower in the north of England.

Compared with the problems with using bank interest or mortgages, seasonal movements in grain prices offer several advantages. Grain was widely traded in a liquid market in every county and data are abundant and were collected in a consistent manner, so there are no missing observations; the riskiness in grain prices is likely to have been subject only to very small regional variations so comparison is relatively straightforward.[21] The potential pitfalls in using grain data are certainly no greater than the potential pitfalls with the other sources and grain prices are the only source that are likely to give a wide and consistent spatial and temporal coverage.[22]

A1.2 Accuracy and representativeness of interest rate estimates based on grain prices. We have argued that grain price data is more readily available and suitable than interest rate data

[21] In principle, the county rates of return that we derive from grain prices could be corrected explicitly for risk differentials. Doing so would be slightly complicated by the fact that our explained variable is going to be the absolute difference in rates of return between each county and London – so the differential between a risky county and London would have to be adjusted upwards when the interest rate of the county was higher than that of London, but downwards when the interest rate was lower than that of London. However, notice anyway that we will incorporate fixed effects (i.e. county dummies) in our regression analysis. So the effect of a risk differential between a particular county and London which was stable over time will be incorporated automatically into the fixed effect. So we need worry only about *changes* in riskiness relative to London. One way to do this, which we implement, is to model risk as the variance of the weekly returns and calculate this for each county in each year. For brevity we do not report the analysis here; the inclusion of risk variables has no effect on the other parameter estimates (unsurprisingly, since the correlation of risk with the other explanatory variables is negligible) and risk is always both economically and statistically insignificant. Results are available on request.

[22] One potential drawback of grain prices is that to move from gross rates of return to interest rates we have to know both the depreciation rates and the storage costs of grain. Data on these two variables are very scarce. We circumvent this problem by working with interest rate differentials rather than interest rate levels (*i.e.* our explained variable will be the interest rate differential between a particular county and London). These differentials will be unaffected by depreciation and storage costs provided that they are the same everywhere. But what if they are not the same everywhere? As explained in the previous footnote, county effects will absorb the influence of a permanent differential between a particular county and London. So we need worry only if storage costs in London and each county are changing at different rates. It is hard to believe that such changes were quantitatively large. Moreover, any such changes will generate measurement error only in the explained variable, which will not bias the estimated coefficients.

from banks or mortgages. But using grain prices to infer local interest rates also requires the economic theory to be applicable to our data. There are two particular points of interest here.

First, John Komlos and Richard Landes (1991) criticized the initial McCloskey and Nash paper on the grounds that medieval farmers could not be assumed to be rational agents in the style of *homo economicus*. This criticism is less relevant for the nineteenth century, but we feel that it is nonetheless appropriate to provide some qualitative evidence that grain traders were certainly rational economic agents. We also need to emphasize that to use the no-arbitrage condition in equation (1) we are assuming inter-temporal efficiency within a region, but limited geographical efficiency between regions. This assumption is supported empirically and is easily understandable, given the high cost of transporting grain between regions.

Second, for the regional rate of return on wheat to be really interesting we also need to believe that agriculture, industry and services were integrated within a region. That is, they faced a common local rate of interest (even though they were isolated from other regions).

On the first point, it is not necessary for all actors in the grain market to be rational because there need only be some rational agents (with sufficient funds), the marginal agents, to ensure that the no-arbitrage condition holds. However, it would obviously strengthen our case if we could show that most or all participants in the grain market were likely to seek a market return on their stocks of grain. So we now consider each type of agent operating in the grain market and show that it is likely that they acted rationally, arbitraging between the grain and financial markets as necessary.

Let us start with the farmer. English agriculture in the late eighteenth century was highly commercialized. The standard pattern was for large landowners to rent out substantial farms (say, 200 acres) to tenant farmers on long term contracts (typically lasting 10 years and sometimes 20 years). These tenant farmers provided all the movable capital (animals, tools, seed, etc.) and hired workers as required from an active labor market (both on annual contracts and on a daily basis). The tenant farmers were geographically mobile and often moved from one locality to another between tenancies. They were used to evaluating investment opportunities and comparing rates of return; and generally they were *not* capital constrained. In fact, agricultural profits were very high in the late eighteenth century and the investment funds for industry came from the agricultural sector. It is therefore no surprise to find in 1796 that farmers were well aware of the wheat price cycle, and they arranged their grain disposals accordingly.

