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Feeding the British: Convergence and Market Efficiency in 19th Century Grain Trade

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Feeding the British:
Convergence and market efficiency in 19th century grain trade.

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Abstract: This paper traces the evolution of the international market for wheat from an emerging market structure after the repeal of the Corn Laws to a mature market characterized by efficient arbitrage after the introduction of the transatlantic telegraph and the growth of trade. Efficiency is documented using traditional price gap accounting as well as error correction modelling. Markets which traded directly with each other as well as markets which did not trade with each other were integrated. The traditional bi-lateral focus in market integration studies has been extended to a multi-variate approach which generates new insights as to the pattern of diffusion of price shocks in the international economy. Shocks in the major importing nation, Britain, dominated in the emerging market phase while shocks in the major exporting economy, United States, dominated international prices movements at the end of the 19th century.

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1. Introduction.

The 19th century witnessed a dramatic change in the international division of labour and specialization in the provision of food. Before the middle of 19th century trade in food was linked to accidental fluctuations in local supply rather than advancing specialization. Food trade as a proportion of total consumption was, on average, below 10 per cent and often close to zero except for the Dutch republic. All this changed dramatically during the 19th century. Hitherto semi-autarkic economies became highly specialised in exports or imports of food. The forces behind this change were *political*, such as the fall in tariffs, and *technological*, such as decreasing transaction and transport costs, and *institutional* such as increased market efficiency. This paper explores the conditions for this transformation in terms of price convergence and market efficiency. For the first time in history markets separated by huge distances became well integrated and efficient.

This article differs from earlier literature by the *combination* of three new characteristics. The commodity studied, wheat, is homogenous since we use identical qualities in exporting and importing markets or by our controlling for quality differentials between local wheat sorts. Second, we use high frequency data, weekly spot market prices, and, finally, a multi-variate error correction approach rather than a bi-variate model, which has been standard procedure in the past. These features enable us to trace the evolution from an emerging market structure to one characterized by market efficiency and to test a number of new hypotheses, which are spelled out below.

It is convenient to distinguish between three aspects of international market integration and all three will be discussed in this paper. First the *convergence of prices,* which, to a large extent, was stimulated by exogenous forces such as tariff policy and technological change affecting transport and transaction costs. The fundamental prediction of trade theory that there are gains from trade and that trade will equalize commodity prices must therefore be rephrased. When convergence of prices was made possible by a decline in restrictions to trade erected by tariffs, transport and transaction costs, nations were permitted to (or forced to) exploit their comparative advantages, which depended on differences in endowments, technology and learning by doing externalities from specialization. Price convergence has been extensively studied in the past (Harley 1980, 1988, 1990; O'Rourke and Williamson 1999) but this paper conveys new results. Unlike earlier attempts we document *if* and *when* observed price gaps actually equalled the sum of tariffs, transport and transaction costs, and by implication, detect whether there is a residual element in the price gap. The nature of that residual is also discussed. We conjecture that increased market efficiency will contribute to a fall in that residual and that it contributed to convergence.

This brings us to the second aspect of market integration: *market efficiency.* Arbitrage needs to be efficient, that is markets must adjust to the transport, tariff and transaction costs adjusted law of one price, henceforward called LOOP. Strong or absolute market efficiency rules when spatial price differences do not exceed the observed tariffs, transport and transaction costs. Instantaneous spatial arbitrage would not even permit temporary violations of LOOP. However in the real world unexpected shocks cause prices to deviate from LOOP now and then. A more fruitful set of standards in testing for market efficiency is to estimate (i) *the size and nature of the residual price gap,* (ii*) the extent of temporary deviations from LOOP* and (iii) *the adjustment speed* by which LOOP is restored after a shock. Essential to efficiency is that deviations from LOOP are transitory.

Efficiency will depend on transparency in the markets, the state of information technology and market structure, i.e. the competitive nature of markets. We will discover distinctive phases in the evolution of market efficiency over time.

The third aspect is the *extent and nature of shocks*. For agricultural commodities in which natural accidents play an important role in output variations it is often the case that shocks are independent locally so that global shocks are smaller, proportionally, than shocks in any given locality. An important implication is, therefore, that market integration tends to reduce local price shock volatility since price shocks for income inelastic goods such as grain are mainly driven by supply shocks. We intend to test this hypothesis, that is whether the emergence of a global wheat market reduced local price shock volatility and to what extent global shocks prevailed over local ones.

This paper will also explore the interrelationship between the first two aspects of market integration discussed above. We conjecture that the characteristics of an emerging international market triggered off by the repeal of the British Corn Laws in the late 1840s differ from the mature market in the last quarter of the 19th century. A gradualist approach to the evolution of market efficiency is suggested. If correct, the residual price gap should fall and the speed of adjustment increase over time. What is the basis for this conjecture?

Falling barriers to trade will stimulate trade when nations exploit their comparative advantages and become increasingly specialized. It can be argued that the higher the volume of trade the more opportunities there are for profit seeking traders to enter into arbitrage. This is the 'thick market' argument and on that basis we will expect adherence to the law of one price and adjustment speed to increase over time as trade is intensified. The access to vital information also became cheaper and hence public, rather than exclusive, through the printed press in the 19th century. All in all this would improve market efficiency and adherence to LOOP. The implicit assumption in this argument is that there were not sufficiently large economies of scale in trade that could erect barriers to entry.

The integration of the international market for wheat in the 19th century was analyzed in the seminal paper by Latham and Neal (1983) by means of simple correlations of price movements between markets using annual averages of prices. Although simple correlations might be informative, the use of low-frequency data is problematic when the frequency of shocks is high. Averaged annual data will therefore not discover changes over time in adjustment speed when adjustments in prices occur over weeks rather than years (Taylor 2001). Since we hypothesize that the second half of the 19th century witnessed a transition from an emerging market structure to a mature information rich market, we need weekly data to detect *changes* in market adjustments and more sophisticated error correction models to avoid the potential shortcomings of conventional correlation analysis.

The analysis of market integration has traditionally been performed in a bi-variate framework, typically selecting and studying two markets at a time. However an integrated market consists of more complicated relationships such as, say, two markets, which do not trade with each other although both might trade with the same third market. To investigate this more realistic trading network we extend the analysis to a multi-variate model. We will look closely at three representative participants in the world grain trade, Britain, Denmark and the United States. Britain was the major importer in the period, while the United States represents the emerging New World exporters that entered the stage around 1850. Denmark is representative of the continental European markets such as Germany and France, which were the first major suppliers of Britain. These three economies are linked by changing trade flows and the analysis highlights the interrelationship between market structure and market efficiency. The United States takes an increasing share of British imports, while Denmark (like a number of continental European nations such as Germany and France) retreats from the British market by the end of the 1870s. Denmark became an importer of US wheat in the last quarter of the 19th century.

We are intrigued by the consequences for market efficiency of the changing international supply pattern evolving during the 19th century. Can nations, we ask, be efficiently integrated without trading directly with each other? Does adjustment speed depend on whether you trade directly with another market or just indirectly through a common third market?

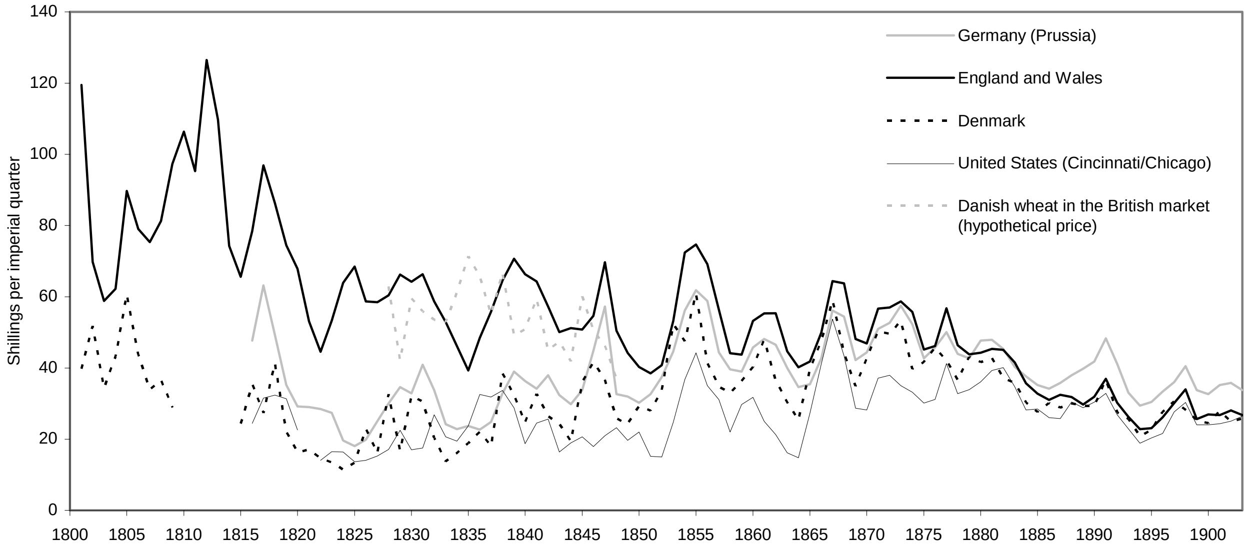
The paper is structured as follows. In section 2 the convergence of price levels between Britain, continental Europe and the United States is documented. Next we proceed by describing the ensuing change in supply of grain to Britain. We then move on to a novel approach of price gap analysis. Unlike earlier studies which routinely ascribe the fall in the price gap to transport cost reductions and tariffs, we also look at other transaction costs in section 3, and we carefully control for quality differences in the wheat types analyzed. In section 4 we explore the efficiency characteristics of market integration and how it evolves over time as supply patterns change. We ask a number of questions: Is adjustment speed increasing over time? Does volatility of the price shock fall as we conjectured above? We will also analyze the changing pattern of market dominance over time. Section 5 concludes.

2. A century of price convergence.

A number of recent contributions (O'Rourke 1997, O'Rourke and Williamson 1999) have focussed on the New World 'grain invasion' into the Old World (Europe) in the last quarter of the 19th century when the transport cost decline was particularly pronounced. We will extend the analysis to the full century because it casts new light on the forces at work bringing price gaps down. Often price convergence has been seen as falling Old World prices converging to rising New World price levels. In the longer perspective this turns out to be an erroneous conclusion. Rising continental European prices *and* US prices in fact converged to falling British prices over the 19th century until the general price decline set in during the last quarter of the century. However there are a number of pitfalls in the traditional approach to price convergence which, in the past, has led to erroneous conclusions (Persson 2004).

It has been quite common to discuss convergence comparing locally produced varieties of wheat. This is problematic because there are significant price differences between local qualities and furthermore the price differential between different qualities might change over time. By and large internationally traded qualities fetched a higher price than qualities that were only traded locally.

Figure 1. Wheat price in England and Wales, continental Europe and United States, 1801-1903. Shillings per imperial quarter.