> [T]here are a set of wealthy farmers who have it in their power to retain a part of their growth in those natural and best of granaries, their ricks. Was it otherwise, as the Corn Laws now stand, we might often, even with a most plentiful harvest, be in the utmost danger of famine.
>
> The argument made use of is, that the little farmer is, through necessity, obliged to thresh out his corn and bring it to market; but that the opulent man will not produce his, until it comes to a certain price. (Arbuthnot, 1796, vol.27, pp.21-22)

We have evidence also from the testimony of farmers and merchants appearing in the Parliamentary enquiry of 1828 (British Parliamentary Papers, 1828, vol. 18, pp.284-9). The witnesses to the committee discuss both ‘normal’ trade conditions and those pertaining during the agricultural depression of the 1820s. We can see that farmers commonly financed the storage of grain through bank lending, in anticipation of higher prices later in the year.

> During the war, the landlords easily raised money at the banks on discount, and consequently were not under the necessity of opposing the speculations of the farmers; since however, the failure of so many banks in the south of Ireland, the landlords, generally, have been unable to continue this indulgence. We find accordingly, by the notes of the different markets, that the delivery of crops is every where, not only quite unreserved, but much earlier than during the war.

And again,

> The want of money has obliged them generally to bring their Corn to market as early as possible of late years, and but few of the more wealthy have seen sufficient prospect of advance to induce them to hold [Corn].

This account is particularly interesting because we can see how higher interest rates in the banking sector are reflected in higher rates of return on holding grain. The tightening of credit rates makes it difficult for farmers to borrow money to finance the holding of grain; so they bring their crop to market earlier, and this drives down the price of grain early in the season. This generates a sharper increase in grain prices over the year, reflecting the higher interest rate pertaining in the banking sector.

Grain factors, millers and meal men (that is, flour merchants) also sought a market rate of return on their stocks; and they were also commonly financed through bank loans. Hence in the depression of 1828 we find that:

> The capital employed in the Corn trade has been less of late years from less accommodation by country bankers and others…

The involvement of English banks in the grain trade was apparently very extensive, and the state of the grain trade was consequently sensitive to conditions in the capital market:

> The capital employed in the Corn trade in the South of Ireland is very much supplied from England, the corn being bought on commission. The failures of the banks have certainly lessened the capital in the Corn trade in Ireland, by lessening the accommodation afforded to persons who have no capital of their own.

Two further points are worth emphasizing. First, agents who were intimately involved in the grain trade were perfectly willing to *withdraw* their capital from the grain trade and redirect it to more remunerative avenues. This is important because if the rate of return on capital is to be equalized between the grain market and the banking sector then it is essential that capital can flow *out of* the grain market as well as into it.

> The capital varies according to the price of Corn. Many millers have laid out a part of their capital in the funds [government securities]…

Similarly,

> Most of the capital employed by merchants or middle men in former years has been lost, and the remainder withdrawn from the trade, there being now no capital employed in the trade in Corn.

Second, we also find that the holding of grain purely as an investment activity was *not* limited merely to farmers and grain factors. It was also seen as a reasonable target for other investors seeking a return on their capital:

> …but many capitalists and merchants unconnected with the [grain] trade, were wont to speculate in Grain, through the factors…

Finally, if we move further forward in time to the 1870s then we find Bagehot (1873) describing how the bill brokers directed funds to flow into and out of the grain market as necessary.

> Their bill cases [*i.e.* portfolios] as a rule are full of the bills drawn in the most profitable trades, and *ceteris paribus* and in comparison empty of those drawn in the less profitable. If the iron trade ceases to be as profitable as usual, less iron is sold; the fewer the sales the fewer the bills; and in consequence the number of iron bills in Lombard Street is diminished. On the other hand, if in consequence of a bad harvest the corn trade becomes on a sudden profitable, immediately ‘corn bills’ are created in great numbers, and if good are discounted in Lombard Street. Thus English capital runs as surely and instantly where it is most wanted, and where there is most to be made of it, as water runs to find its level.

In order for the rate of return in the grain market to reflect the rate of return in the financial market it is not necessary for there to be *direct* links between the two sectors (i.e. banks investing in the grain market). But the existence of direct links obviously greatly strengthens our case. The evidence presented above demonstrates that capital could easily flow into and out of the grain market *and* that there were strong direct links between the grain market and banks. First, grain market capital came from individual agents who were able to trade directly in both grain markets and financial markets (*i.e.* their investment in grain was not mediated through putting their money into a bank). We can see this process occurring when individuals bought grain stocks through grain factors. Second, agents who were themselves involved in the grain trade held large grain stocks if they expected a high rate of return; but they were also willing to withdraw their capital from the trade and find alternative investments if there were higher expected returns outside the grain trade. This suggests strongly that capital could flow out of the grain trade just as easily as it could flow into the trade. Third, financial institutions were involved in financing *both* the grain trade and other trades – so they were willing and able to arbitrage between the two markets. We can see this process occurring when country banks financed farmers and traders who wanted to hold grain stocks. All this evidence demonstrates that grain markets and financial markets were linked directly by a host of rational economic agents, drawn from inside and outside the agricultural sector. Therefore it is reasonable to interpret the appreciation of grain stocks as *a* rate of interest, and we would expect this to reflect *the* rate of interest.