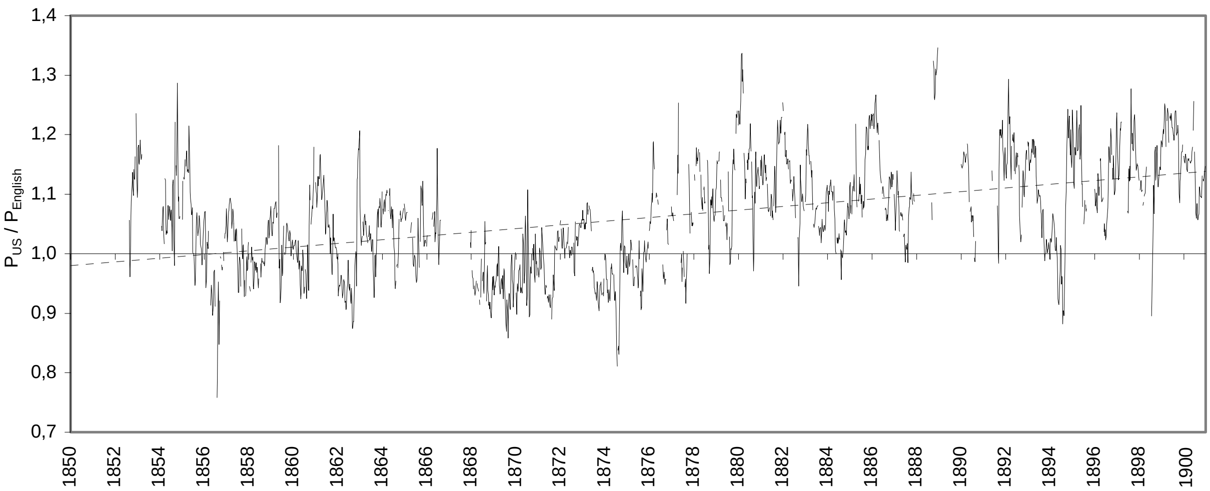


Sources: Cole (1938), Statistical supplement, pp. 174-278, NBER Macrohistory Database (www.nber.org/databases/macrohistory/contents), series 04001, British Parliamentary Papers (1904), pp. 214-17 and 240-41.

Note: The price of Danish wheat in the British market is the sum of the price in Denmark, transport costs between Denmark and Britain, and the British wheat import duty. The price of wheat in the United States is the price in Cincinnati until 1841 and subsequently in Chicago.

Figure 1 displays the pattern of price convergence of wheat in a number of nations expressed in shillings per imperial quarter. It is necessary to stress that prices do not refer to a uniform quality and for the reason stated above, Figure 1 is therefore not suitable for precise conclusions or imputations concerning the evolution of transport and transaction costs as has been the practice in the past. For example, given that transport and transaction costs between New York and Britain amounted to a little more than 10 per cent of the New York price at the end of the 19th century, it would be absurd to interpret the near zero price gap by 1900 in Figure 1 as an indicator of transport and transaction costs. Why has the price differential between British and US wheat collapsed to almost zero? The reason is that the US price refers to an export quality while the British price refers to an average of British wheat sorts at local markets, the so-called Gazette average.

Figure 2. The relative price difference between North American and English wheat in Britain.



$$(P_{US}/P_{English}) = \beta_0 + \beta_1 t + e_t$$

$$= 0.98826 + 0.0000594t + e_t$$

t values (285.10) (24.75) $R^2 = 0.2322$

Sources: Persson (2004), Rich (2004).
Note: American wheat prices in London or Glasgow relative to average prices of English wheat in England and Wales (Gazette Average).

Figure 2 reveals quite clearly that the quality premium of US wheat increases by a little more than 10 per cent in the second half of the 19th century.[1] As a consequence US wheat sold at a price substantially above local wheat in British markets. There is no denying that there was price

[1] The quality premium is defined as the price differential between two qualities, say US Red Winter and Essex and Kent Red, at the same market, say, London.

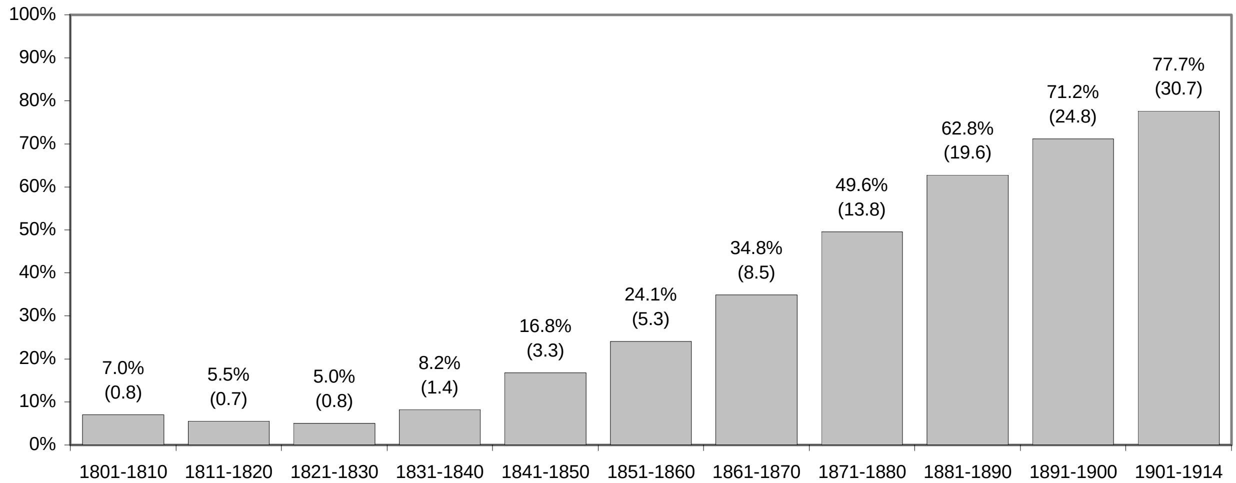
convergence but a significant part of it was caused by US wheat improving in quality and price relative to the Gazette average.

Having said that, some approximate and broad conclusions will hold, however. What is striking is that the British price level stands out as uniquely inflated in comparison with both the North American and European levels which both converge to the British level from below during the decades after the repeal of the corn-laws. Continental prices are represented by prices in Germany (Prussia), which was the single largest supplier of wheat to until the 1860s when Russia emerged as a major supplier. Prices in France, a minor supplier, were at approximately the same level as in Germany.

The British tariff was often prohibitive for Denmark, and by implication more so for continental European exporters such as Germany and France, which enjoyed slightly higher price levels. Although US prices were equal or slightly lower than the European levels in the Corn Law period, the high transport costs practically excluded New World grain from the British market until the 1850s. Between 1815 and 1828 the sale of imported grain to Britain was prohibited in 135 out of 159 months but grain could be imported if held in so-called bonded warehouses. Looking at the subsequent period, when the ban on imports was lifted and a sliding scale tariff was introduced, trade policy became a little less prohibitive. This fact can be grasped by imposing the transport, transaction and tariff costs on the price in Denmark, called the *hypothetical price* in Figure 1. In constructing that curve we are asking what Danish wheat would have cost in Britain given the price in Denmark plus British tariffs and transport costs between Denmark and Britain. The interpretation is straightforward. If the hypothetical curve is above the price of British wheat then tariffs and transaction costs gave Britain absolute protection and that happened often enough in the 1828 to 1848 period. The sliding scale consequently fulfilled its stated purpose to protect British producers when prices were low in Britain and to mute price increases when scarcity prevailed.

There is a striking similarity in the general drift of continental European *and* US prices and they converge from below to the British price level, which is subject to a secular fall from its post-Napoleonic peak. The US prices used are from Cincinnati and later Chicago and are significantly, about 10 per cent, lower than price in exporting ports on the North American east coast. For Denmark the convergence to the higher British price level is completed by the late 1870s, by which time wheat exports had stopped. From then on prices in all markets, including the United States, are falling although that fall is muted for Germany. A number of continental economies (Germany, Italy, France) part company, with the others allowing their price level to rise above that of Britain, Denmark and the United States for the first time in the 19th century. The observed shift and its timing are consistent with the expected effect of the re-introduction of grain tariffs on the Continent and we can therefore safely assume that the shift is not a quality shock. Denmark, however, remained in the free-trading bloc. Of the continental nations only Russia remained a substantial exporter, while Germany lost its British market share a little later than Denmark. After the repeal of the Corn Laws British imports shot up, so that by the end of the century less than 25 per cent of wheat consumption was produced domestically compared to more than 90 per cent prior to the repeal of the Corn Laws as demonstrated in Figure 3 below.

Figure 3. Share of the population in Great Britain dependent on imports of foreign wheat. Percentage of population and millions (in brackets).



Sources: Mitchell (1988), pp. 11-13, 221 and 225-226, and Brunt and Cannon (2004), Appendix I.
Note: Authors' estimates, based on an assessed annual consumption of 6 bushels of wheat per capita (2.18 hl or 167 kg) and known figures of the import of wheat and wheat meal and the population of Great Britain. Although the import figures cover the United Kingdom in the period 1840-1914, the Irish share of the import of foreign wheat has been deducted from the figures. There are no data on Irish imports of foreign wheat for the period 1906-1914 and consequently the UK imports have been reduced by 7 per cent, reflecting the Irish share in the ten preceding years.

The sharp increase in British wheat imports established a world market in wheat centred around Britain with the supply 'hinterland' gradually extending into the New World. As a consequence the geographical supply pattern changed as shown in Table 1.

Table 1. Wheat imports to the United Kingdom by exporting nation, 1800-1914. Percentage of total import.

	1831-1840	1841-1850	1851-1860	1861-1870	1871-1880	1881-1890	1891-1900	1901-1914
Germany[1]	32.0	40.3	26.1	20.5	7.4	3.5	1.2	n/a
France	11.8	9.8	8.9	3.2	1.6	n/a	n/a	n/a
Russia	13.3	15.1	18.4	26.9	20.4	20.2	16.8	14.5
Canada	4.5	1.8	1.6	5.5	6.8	3.7	5.9	15.1
United States	1.9	4.2	15.5	27.2	47.8	43.3	45.8	23.8
Argentina	n/a	n/a	n/a	n/a	n/a	2.1	11.5	17.5
India	n/a	0.0	0.0	0.0	3.9	16.2	9.7	16.4
Australia and New Zealand	n/a	0.4	n/a	0.4	3.3	4.8	3.2	9.5
Denmark	3.9	3.5	6.2	2.0	0.7	0.1	0.0	0.0

Sources: Mitchell (1988), pp. 225-26 and 229-31 (covering the years 1831-1840, 1885-1914), and official reports to the British Parliament (covering the years 1840-1885). Imports from Denmark are reported in official Danish trade statistics and imports from France 1831-40 are recorded in the trade statistics published by the French authorities. See reference for details on sources.
Note: n/a = not available [1] Prussia alone until 1840

Table 1 shows the distribution of British wheat imports by exporting countries. Until the 1860s wheat from Germany and Russia (mostly from the Black Sea region) dominated British imports. Throughout the 1860s and 1870s wheat from the overseas producing countries gained an increasing share of the market, crowding out most of the European wheat by the end of the 19th century.