A1.3 The nature of capital and the rate of return in the British economy. We have argued that we can estimate the rate of return on capital using grain prices because there were strong links between the grain market and other markets (and hence the returns should move together). But this really understates our case. Suppose that markets were segmented and rates of return therefore differed from one to another (returns in the shipping industry differed from iron and steel, which differed from agriculture, which differed from the insurance industry, and so on). Moreover, suppose that markets were geographically segmented and rates of return differed from place to place (returns on shipping were not the same in London and Liverpool, and so on). Then if we wanted to measure geographical variations in the cost of capital, what could we reasonably take to be *the* rate of return in each locality? It would be no use comparing coal in

Northumberland to grain in Norfolk because the coal and grain markets would have different risk characteristics. And it would be no use trying to compare coal in the two places because Norfolk does not produce any coal. In modern economies it might be natural to take the return on equities, or the rate of interest on housing loans (bearing in mind that we cannot use government debt because we are interested in regional variation). But both of these markets were small in the British economy until the late nineteenth century. We need a market that attracted a large volume of capital everywhere. Which market attracted the most capital in the eighteenth and early nineteenth centuries? It was, of course, the grain market.

Grain had to be stored throughout the year. If we assume that the rate of consumption was constant from one harvest to the next, then grain stocks would decline linearly. So on average the amount of grain in storage would be equal to half of the total quantity harvested. Since we know the size of the harvest and the price of grain, we can thus calculate the average value of circulating capital which was invested in grain stocks on any day of the year. We made this calculation for 1760 and 1860 and then compared the value of circulating capital invested in grain stocks to that invested in the non-farm sector using the data from Charles Feinstein (1978). The results are reported in table A1 below:

Table A1. Circulating capital in the British economy, 1760 and 1860 (£m at 1861 prices).

	1760	1860
Total for the non-farm sector	40	210
Total for the farm sector	140	240
Grain stocks	**48**	**61**

In 1760 the value of circulating capital invested in grain stocks was greater than that invested in the *whole* of the non-farm sector; even as late as 1860, the capital invested in grain was around one third of the entire non-farm sector. Any particular industry (even leading sectors such as cotton or steel) would have been easily out-classed by the grain market, in terms of circulating capital. Moreover, the leading sectors were heavily regionally concentrated in Lancashire and Yorkshire, whereas the grain market was important in every locality. So as a barometer of the rate of return on capital across the country, the grain market is a far superior instrument.

The immense influence of agriculture on the prosperity of the British industrial sector was being emphasized by Bagehot as late as the 1870s:

> But every such industry is liable to grave fluctuations, and the most important – the provision-industries – to the gravest and the suddenest. They are dependent on the seasons. A single bad harvest diffused over the world, a succession of two or three bad harvests, even in England only, will raise the price of corn exceedingly, and will keep it high. And a great and protracted rise in the price of corn will at once destroy all the real part of the unusual prosperity of the previous good times. It will change the full working of the industrial machine into an imperfect working; it will make the produce of the machine less than usual instead of more than usual; instead of there being more than the average of general dividend to be distributed between the producers, there will immediately be less than average.

So if we are trying to estimate *the* interest rate in the British economy during the Industrial Revolution, then it makes most sense to take the grain market as the benchmark case. The grain market absorbed more capital than any other market or sector and the rate of return that it generated is one by which all others may be judged.

Appendix 2.

If the standard model of asset prices is correct then the logarithm of wheat prices should follow a random walk with drift from January to July and log-price changes should be uncorrelated over time. Both of these requirements would have to be modified if there were any random measurement error in the prices or if the quality of wheat varied on a weekly basis. The prices quoted are average prices for several towns and the composition of towns could also change slightly (if a particular town's prices were not reported on an occasional basis), so there could also be some random components in the price series due to composition effects.