The United States was the largest overseas supplier, but lost a significant part of its market share to new overseas suppliers such as Canada, India, Argentina and Australia shortly before and after the turn of the century. Did Britain's predominance in the wheat trade make it a price maker? And did the rise of a major supplier like the United States challenge that position? These questions are addressed in section 4.

Despite being the largest European wheat producer, France did not play an important role on the British wheat market. Compared with France the Danish share of the British market was quite large, particularly during the peak of the so-called Grain Sales period in the 1850s (although Danish wheat production was less than 1 per cent of the wheat production in France).

The continental nations, which resorted to protectionist policies after 1880, also retreated from the British food market altogether while Denmark, remaining in the free trade bloc, kept its presence in the British market only by switching from grain to exports of dairy products and meat. At about the same time Germany and France introduced grain tariffs, in the late 1870s and early 1880s, Denmark had evolved to a net importer of grain, including, of course, fodder grain. This switch reflected the change in relative prices in the deflationary period in the fourth quarter of the 19th century. There was a remarkable difference between the drift in the price of grain and animal products. Since the fall in grain prices was sharp relative to other agricultural prices, the relative price of animal products increased considerably. By increasing their price level on grain the protectionist bloc muted that fall in relative prices and retarded the transformation of agriculture. What were the consequences for price convergence and efficiency of the development of an international market for grain? We will turn to these questions next.

3. The phases of convergence.

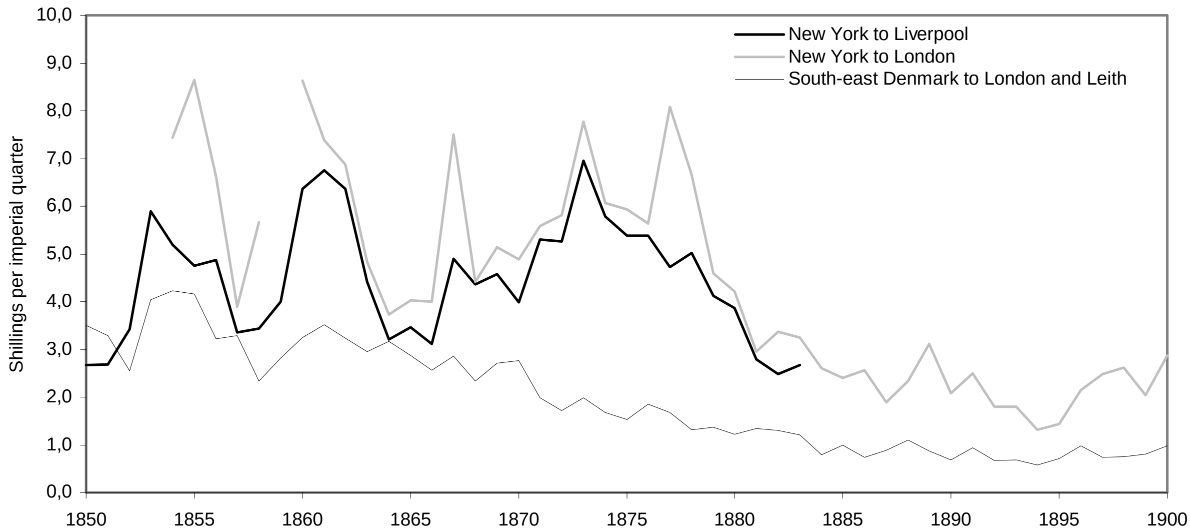
As explained in the preceding section a precise analysis of price convergence and of the price gap and its components cannot be based on different qualities of wheat and this section promises a more elaborated framework.

The price gap between importing and exporting nations can be decomposed in the following way as shown on the right hand side of equation 3.1.

$$P^m - P^x = Tt^{x,m} + Tn^{x,m} + Tf^m + Q^{x-m} + R \qquad (3.1)$$

Where P^m and P^x are the price in export and import markets respectively. $Tt^{x,m}$ is transport costs from the exporting market to the importing market, $Tn^{x,m}$ is transaction costs in exporting and importing markets, Tf^m is the import tariff. Q^{x-m} is the price premium of export wheat relative to wheat in the importing market, that is the price of the exported quality in importing market minus the price of the local quality in the importing market. Q^{x-m} can be either positive, indicating that consumers value the export quality higher than the local quality, or negative, indicating that local wheat fetches a higher price. The way to estimate Q^{x-m} is simply to look at the price differential between two varieties of wheat in a single market, say US Red Winter No 2 traded in London with, say, Essex and Kent Red in London. In most cases we set $Q^{x-m} = 0$ simply by using identical qualities in the analysis. R is a residual, which can catch unobserved transaction costs as well as market inefficiencies, that is, rents which have not been arbitraged away. If R is zero, markets can be said to obey LOOP in the strong or absolute sense.

Figure 4. Transport costs in grain trade between the United States, Denmark and Britain, 1842-1900. Shillings per imperial quarter.

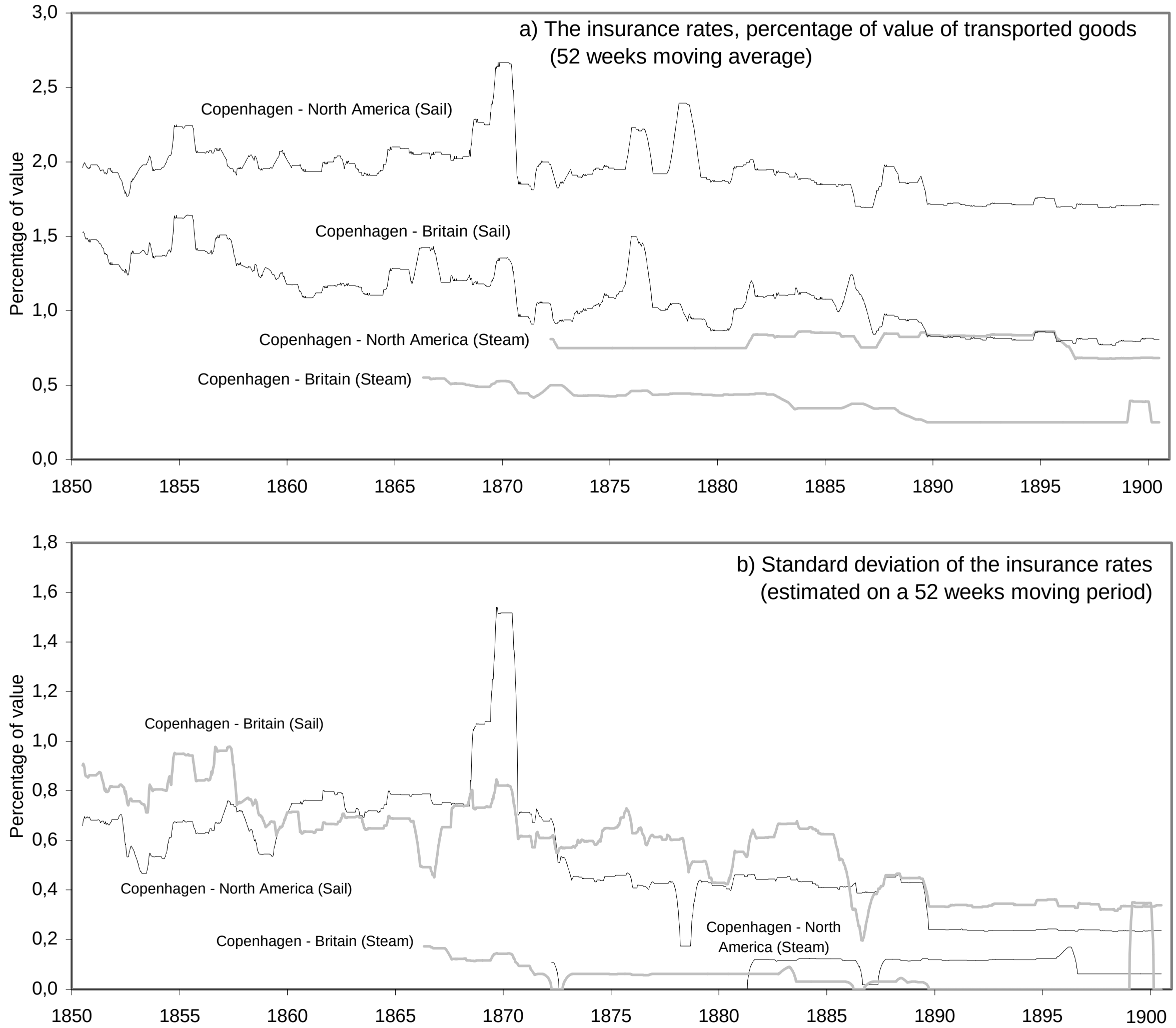


Source: Persson (2004, Appendix 1), Monrad Møller (1995), North (1958). See Appendix A1 for details.
Note: Transport of grain, New York to Liverpool or London, is an average of both sail and steam. The Danish transport costs are described in Appendix A1.

In Figures 4 and 5 we look at the evolution of two important elements of transactions costs, transport and insurance costs. While the fall in nominal trans-Atlantic freight rates was restricted to the last quarter of the 19th century, known for its general deflationary tendency, the Anglo-Danish route is characterized by a fall throughout the entire period. The difference between Anglo-Danish and trans-Atlantic rates does not exhibit a consistent trend. In fact the difference is large by the mid 1870s and declines from then on. Trends are, however, difficult to ascertain since freight rates varied a lot from year to year. The cyclical variation between peak and trough especially in the early years is larger than the trend fall in transport costs over the entire period (Klovland 2004). It must be stressed that what is true for nominal rates is not necessarily true for real rates. Most of the decline in freight rates occurred with deflation making the real decline quite modest (Persson 2004).

Figure 5. North-Sea and Trans-Atlantic insurance rates, 1850-1900.

Percentage of value of transported goods.



Source: Mæglernes Priskurant (Copenhagen Broker's List), 1850-1900. See Appendix A1 for further details.

Insurance rates also fell but the fall was not remarkably strong and was concentrated on sail, which was losing its market share in the period. However as steam, with insurance rates at about half that of sail, replaced sail over the second half of the 19th century, the effective insurance rate fell by about half. It is worth noting that the standard deviation, Figure 5b, also falls. That fall reflects the fall in seasonal differences in insurance rates. Winter rates were initially much higher than summer rates but as the quality of the vessels improved, the seasonality in causalities fell and hence insurance rates fell. Insurance rates for the trans-Atlantic route were about double that of the Denmark-Britain route.

Table 2. The structure of the price gap in Anglo-Danish wheat trade, 1845-1875. Shillings per imperial quarter.

Period[1]	1845-1849		1849-1860		1861-1869		1869-1875	
Quality	Average	Best	Average	Best	Average	Best	Average	Best
Price gap	17.31*	14.68*	10.64*	8.36*	8.16*	5.92*	4.92*	3.04*
std. err.	(0.62)	(0.65)	(0.40)	(0.38)	(0.32)	(0.30)	(0.28)	(0.25)
Percentage of average price in Danish export harbours	46.4%	36.6%	25.7%	19.1%	19.0%	13.1%	10.3%	6.1%
Transport	4.61	4.61	3.55	3.55	2.93	2.93	2.02	2.02
Insurance	0.58	0.59	0.60	0.60	0.50	0.50	0.44	0.44
Shipping charges and port handling costs	1.43	1.43	1.35	1.35	1.16	1.16	1.14	1.14
Import duty	10.09	10.09	1.00	1.00	1.00	1.00	0.00	0.00
Residual	-0.06	-2.57*	4.16*	1.86*	2.57*	0.32	1.30*	-0.58*
std. err.	(0.45)	(0.45)	(0.21)	(0.20)	(0.20)	(0.19)	(0.22)	(0.19)
Percentage of average price in Danish export harbours	0.2%	-6.4%	10.0%	4.3%	6.0%	0.7%	2.7%	-1.2%
N	164	164	525	525	368	368	307	307

Sources: Prices in Copenhagen and insurance rates from Mæglernes Priskurant (Copenhagen Broker's List). Prices in London of Danish and Holstein wheat from The Times. Transport costs from Monrad Møller (1995) and North (1958). Shipping charges and port handling costs, see Appendix A1. Import duties from The Economist or calculated from weekly English wheat prices (Gazette Average) and the duty tariff scale.
Note: The estimate of each entry is a mean value of weekly observations, which implies that the entries in the columns are not strictly additive. The price gap is the price in London of Danish and Holstein wheat minus the price in Copenhagen of Danish wheat. The price level in Copenhagen has been reduced by 5 per cent, reflecting a lower price in the Danish wheat export harbours in the south-eastern part of Denmark. Transport and other transaction costs refer to trade between the Danish export harbours and British east coast harbours.
[1] The first two periods are divided at January/February 1849 and the two last periods are divided at April/May 1869.
* Significantly different from zero at the 5 per cent level.

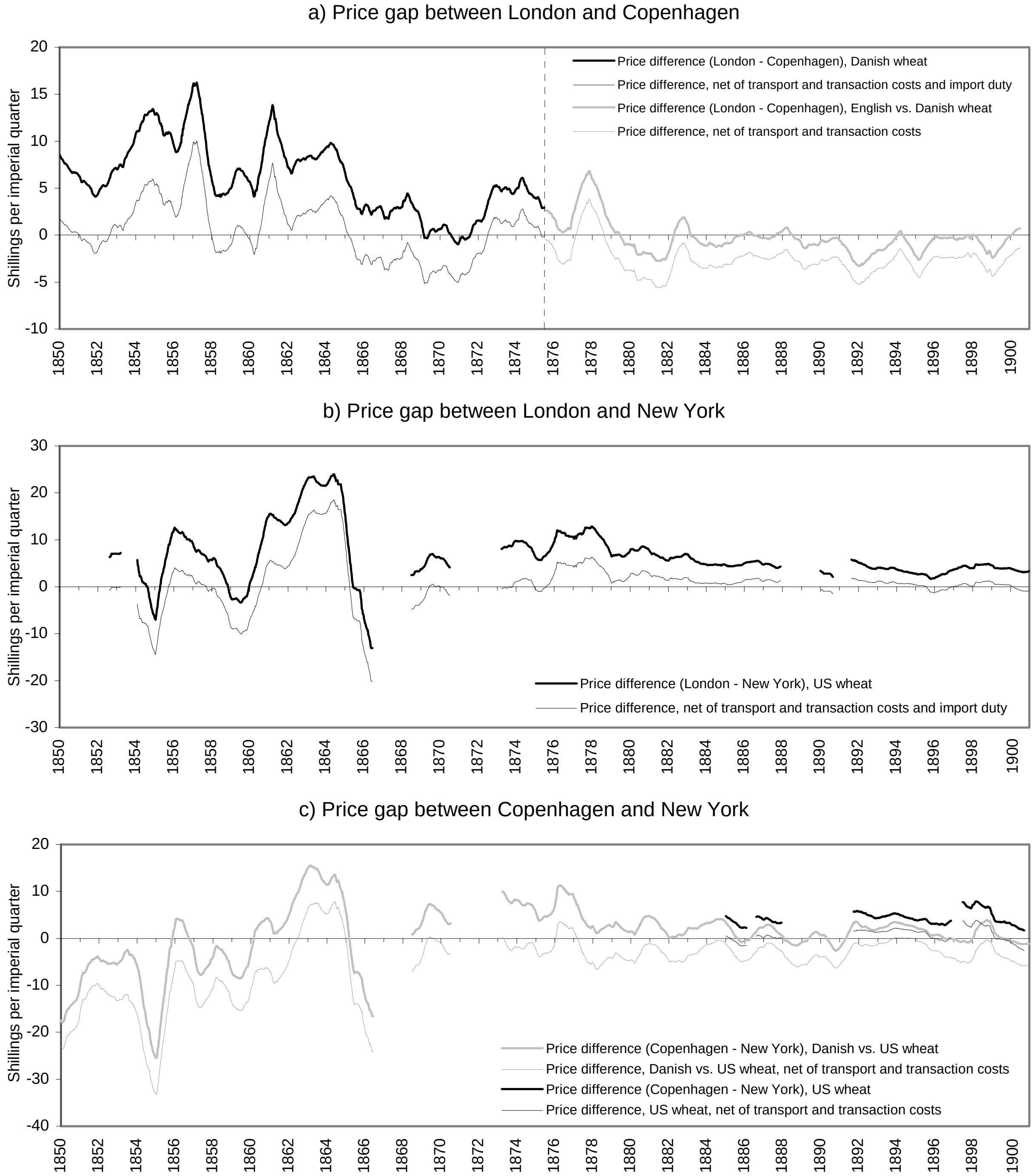
What is the relative impact of the different elements in transaction and transport costs when it comes to reducing the price gap between markets? This question is addressed in Table 2. We look at the price gap between Denmark and Britain before and after the repeal of the Corn Laws and we decompose that gap into its constituent elements such as tariffs, transport costs, insurance rates, port charges etc. The first period in Table 2 is the end of the Corn Law period, 1845-49 and from then on tariffs were reduced to just 1s per imperial quarter, to disappear entirely in the late 1860s. The price gap is estimated for two qualities in Denmark, 'Best' and 'Average'.

The story conveyed by Table 2 is straightforward. The price gap fell sharply after the repeal of the Corn Laws, that is from the first to the second period in Table 2 and continued to fall slowly over the entire period. In percentage point terms the price gap fell from 46 per cent to 10 per cent from the first to the last period for the average quality. Almost all of the initial decline had to do with the fall in the British import duty from an average of 10s per imperial quarter to 1s. During the remaining years the decline in the price gap was conditioned in roughly equal measure by transport cost reductions and a fall in the residual, the latter fall being slightly more pronounced. The other transaction costs also fell gently but since they were small the impact on the closing of the price gap was modest.

It is worth speculating a little on the fall in the residual from some 10 per cent in 1849-1860 to 3 per cent of the price in Denmark in 1869-75 (looking at average qualities), or from about 4s per imperial quarter to almost 1.5s. There are two elements in the residual which are not easy to separate precisely. The residual may contain non-observed arbitrage and trade costs such as commissions. Furthermore, measurement errors in the observed transaction costs are likely to occur even though they need not be biased, so it is not obvious that measurement errors should make the price gap smaller over time. However, it is probable that part of the decline in the residual was associated with improved efficiency in the market place since it is unlikely that actual trading costs of several shillings per imperial quarter could remain unrecorded. We expect that the residual should be zero or close to zero in an efficient market and this is also true for the two last periods for trade in 'Best' wheat, which was the preferred quality in Anglo-Danish trade.[2] During the last years of Danish wheat exports the residual was actually negative and we interpret that as an indicator of Danish exports being crowded out from the British market. The transport and transaction costs adjusted law of one price was therefore established as trade flourished in the last quarter of the 19th century.

[2] 'Best' wheat had a negative residual in the last years of the 1840s, which can be interpreted as a Corn Law effect. When prices fell in London, tariffs increased and made Danish exports unprofitable. Danish exports were interrupted and traders in London sold their inventories of Danish wheat below the current tariff, transport and transaction cost covered price.

Figure 6. Gaps between wheat prices in London, New York and Copenhagen, 1850-1900. Shillings per imperial quarter.



Sources: Persson (2004), Rich (2004), see Appendix A1.
Note: For all curves a 52 weeks moving average is used. Figure 6a shows the price difference between Danish and Holstein wheat in London and Danish wheat in Copenhagen until 1875, and subsequently the price difference between English wheat in England and Wales and Danish wheat in Copenhagen. Figure 6b shows the price difference between US wheat of same quality in London and New York. Figure 6c shows the price difference between Danish wheat in Copenhagen and US wheat in New York in the period 1850-1900 and the price difference between US wheat in Copenhagen and New York in the period 1885-1900.
The details of freight, insurance and other transaction costs are in Appendix A1.

We can extend the discussion of the gradual evolution of LOOP by analyzing European-North American wheat trade, see Figure 6. In all three figures the thick black curve refers to the gross price difference, while the thin black curve refers to the price difference when total tariff, transport and transaction costs have been deducted from the gross difference. Black curves refer to identical qualities in exporting and importing markets. For LOOP to hold the thin black curve should converge to the zero line since the difference between the thin black curve and the zero line amounts to the residual price gap. The grey thick and thin curves represent gross and net price differences, but the qualities compared are not strictly identical. It is therefore not appropriate to draw precise conclusions on the basis of these curves. The thick black curve in Figure 6a is the price of Danish-Holstein wheat in London minus the price of Danish wheat in Copenhagen. Since Danish wheat exports to Britain cease in the last quarter of the 19th century, the right hand side of Figure 6a refers to Danish wheat in Copenhagen and the Gazette average of English wheat in England and Wales. In Figure 6b we have access to identical qualities throughout the period, while in Figure 6c, identical qualities are only available in the last 15 years of the period. The principal new result that emerges from an observation of Figures 6a and 6b in conjunction with the data in Table 2 is that there is an 'emerging market' phase when LOOP was subject to large shocks, i.e. displaying large residuals. However it is obvious that there is a gradual elimination of the residual taking place. US wheat traded in Copenhagen in the last 15 years of the period was also very close to LOOP, cf. the thin discontinued black curve in Figure 6c. The less than perfect match might have to do with the fact that it was not always possible to control that the wheat quality traded in New York was strictly identical to the US wheat traded in Copenhagen. As should be clear from Appendix A1 the quality information in Copenhagen is at times a little ambiguous.