Within each year we test for a unit root for each county using augmented Dickey-Fuller tests. Over the period 1801-1820 this gives us 41*20=820 test statistics. Following the procedure recommended by Maddala and Wu (1999) for testing unit roots within a panel context we calculate the statistic

$$(2) \qquad -2\times\sum_{year=1801}^{1820}\ln\pi_{year} \sim \chi^2_{40}$$

where π_{year} is the p-value of the ADF statistic for the unit root test in the relevant year. The result that the statistic has a chi-squared distribution is due to Fisher (1932). We calculated the p-values of the ADF statistic from our own Monte Carlo experiments with 60,000 replications. Note that Maddala and Wu's (1999) Monte Carlo experiments suggest that this test will have almost exactly the correct size for our sample sizes, even if the power is low (as is common with unit root tests). Our results are reported in table A2 and support the hypothesis of a unit root in the log-prices: for only one county out of 42 do we narrowly reject the null hypothesis and, given the number of tests, this is likely to be a Type I error.

Table A2. County tests for a unit root.

Bedfordshire	0.553	Herefordshire	0.295	Shropshire	0.180
Berkshire	0.386	Hertfordshire	0.066	Somersetshire	0.786
Buckinghamshire	0.169	Huntingdonshire	0.594	Staffordshire	0.316
Cambridgeshire	0.792	Kent	0.084	Suffolk	0.611
Cheshire	0.238	Lancashire	0.379	Surrey	0.388
Cornwall	0.992	Leicestershire	0.713	Sussex	0.236
Cumberland	0.959	Lincolnshire	0.694	Warwickshire	0.835
Derbyshire	0.615	Middlesex	0.552	Westmorland	0.190
Devonshire	0.859	Norfolk	0.427	Wiltshire	0.400
Dorsetshire	0.907	Northamptonshire	0.795	Worcestershire	0.419
Durham	0.042*	Northumberland	0.300	Yorkshire	0.693
Essex	0.066	Nottinghamshire	0.559	London	0.388
Gloucestershire	0.984	Oxfordshire	0.675	North Wales	0.236
Hampshire	0.102	Rutlandshire	0.865	South Wales	0.835

Notes to table. Fisher tests for a unit root for each county in the period 1801-1820 based on 20 (London 15 only) ADF tests of 30 observations each. Entries are p-values of the chi-squared statistic in equation (2). Similar results are obtained for the longer period 1770 to 1820.

Proceeding on the basis that each of the series displays a unit root, we imposed this restriction and tested to see whether the price changes were autocorrelated using a range of regressions such as:

$$(3) \qquad \Delta \ln P_{week} = \alpha + \lambda_1 \Delta \ln P_{week-1} + \lambda_2 \Delta \ln P_{week-2} + u_{week}$$

The λ parameters were close to zero (over the period 1801-1815 the average λ_1 for each county from regression (3) lay in the range –0.41 to 0.40 and averaged 0.056). Formal tests for $\lambda_1 = 0$ and $\lambda_2 = 0$, aggregated using equation (2), are reported in table A3 (similar results were obtained from the joint test $\lambda_1 = \lambda_2 = 0$ and for results using more or fewer lags in the analysis). Clearly, there is no reason to believe that price changes are autocorrelated.

Table A3. Significance of autocorrelation in price changes.

	λ_1	λ_2		λ_1	λ_2		λ_1	λ_2
Bedfordshire	0.84	0.86	Herefordshire	0.82	0.85	Shropshire	0.85	0.86
Berkshire	0.84	0.82	Hertfordshire	0.80	0.84	Somersetshire	0.83	0.84
Buckinghamshire	0.85	0.85	Huntingdonshire	0.82	0.84	Staffordshire	0.83	0.87
Cambridgeshire	0.82	0.85	Kent	0.80	0.85	Suffolk	0.86	0.85
Cheshire	0.82	0.84	Lancashire	0.85	0.87	Surrey	0.82	0.83
Cornwall	0.84	0.84	Leicestershire	0.83	0.86	Sussex	0.80	0.83
Cumberland	0.86	0.86	Lincolnshire	0.84	0.85	Warwickshire	0.85	0.88
Derbyshire	0.84	0.86	Middlesex	0.84	0.85	Westmorland	0.84	0.88
Devonshire	0.84	0.86	Norfolk	0.84	0.82	Wiltshire	0.81	0.87
Dorsetshire	0.85	0.86	Northamptonshire	0.81	0.86	Worcestershire	0.85	0.87
Durham	0.84	0.85	Northumberland	0.83	0.86	Yorkshire	0.85	0.85
Essex	0.86	0.87	Nottinghamshire	0.83	0.87	London	0.71	0.75
Gloucestershire	0.84	0.87	Oxfordshire	0.85	0.86	North Wales	0.87	0.88
Hampshire	0.85	0.87	Rutlandshire	0.85	0.87	South Wales	0.83	0.84

Notes to table. These are Fisher tests for a unit root for each county in the period 1801-1820 based on 20 (London 15 only) ADF tests of 30 observations each. Entries are p-values of the chi-squared statistic in equation (2). Similar results are obtained for the longer period 1770 to 1820.