The interpretation of the right hand side of Figure 6a referring to London-Copenhagen is also straightforward. Although it traces the price differential of two different qualities, they were both traded at about a 10 per cent 'discount' relative to US Red Winter in their respective home markets. Therefore they can be assumed to be of roughly equal quality. Given a close to zero gross price difference and positive transport and transactions costs, trade can be ruled out and in fact it ceased in the early 1870s. The left hand part of Figure 6c might look a bit confusing given the pattern displayed in Figure 1 since Figure 6c suggests that the price of Danish wheat is lower than the US wheat, while Figure 1 suggests the opposite for the 1850 to 1870 period. However this paradox can easily be resolved. Figure 1 use prices at the production location while Figure 6 uses prices at export or imports locations. In the 1850s the price difference between Chicago and New York were substantial.

Finally, it is worth stressing that the black thick curve in Figure 6b indicates that the price gap between US wheat traded in London and New York fell but remained substantial at about 3-4s per imperial quarter, which is roughly 10 per cent and can be accounted for primarily by observed transport and transaction costs.

Summing up, we have found clear evidence that convergence to the law of one price is a gradual phenomenon and it can be interpreted as a sign of increasing competitiveness. This interpretation is supported by the gradual sophistication of commercial intelligence as witnessed by the proliferation of the commercial press contributing to an appropriate information environment. The fear that economies of scale in trade made entry more difficult over time is not borne out by the data. The residual, which at least partly can be generated by non-competitive practices in trade, actually fell as trade flourished.

4. Market efficiency in a network of trading partners.

The foregoing analysis suggests that the size of residual costs fell between what we call the 'emerging market period' after the repeal of the British Corn Laws and the last quarter of the 19th century contributing to convergence to LOOP. We will now investigate the impact of that development on market efficiency. The traditional approach to market efficiency looks at the correlation of prices or the speed of adjustments to an equilibrium price differential between markets in bilateral trade. This latter approach makes the determination of equilibrium differentials quite easy: price differences shall not exceed transport and transaction (including tariffs) costs and prices must adjust to that equilibrium. However arbitrage in the world economy is normally multilateral and therefore bilateral LOOP might not hold for markets when they do not trade with each other. However, they can still be integrated by trading with a common third market.

The following stylized example illustrates the point and incidentally gives a good picture of the shifts in supply patterns in the 19th century.

Imagine three trading markets, Britain, Denmark and the United States. Grain is exported from the United States to Europe at a cost of 6 to Britain and 7 to Denmark. The price is 100 in the United States and consequently 106 in Britain, which is an importer throughout the period. Transport and transaction costs between Britain and Denmark are 2. The Danish-American LOOP at the price 107 in Copenhagen is violated when Denmark exports to Britain at the Danish price of 104 in the bilateral LOOP with Britain. However the Danish price can rise above 104 to 107 although exports to Britain will have to cease at the higher price. This is what happens over time. Denmark switches from being an exporter to an importer of wheat. By the late 1870s Denmark ceases its exports to Britain and starts importing from the United States. At that time a bilateral LOOP with the United States should hold at a Danish price of 107, which is smaller than the price in Britain (106) plus transport costs (2) from Britain to Denmark.

These configurations have consequences for the appropriate equilibrium concept. Let us define a multilateral LOOP, called M-LOOP accordingly. In a three market world, A, B and C, where B and C do not trade with each other but both trade with A the M-LOOP is such that

(i) the (absolute) value of the equilibrium price differential between B and C is equal to the transport and transaction costs from B to A minus the transport and transaction costs from C to A which are smaller than the transport and transaction costs between B and C.

The argument can easily by extended to an economy with many markets.

(ii) The (absolute value) of the equilibrium price differential between any pair of economies that do not trade directly with each other but with other economies is equal to the minimum transport cost differential to a third economy with which they both trade.

What we now need to do is to test for LOOP for trading pairs and M-LOOP for indirect trading pairs.

In the following we develop the theoretical framework for three trading markets: market A (Britain) is importing from the two remaining markets: B (United States) and C (Denmark).[3] Furthermore, we assume no direct trade between market B (United States) and C (Denmark). A crucial assumption in order to derive the model is to know the trading flows. If we apply the LOOP to the markets that actually trade, we can derive an equilibrium relationship between pairs of trading markets. By using the version of LOOP that takes account of transport costs and other transaction costs, the two equilibria are given by

$$\begin{aligned} P^A &= P^B + Tt^{BA} + Tn^{BA} + Tf^{BA} \\ P^A &= P^C + Tt^{CA} + Tn^{CA} + Tf^{CA} \end{aligned} \tag{4.1}$$

[3] The reason we limit the focus to three markets has to do with the lack of sufficiently large and robust data on prices and transaction costs from other relevant markets. The fact that prices have to be observed in all markets at the same time reduces the number of useful observations substantially.

where P^j is the price in market *j*, Tt^{ij}, Tn^{ij} and Tf^{ij} are the transport costs, transaction costs and tariffs associated with transporting grain from market *i* to *j*. From these two equilibria we can derive the implicitly given relationship between the prices in market B and C, which do not trade directly with each other:

$$\begin{aligned} &P^B + Tt^{BA} + Tn^{BA} + Tf^{BA} = P^C + Tt^{CA} + Tn^{CA} + Tf^{CA} \\ &P^B = P^C + Tt^{CA} + Tn^{CA} + Tf^{CA} - (Tt^{BA} + Tn^{BA} + Tf^{BA}) \end{aligned} \tag{4.2}$$

We then characterise the M-LOOP by the three equilibria stated in (4.1) and (4.2), where (4.1) states the equilibrium relationship between trading markets and (4.2) the equilibrium relationship between non-trading markets. We can then examine the M-LOOP by analysing the equilibrium relation between pairs of markets.

To examine the existence of M-LOOP, we adopt the approach used for the LOOP, namely to consider the equilibrium as an attractor, rather than a state where the prices rest. This implies that prices in the three markets should adjust so that the equilibria are restored. The idea is that prices may be exposed to supply or demand shocks, which may push the prices out off equilibrium, and that the prices do not immediately adjust, but will do so over time. This model can be formulated as a multi-variate error correction model. However, before formalising the multi-variate error correction model, we will first test whether the theoretically derived equilibria actually exist. The commonly used approach is to test whether the equilibrium relations are stationary relations or in technical jargon whether prices are cointegrated.

4.1 Cointegration tests

Testing for cointegration can be done by using either the Engle and Granger technique (Engle and Granger 1987) or by using the Johansen maximum likelihood estimation, see Johansen (1988). In this paper we are using the Engle and Granger approach. In that approach each equilibrium relationship is estimated separately and subsequently tested to be a stationary process by using the Dickey-Fuller test.

In the original approach by Engle and Granger (1987) the equilibrium relationship is estimated by an OLS regression. However, in our context the equilibrium relations are known by equations (4.1) and (4.2), but as discussed in section 3, we have an unobserved residual. We depart from the formulation in equation (3.1) and assume that other transaction costs, the residual, are constant over each period and proportional to the price. To enhance readability we now define a term *T* which is the sum of observed transport costs, transaction costs and tariffs. We can then formulate the equilibrium relation as:

$$P^j = (P^i + T^{ij})\mu^{ij}$$

where T^{ij} is the observed transport costs and transaction costs and μ^{ij} measures unobserved transaction costs. This means that we have to estimate the residual μ in a first step regression. In order to do this we follow the usual approach by transforming all prices by the logarithm. The equilibrium relationship can be formulated as

$$\ln(P_t^j) = \ln(P^i + T^{ij}) + \ln(\mu^{ij})$$

On the basis of the estimated equilibrium relationship (or cointegration relationship) we can construct the equilibrium errors

$$\begin{aligned} e_t^{AB} &= \ln(P_t^A) - \ln(P_t^B + T_t^{BA}) - \hat{\delta}^{BA} \\ e_t^{AC} &= \ln P_t^A - \ln(P_t^C + T_t^{CA}) - \hat{\delta}^{CA} \\ e_t^{BC} &= \ln(P_t^B + T_t^{BA}) - \ln(P_t^C + T_t^{BC}) - \hat{\delta}^{CB} \end{aligned} \tag{4.3}$$

where $\delta^{ij} = \ln(\mu^{ij})$. The estimate of δ is determined as $\hat{\delta}^{ji} = \frac{1}{T}\sum_{t=1}^{T} \ln P_t^i - \ln(P_t^j + T_t^{ji})$. In the next step, a Dickey-Fuller test is used to test whether these equilibrium errors are stationary processes. This is done by running the following regression

$$\Delta e_t = \lambda_0 + \lambda_1 e_{t-1} + v_t$$

and test whether $H_0 : \lambda_1 = 0$ (Non-stationary process). The distribution of the t-statistics is the Dickey-Fuller distribution. In Table 3, we report the result of the cointegration test. Note, that in the case where we have two importing markets and one exporting market (e.g. the later period), the equilibrium relations (4.1) and (4.2) and thereby (4.3) will look slightly different (see Appendix A3 where the equilibrium relations are defined).

Table 3: Cointegration test (Engle-Granger approach)

	$\hat{\delta}^a$	No obs.	DF-test	DF p-value	Stationary
Period 1855-1862					
Liverpool-New York	0.099*	263	-4.205	0.001	Stationary
Liverpool-Copenhagen	0.146*	373	-4.860	0.000	Stationary
New York-Copenhagen#	-0.050*	243	-3.343	0.013	Stationary
Period 1885-1895					
London-New York	0.030*	355	-6.181	0.000	Stationary
Copenhagen-New York	0.034*	323	-4.285	0.000	Stationary
London-Copenhagen#	-0.002	240	-2.892	0.046	Stationary

[a] Unobserved transaction costs (proportional to the price)
#denoting no trading markets
* Significantly at the 5 per cent level
Sources: See Appendix A1.
Note: 1855-1862: White Western in New York, US White in Liverpool, Danish wheat in Copenhagen. The Copenhagen prices are corrected for quality difference between US and Danish/Holstein wheat in London, thus reflecting a hypothetical price on US wheat in Copenhagen. Prices in New York and Copenhagen are adjusted for observed transaction costs.
1885-1895: Red winter No 2 in New York and London, American wheat in Copenhagen. Prices in New York are adjusted for observed transaction costs.

The estimates show clearly that all markets are integrated, and even markets that do not trade with each other are integrated. This suggests that already in the early period, 1855-1862, Britain, United States and Denmark were well integrated. The results also illustrate M-LOOP, since the estimates of δ cannot be interpreted as unobserved transaction costs in the case where the markets are not trading directly. We will therefore expect $\hat{\delta}$ to smaller than the actual transaction costs, which is also what we obtain. On the other hand, in the cases where we actually have trade between markets the estimates are in line with the expectation that the residual falls over time. These results are clearly supportive of the findings in Table 2 and Figure 6. In the period 1855-1862, the unobserved transaction costs amount to about 10 per cent for grain exported from New York to Liverpool, while the similar number for grain exported from Copenhagen to Liverpool is about 15 per cent. In the second period, 1885-1895, the unobserved transaction costs, are much lower, namely about 3-4 per cent. We interpret this fall as a spectacular increase in market efficiency. Although what we refer to as unobserved transaction costs can be actual costs, such as commissions on which we do not have data, the likely magnitude of such costs, let alone the decline, cannot match the magnitude in the fall in the residual. A more plausible story suggests that excessive trading profits in the emerging market phase have been squeezed as trade became more regular and well informed.

4.2 The multi-variate error correction model

We here present the error correction model for three markets: A, B and C, where market A imports from market B and C. The prices in these three markets do adjust to two equilibria in equation (4.1). The model is given by

$$
\begin{aligned}
\Delta \ln(P_t^A) &= \alpha^A \left[\ln(P_{t-1}^A) - \ln(P_{t-1}^B + T_{t-1}^{BA}) - \delta^{BA}\right] + \gamma^A \left[\ln(P_{t-1}^A) - \ln(P_{t-1}^C + T_{t-1}^{CA}) - \delta^{CA}\right] + \varepsilon_t^A \\
\Delta \ln(P_t^B) &= \alpha^B \left[\ln(P_{t-1}^A) - \ln(P_{t-1}^B + T_{t-1}^{BA}) - \delta^{BA}\right] + \gamma^B \left[\ln(P_{t-1}^A) - \ln(P_{t-1}^C + T_{t-1}^{CA}) - \delta^{CA}\right] + \varepsilon_t^B \\
\Delta \ln(P_t^C) &= \alpha^C \left[\ln(P_{t-1}^A) - \ln(P_{t-1}^B + T_{t-1}^{BA}) - \delta^{BA}\right] + \gamma^C \left[\ln(P_{t-1}^A) - \ln(P_{t-1}^C + T_{t-1}^{CA}) - \delta^{CA}\right] + \varepsilon_t^C
\end{aligned}
$$

where $\Delta \ln P_t^j = \ln P_t^j - \ln P_{t-1}^j$ is the first difference in log prices. The parameters of the model are $\alpha^A, \alpha^B, \alpha^C, \gamma^A, \gamma^B, \gamma^C, \delta^{BA}$ and δ^{CA}. In order to make the interpretation of the parameters in the model easier, the model can also be expressed as

$$
\begin{aligned}
\Delta \ln P_t^A &= \alpha^A \left[\ln(P_{t-1}^A) - \ln(P_{t-1}^B + T_{t-1}^{BA}) - \delta^{BA}\right] + \gamma^A \left[\ln(P_{t-1}^A) - \ln(P_{t-1}^C + T_{t-1}^{CA}) - \delta^{CA}\right] + \varepsilon_t^A \\
\Delta \ln P_t^B &= (\alpha^B + \gamma^B)\left[\ln(P_{t-1}^A) - \ln(P_{t-1}^B + T_{t-1}^{BA}) - \delta^{BA}\right] + \gamma^B \left[\ln(P_{t-1}^B + T_{t-1}^{BA}) + \delta^{BA} - \ln(P_{t-1}^C + T_{t-1}^{CA}) - \delta^{CA}\right] + \varepsilon_t^B \\
\Delta \ln P_t^C &= \alpha^C \left[\ln(P_{t-1}^C + T_{t-1}^{CA}) + \delta^{CA} - \ln(P_{t-1}^B + T_{t-1}^{BA}) - \delta^{BA}\right] + (\alpha^C + \gamma^C)\left[\ln(P_{t-1}^A) - \ln(P_{t-1}^C + T_{t-1}^{CA}) - \delta^{CA}\right] + \varepsilon_t^C
\end{aligned}
$$

Then it is easy to verify that if the prices adjust to the equilibria we need to have that $\alpha^A < 0, \gamma^A < 0, \alpha^B + \gamma^B > 0, \gamma^B < 0, \alpha^C < 0, \alpha^C + \gamma^C > 0.$ Note that these conditions only hold if we have one importing market and two exporting markets as in the early period. In the later period Denmark ceased to export to Britain and began to import from the United States. Appendix A2 outlines the new set of equilibrium relations in this context. As a consequence the signs of the parameters are different. In this new setup the conditions will be

$\alpha^A + \gamma^A < 0, \gamma^A > 0, \alpha^B > 0, \gamma^B > 0, \alpha^C > 0, \alpha^C + \gamma^C < 0.$

Performing the analysis of three markets simultaneously, rather than analyzing pairs of markets, has a number of advantages. First, we are able to test whether markets, which do not directly trade, can still be integrated. Second, by analysing all economies in one single multi-lateral model, the interrelationships among the economies are revealed and we are able to examine how local shocks are disseminated throughout the network of economies.

Table 4: Estimation result from the multi-variate error correction model

1855-1862	Liverpool (Importer)	New York (Exporter)	Copenhagen (Exporter)
$\delta^{NY.L}$	0.099*	0.099*	0.099*
(Transaction cost: New York-Liverpool)#	(0.006)	(0.006)	(0.006)
$\delta^{L.C}$	0.145*	0.145*	0.145*
(Transaction cost: Liverpool-Copenhagen)#	(0.005)	(0.005)	(0.005)
α (Liverpool-New York)	-0.038*	0.073*	0.042
	(0.015)	(0.028)	(0.027)
γ (Liverpool-Copenhagen)	-0.002	0.033	0.112*
	(0.015)	(0.027)	(0.026)
Variance of ε (10^{-3})	0.54	1.76	1.60
R^2	0.02	0.03	0.08
N	265	254	254
1885-1895	**London (Importer)**	**New York (Exporter)**	**Copenhagen (Importer)**
$\delta^{NY.L}$	0.027*	0.027*	0.027*
(Transaction cost: New York-London)#	(0.002)	(0.002)	(0.002)
$\delta^{NY.C}$	0.030*	0.030*	0.030*
(Transaction cost: New York-Copenhagen)#	(0.002)	(0.002)	(0.002)
α (London-New York)	-0.202*	0.059	-0.059
	(0.036)	(0.032)	(0.032)
γ (Copenhagen New York)	-0.005	0.016	-0.063*
	(0.024)	(0.031)	(0.022)
Variance of ε (10^{-3})	0.35	0.60	0.27
R^2	0.14	0.01	0.08
N	258	276	253

estimated in the first step
*Significant at the 5 per cent level
Numbers in brackets are standard errors
Source: see table 3.

The model is estimated by using the two step procedure by Engle and Granger. The estimation results are reported in table 4. The table is difficult to read without a few explicatory words. Look at the third cell from the top in the column headed by Liverpool. The number in that cell is -0.038* and that number is the significant α^{A}-parameter denoting the adjustment of the Liverpool price to the Liverpool-New York equilibrium. The next cell in that row displays the number 0.073*, which is the α^{B} –parameter indicating the adjustment of New York prices to the Liverpool-New York equilibrium. Remain in that column and take one step down to next cell with the value 0.033. That is the γ^{B}-parameter measuring the (insignificant) adjustment of New York prices to the Liverpool-Copenhagen equilibrium. The third cell in the same row has the value 0.112* and it is the significant γ^{C}-parameter measuring the adjustment of Copenhagen prices to the Liverpool-Copenhagen equilibrium.

The estimation results of table 4 confirm that prices in the markets actually adjust to the equilibria. A closer look at the estimated adjustment coefficients (α and γ) reveals that all the estimated coefficients, except for four insignificant parameters[4] are in accordance with the conditions stated above. Furthermore, in 1855-1862 the prices in Britain and the United States primarily react to deviations from the Britain-United States equilibrium, while the Danish market mostly reacts to deviations in the Britain-Denmark price relationship. In the period 1885-1895 the pattern is the same except that prices in the United States do not adjust much to the two equilibria. This finding suggests that in that period price shocks in the United States dominate international price movements, as will be further below. To illustrate the adjustment process and how local shocks are disseminated through the other markets, we have performed a number of simulation experiments.

4.3 Simulation experiments

The main purpose of the simulation experiment is to illustrate how the adjustment between prices in the three markets takes place. In these simulations we therefore ignore transaction costs. In each experiment we assume that one of the markets is hit by a shock at period 0, which increases the price by 10 per cent. Before period 0 all prices are assumed to be one. Furthermore, we assume that there are no other shocks to the system of prices. After period 0 the prices start to adjust mutually to the disequilibrium. In Figures 7 and 8 shocks occur, from left to right, in Britain, the United States and Denmark. In the first graph in Figure 7 the price in Britain increased by 10 per cent in period 0. What we see is that the British price shock triggers off a response in the United States and Denmark so that prices start to increase. After 4 periods (4 weeks) the price gap between the United States and Britain is only 5 per cent, i.e. half of its initial level after the shock. The first graph also shows that the closing of the price gap between Britain and the United States and Britain and Denmark is primarily due to the fact that prices in the United States and Denmark increase a lot, rather than a

[4] In the period 1855-1862, we get wrong signs of γ^{B} and α^{C} and in the period 1885-1895 we get wrong signs of γ^{A} and α^{C}.

price decrease in Britain. The second and third graphs in Figure 7 confirm that the adjustment is mainly due to price changes in United States and Denmark. In fact an isolated shock in Denmark does not seem to affect prices in Britain at all. The obvious interpretation is that Denmark was a comparatively small player and the wheat it exported had several more or less perfect substitutes exported from other markets. A shock in the United States on the other hand (middle graph in Figure 7) triggers off the expected upward adjustment in Britain but a perverse reaction in Denmark initially when prices fall. The explanation is that the parameter on the United States-Denmark equilibrium has the wrong sign (but is insignificant). What in the end forces Danish prices to adjust in the right direction is that they adjust to British prices. Again this makes sense. At this time, Denmark traded directly with Britain and, it can be assumed, focussed on that market.

There are signs of British market dominance in the first period presumably caused by the fact that Britain emerged as a major importer in the world. In the emerging market phase there was a number of suppliers of which none had the market share that the United States achieved in the second period, when the United States supplied almost half the imports of wheat to Britain. In that period, as shown in Figure 8, most of the adjustment comes from changes in prices in Britain and Denmark. The two sets of figures also reveal that the adjustment is faster in the second period. In the last period the price gap between the United States and Britain was reduced to half in less than three weeks, as compared to four in the first period. The first two graphs (from the left) in Figure 8 indicate that the United States now enjoys market dominance in that other markets assume most of the adjustment. A British price shock is mainly self-adjusting while other markets, the middle graph, adjust swiftly to the US price shock. Again the Danish prices first react perversely to a shock in Britain, wrong sign again, but finally adjust in the expected direction because of the pull of US prices. This is plausible since Denmark now trades directly with the United States and only indirectly with Britain.

Is there an explanation for the US ascendancy to market dominance? One plausible explanation is the sheer weight of US exports in the major wheat market, see Table 1. It is worth stressing that the term 'market dominance' does not imply market power in the sense that US traders could manipulate prices. The point is simply that there is an asymmetry in adjustment, which seems to be linked to US market share in the second period and to the absence of a dominant exporter to Britain in the first period.