Appendix 3: Analysis using town-level bank data

The analysis in section 3 implicitly assumes homogeneity within counties. Our county wheat prices are based only on the prices in a subset of towns within each county (the "wheat towns"). To test the robustness of our analysis we re-estimate equation (3) using the number of bank outlets just in these wheat towns, lest banking in these towns was different from the county as a whole. To be consistent, we also constructed a new measure of turnpike mileage based just on these towns. Our IV estimation then proceeded similarly to that of section 3. Summary data for the main variables are reported in table A3.1.

Table A3.1. Summary statistics

	Mean		
	1801-1815	1801-1805	1811-1815
Absolute difference in returns	0.233	0.303	0.180

Wheat town bank outlets per capita	0.237	0.197	0.267
Non-wheat town bank outlets per capita	0.032	0.023	0.041
Town turnpike miles (000)	0.208	0.205	0.212
	Standard Deviation		
	Overall	Between group	Within group
Absolute difference in returns	0.188	0.058	0.179
Wheat town bank outlets per capita	0.123	0.104	0.066
Non-wheat town bank outlets per capita	0.027	0.024	0.013
Town turnpike miles (000)	0.137	0.138	0.008

An interesting possibility is that the density of bank outlets in non-wheat towns could be used as an additional instrument – although this would only be valid if the idiosyncratic component of the interest rate in wheat towns was uncorrelated with the banks in wheat towns. In fact, this variable is not highly correlated with the supply of banks in wheat towns (a correlation of only 0.26 for bank outlets), confirming that the wheat towns are not entirely representative of the counties within which they are situated and that non-wheat town banks probably would be a valid instrument (although we do not rely on them in our analysis).

Table A3.2 reports the results from using town level data. As with the county-level data, there is a marked difference between the OLS and IV/GMM estimates for the effect of banking, but the IV and GMM estimates are very similar to one another. Columns IV(ii) and GMM(ii) includes the additional instrumental variable: conventional tests suggest that this is not invalid, although it anyway makes little difference to the results.

Table A3.2. Regression results using town-level bank data.

	OLS	IV (i)	IV (ii)	GMM (i)	GMM (ii)
Wheat town bank outlets per capita	-0.239** (0.120)	-1.188*** (0.365)	-0.950*** (0.288)	-1.223*** (0.357)	-1.039*** (0.270)
Wheat town turnpike mileage	-2.459*** (0.762)	-2.898 (2.747)	-4.073 (2.568)	-2.740 (2.667)	-3.639 (2.465)
Centered R^2	0.113	-0.002	0.037	-0.010	0.024
Uncentered R^2	0.649	0.604	0.620	0.601	0.614
Number of obs.	615	615	615	615	615
Hansen J-test $\chi^2(3)$ or $\chi^2(4)$		0.320 [p = 0.96]	0.961 [p = 0.92]	0.320 [p = 0.96]	0.961 [p = 0.92]

Notes to table: The details are the same as for table 6: the only difference is the set of explanatory variables and the instrumental variables. For IV(i) and GMM(i) the instruments are population density for the divisions adjacent to the wheat towns (this was used instead of a simple town population measure because of difficulty in defining the precise census area for different towns); the number of newspapers both in production and circulation in a county; the mean and total circulation of newspapers in the wheat towns. The corresponding Hansen J-test for the validity of these instruments has three degrees of freedom. For IV(ii) and GMM(ii) the number of non-wheat town bank outlets within a county, divided by non-wheat town population is included as an additional instrument. The Hansen J-test for the validity of all six instruments then has four degrees of freedom; the Newey-West C-statistic is the test for the validity of the additional instrument alone.

These estimates suggest a slightly larger role for banks in explaining the fall in the differentials in rates of return over the period because, although the coefficients are smaller, there was a steeper increase in the per capita level of banking outlets in the wheat towns than the counties as a whole. The two GMM parameter estimates suggest that increasing the per capita level of banking outlets reduced the rate of return differentials by 8.5 or 7.3 percentage points respectively. By contrast, the estimated effect of turnpikes in these regressions is much smaller, with point estimates of either 1.9 or 2.5 percentage points. Moreover, as with the analysis of the county-level data, the biggest problem with the turnpike variable is the imprecision of the estimate. Similar results were obtained when we looked at sub-samples of the data.

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