Figure 7: Simulation experiment for the period 1855-1862

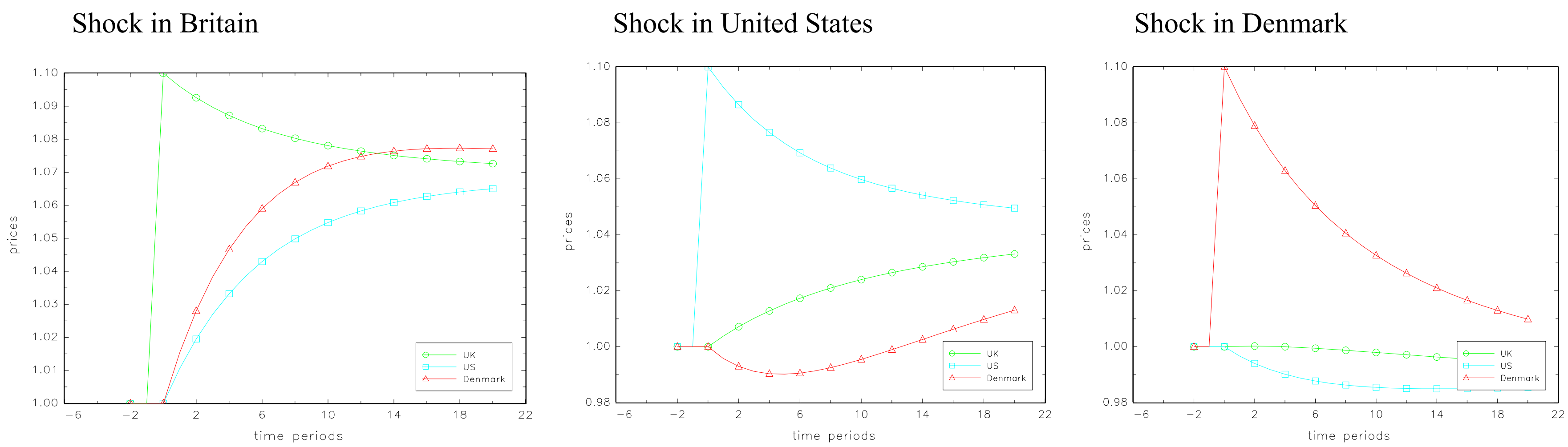
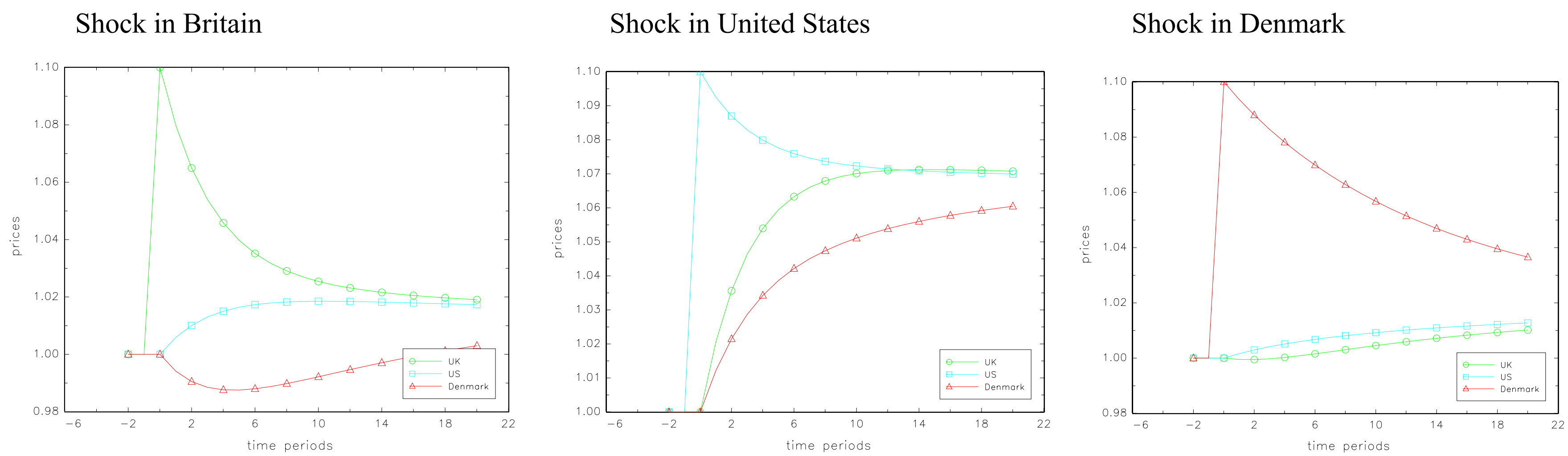


Figure 8: Simulation experiment for the period 1885-1895



4.4 Common trend

The finding that there was a change in the pattern of market dominance can be further substantiated by the detection of a common trend.

The fact that we find that the system of three markets does adjust to two equilibria, implies that prices in all three markets are driven by one common non-stationary trend.[5] On the basis of the estimated adjustment parameters it is possible to find the estimated common trend.[6] The common trend in this model consists of the accumulation of shocks from the three markets, but the different markets may have different weights. Below we present the common trend for the two periods. In both periods we have normalized the impact of the shocks in the US to one.

Common trend 1855-1862:

*1.63*shocks in Britain + 1.00*shocks in United States – 0.27 *shocks in Denmark*

Common trend 1885-1895:

*0.22*shocks in Britain + 1.00*shocks in United States + 0.24 * shocks in Denmark*

The estimates of the common trend clearly show that the centre of gravity in the international wheat market has changed between the two periods. In the early period prices were primarily driven by shocks in Britain, and to some extent by shocks in the United States. The shocks in the Danish market did not have much of an impact.[7] In the later period it is demonstrated that it is the shocks in the United States that primarily determine the trends in the other prices. Now the shocks in Britain and Denmark only have a small impact on the common trend.

There is an obvious problem in the analysis above that the second largest wheat exporter at the end of the 19th century, Russia, is not included in the analysis. The price data we have for Russia, (Odessa) are unfortunately not possible to use in the multi-variate analysis, since we do not have a sufficient number of observations. However we have performed a bi-variate analysis including New York and Odessa and the results support our conclusion that US price shocks dominate Odessa shocks. That is, shocks in Odessa do not affect New York prices but New York prices do have an influence on Odessa prices. Barry K. Goodwin and Thomas J. Grennes (1988) have performed a

---

[5] The number of common trends are determined as (number of prices) - (number of independent cointegrated relations).

[6] The common trend is determined as $(\Gamma_\perp)'\sum_{i=1}^{t}\begin{bmatrix}\varepsilon_t^A\\ \varepsilon_t^B\\ \varepsilon_t^C\end{bmatrix}$, where $\Gamma=\begin{bmatrix}\alpha^A & \gamma^A\\ \alpha^B & \gamma^B\\ \alpha^C & \gamma^C\end{bmatrix}$. See Johansen (1995 p. 41).

[7] The fact that the impact of shocks in Denmark is negative is odd, however it is probably be due to imprecise estimates.

multivariate analysis including Odessa, New York and Liverpool based on monthly observations from the late 19th and early 20th centuries. However, using monthly observations will conceal a lot of adjustments when information transmission is fast and generate a bias in the estimates of the adjustment speed. Not surprisingly the reported adjustment speed suggests half-life of shocks of almost 3 months for the New York to England linkage while our documented half-life was less than 3 weeks , see first and second panels in Figure 8 above. Having said that it seems as if our conclusion that shocks in New York dominate over Odessa and England is supported by their data, cf. panel c in Figure 7 from Goodwin and Grennes (1988, p. 425).

4.5 Variance of shocks

The last issue we consider in table 4 is the variance of the shocks. From the table it can be seen that the variance of the shock is decreasing from the early to the late period. This is in line with what we hypothesized in section 1. It can be plausibly argued that, for income and price inelastic commodities like grain, the main disturbance in price stems from stochastic local harvest shocks rather than demand shocks as long at markets are poorly integrated. But local shocks are largely independent over vast geographical areas. The timing of adverse weather conditions are manifestly different not only in, say, southern and northern Europe but more so across continents and hemispheres. So the global output shock is, proportionally at least, smaller than local output shocks. When trade reduces local supply shocks, then variance in local price shocks can be expected to fall. Furthermore, we find that the variance is always higher (two to three times) in the exporting markets than in the importing markets. This finding suggests that exporting economies seem to be less able to reduce local supply shocks through trade than importing nations. In the last period this is understandable since US wheat exports were the British market.

Trade will make local supply less dependent on local output shocks and increasingly linked to global supply shocks and therefore price shocks will be increasingly correlated internationally. This is also what we find. The correlation between the price shocks in the three markets is reported in table 5. The results show that shocks was uncorrelated in the early period, but became correlated over time. This suggests that in the last period part of the shock was global (or at least common for the three markets) although a considerable part of the shock remained local. In the last period the global shock accounts for about 30-40 per cent of the total variation in shocks in Britain and Denmark, while it is only 15 per cent in the United States.

Table 5: Correlation matrix of the estimated price shocks

		Britain	United States	Denmark
1855-1862	Britain	1	0.019	0.070
	United States		1	0.048
	Denmark			1
1885-1895	Britain	1	0.359*	0.339*
	United States		1	0.246*
	Denmark			1

To sum up, our results show that not only do we have a faster adjustment to deviations from M-LOOP and small variance of the shock that the prices were exposed to in the last period, we do also find that the shocks in the prices are highly correlated in the late period. These three findings will, all together, imply that we observe much less variation between prices in the three markets in the later period compared to the early period. This means that we are more likely to observe that prices in Britain, the United States and Denmark move together in the period 1985-1885 compared to the period 1855-1862.

5. Conclusion.

This article has advanced a number of new results.

The international wheat market passed through an emerging market period after the repeal of the British Corn Laws and reached a mature and efficient state only in the last quarter of the 19th century. Although the markets were integrated in the sense that they passed co-integration tests early on, the equilibrium price differential had a considerable unexplained residual.

Prices converged over the 19th century primarily because of the fall in tariffs and then in equal proportion by a fall in transport costs and residual transactions costs. There was a modest decline in observed transaction costs. Unlike previous studies, which did not control for quality differences between local wheat sorts properly, it is shown that a substantial price differential remained. However that price differential was almost entirely explained by known transport and transaction costs at the close of the 19th century.

An increase in efficiency has been documented by the gradual elimination of a residual element in the price gap that reflected, partly at least, market imperfections. Furthermore, the speed of adjustment which re-established inter-market equilibria increased over time. Although markets that did not trade with each other were integrated, adjustment speeds was slower and adjustment was primarily driven by their adjusting to a common third market with which they both traded.

The variance of price shocks fell as markets became increasingly global, that is when the global market muted local shocks as market integration proceeded.

Finally it has been shown that market dominance shifted from the major importer, Britain, to the major supplier, the United States, in the course of the 50 years after the repeal of the British Corn Laws.

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Appendix

Appendix A1: Data

1. Wheat prices.

All prices refer to spot transactions. When two or more prices were registered on a given market day the mean has been used.

New York

The US wheat prices are from Persson (2004). Original sources are:

- 1850-1853: New York Journal of Commerce.
- 1854-1877: New York Times.
- 1878-1900: Beerbohm's Evening Corn Trade List, London.

All prices are quoted in dollars per Winchester bushel and refer to Monday market or a market day close to Monday. If not otherwise stated, in the paper the following qualities are used:

- January 1850 - June 1855: White Genesee
- July 1855 - February 1860: Red Southern
- March 1860 - 10th December 1877: Red Western
- 31st December 1877 - 1900: Red Winter

For further details, see Appendix 1 in Persson (2004).

Chicago

Prices from NBER Macrohistory Database (www.nber.org/databases/macrohistory/contents, series 04001) and are monthly averages of wholesale prices of US wheat in Chicago.

NBER use that quality of wheat in which most transactions were made, which gives the following series: Spring Wheat 1841-1857, Standard Spring 1858-1859, No. 2 Spring 1860-1863, No. 1 Spring 1864-1870, No. 2 Spring 1871-1897, "Regular" Wheat (Deliverable on Contracts) 1898-1904.

US dollar conversion rates

All US prices have been converted to shillings using the exchange rate in New York for pound sterling at the 60 days bills of exchange in London (see Persson (2004), Appendix 1). Due to the fact that the US dollar was not convertible to gold between 1862 and 1878, US prices in that period are converted to dollars with fixed gold value.

London, Glasgow

Like the US wheat prices these prices are from Persson (2004). The original sources are:

- 1852-1877: The Times, London.
- 1878-1900: Beerbohm’s Evening Corn Trade List, London.

All prices are quoted in shillings per imperial quarter and refer to Monday market or a market day close to Monday. If not otherwise stated, in the paper the following qualities are used:

- In London: August 1852 - June 1855: American White
  1855-1867: American Red/Red Winter
  1868-1877: American
  1878 - February 1885 Red Winter
  March 1885 - August 1895 Red Winter no. 2
- In Glasgow: 1895-1900: Red Winter no. 2
  (The London price of US Red Winter is not available from 1895 to 1900).

In addition to these data we use a series of prices on wheat from Denmark and Holstein on the London Mark Lane market 1845-1875. The source is The Times.

Liverpool

In section 4 prices on US wheat in Liverpool replace the London prices in the period 1855-1862. These prices are taken from The Liverpool Courier (covering the years 1855, 1857-1862) and the Liverpool Journal (1856). Original prices are in shillings per 70 or 100 lbs, and the quality is “American white”. Prices refer to Tuesday market.

England and Wales

The so-called Gazette Average is an average of English wheat in England and Wales, originally published every week in the London Gazette, and reprinted in The Economist, which we have used. The Gazette Average is an average of prices on a varying number of representative markets in England and Wales and covers many different wheat qualities.

Copenhagen

The prices in Copenhagen of Danish wheat 1842-1900 and wheat from the United States 1885-1900 are taken from the *Mæglernes Priskurant* (The Copenhagen Broker's List), a commodity price list published every week by the commodity brokers in the city. The prices are wholesale prices and in the so-called Grain sales period until the 1870s the prices were on grain shipments intended for export. The prices were dated on a Friday and published the following day, except for weeks when Friday was a holiday (i.e. Good Friday and the Danish holiday *Store Bededag* on the fourth Friday after Easter). That produces a price series containing some 49-50 observations per year.

The prices are spot prices and on the Danish wheat, minimum and maximum prices are quoted. An average of these prices is used in this paper if not otherwise stated.

By the end of the 19th century several different qualities of North American wheat were quoted in Copenhagen at the same time. In this paper the following qualities are used:

- Red winter no. 2: 1885-1890
- American: 1891 - week 44, 1896
- American (Spring): week 45, 1896 - week 42, 1897
- (Kansas) Hard winter no. 2: week 43 1897 - 1900

The prices in the original source were quoted in *kroner* (or *Rigsbankdaler* before 1875) per grain barrel (approximately 139.1 litre), and are converted to shillings by the pound sterling exchange rates quoted on the Copenhagen Stock Exchange and published in *Mæglernes Priskurant*.

For further details, see Rich (2004), chapter 4.

2. Transport costs

New York to Liverpool and London

Data from sources as for wheat in New York, except that transport prices in 1878 stem from the New York Times. Prices in pence per bushel. In almost all cases prices refer to so-called berth rates for transports to London and Liverpool. Berth rates were offered by liners loading grain as well as other goods. These were often slightly cheaper than chartered freights because loads had to be discharged immediately after arrival. If not otherwise stated, in the paper the following freight rates are used:

- 1850-1864: New York-Liverpool sail
- 1865-1880: New York-Liverpool steam
- 1881-1900: New York-London steam

Generally a 52 week moving average of the freight rates is used, except for figure 4 and section 4 where respectively an annual average and weekly observations are used.
In this paper we assume that the transport costs between New York and Copenhagen are 10 per cent higher compared to the New York to Britain routes.

South-east Denmark to London and Leith:
We use a series of annual freight rates on grain transport between Denmark and the east coast of Great Britain constructed on data provided by Monrad Møller (1995) and D. North (1958).
Monrad Møller (1995) has compiled a series of freight rates on grain shipments from harbours on the isles of Lolland, Falster, Møn and the southern coast of Sjælland to London or Leith (near Edinburgh). The series consist of annual averages of freight rates in the period 1827-1870, with observations missing in 1830-33, 1836-38, 1858-60 and 1862. The freight rates are collected from consular reports from the Danish consuls in the two British harbours and a annual average is only calculated when freights on at least 10 shipments were reported.
North (1958) has compiled a series of annual freight rates on grain from the Baltic Sea to Great Britain. The rates are shown as freight factors, i.e. freight rates divided by the wheat prices in England and Wales (Gazette Average). Using the same wheat prices we have transformed the freight rates to shillings per imperial quarter and constructed a freight index. This index is used to interpolate the missing data in the Monrad Møller series and to extend the series to 1900.
This procedure gives a series in line with freight rates published in *Mæglernes Priskurant* in the late 1880s.
For further details, see Rich (2004), chapter 4.

3. Other transaction costs

Freight insurance

The source to the freight insurance rates is the *Mæglernes Priskurant* (The Copenhagen Broker's List). Weekly insurance rates on freights between Copenhagen and the east coast of Great Britain have been compiled for the period 1842-1900, together with insurance rates on freights between Copenhagen and the east cost of North America for the period 1850-1900. Insurance rates on freights by sail are quoted in the entire period and quotations on steam rates begin in 1865 on Copenhagen-Great Britain and in 1871 on Copenhagen-North America routes.

It is assumed that insurance rates for New York-Liverpool/London are the same as between Copenhagen and North America. If not otherwise stated, in the paper sail rates are replaced by steam rates in 1871 for North America to Europe routes. Between Great Britain and Denmark a weighted average of sail and steam rates is used – the weights are:

	Sail	Steam
-1865	1.00	-
1865-1874	0.75	0.25
1875-1884	0.50	0.50
1885-1889	0.35	0.65
1990-1894	0.25	0.75
1895-	0.15	0.85

The weights reflect that almost none of the Danish grain export to Great Britain up to the end of the so called Grain Sales period around 1870 was transported by steam and that sail had a decreasing share of the trade between Denmark and Great Britain in the last 30 years of the 19th century.

The insurance rates are quoted as percentage of the cargo's value and in this paper it is expressed in shillings per imperial quarter, calculated on the basis of the wheat price in the export harbour.

Shipping charges and port handling costs

The Danish shipping and port charges are taken from custom and duty handbooks by the Danish customs officer J.T. Bayer. The many different duties and charges are summarized the following way:

Danish shipping and port charges	in force
Øresundstold (Sound tax)	until April 1857
Lastepenge (Load money)	until April 1864
Fyrafgift (Lighthouse duty)	until April 1864
Skibsklareringsspotler (Shipment clearance charge)	until April 1864
Skibsafgift (Shipping charge)	from April 1864
Port charge, Copenhagen	from April 1864 to Nov. 1894
Bolværkspenge (Wharfage), Copenhagen	until Nov 1894

The levels of all shipping and port charges are independent of the value of the cargo. For further details on Danish shipping and port charges, see Rich (2004), chapter 4.

All the shipping and port charges sum up to the following costs:

	Shillings per imperial quarter	Percentage of wheat price in Copenhagen[1]
Before April 1854	0.44	1.1%
April 1854 - March 1857	0.39	1.0%
April 1857 - March 1864	0.19	0.5%
April 1864 - October 1894	0.14	0.3%
November 1894 - 1900	0.09	0.2%

Source: Rich (2004), table 4.7

Note: [1] Average of the wheat prices in Copenhagen 1850-1900.

Following the findings in Persson (2004) it is assumed that the total port handling cost (i.e. costs in both the sender and recipient harbours) is 1 s. pr. imperial quarter.

Import duty

The duty rates are taken from The Economist or are calculated from the weekly Gazette average price on English wheat prices and the current duty tariff scale.

4. Conversion convention

All data have been expressed in monetary units and measures used in the United Kingdom, i.e. shillings per imperial quarter for wheat.

1 Danish grain barrel (139.12 litre) = 0.478 imperial bushel = 3.83 imperial quarter

1 Winchester bushel (35.24 litre) = 0.969 imperial bushel = 0.121 imperial quarter

Appendix A2: Equilibria for two importing markets and one exporting market

In the following we derive the equilibria relations for three trading markets where market A (Britain) and market C are importing from market: B (United States). We assume no direct trade between market A (Britain) and C (Denmark). By using the version of LOOP, that takes account of transport costs and other transaction costs, the two equilibria are given by

$$P^A = P^B + Tt^{BA} + Tn^{BA} + Tf^{BA}$$
$$P^C = P^B + Tt^{BC} + Tn^{BC} + Tf^{BC}$$

where P^j is the price in market *j*, Tt^{ij}, Tn^{ij} and Tf^{ij} are the transport costs, transaction costs and tariffs associated with transporting grain from market *i* to *j*. From these two equilibria we can derive the implicitly given relationship between the prices in market A and C:

$$P^A - (Tt^{BA} + Tn^{BA} + Tf^{BA}) = P^C - (Tt^{BC} + Tn^{BC} + Tf^{BC})$$
$$P^A = P^C + (Tt^{CA} + Tn^{CA} + Tf^{CA}) - (Tt^{BC} + Tn^{BC} + Tf^{BC})$$

Appendix A3: Test for unit root

To examine the properties of time series used in this study we examine whether the series are a unit root process. If the series are a unit root process stationary, the level will behave as a non-stationary process while the series in first differences behaves as a stationary process. To test for stationarity we apply the Dickey-Fuller test for a unit root (non-stationarity). All prices are transformed by the logarithm. In Appendix table 1 the results of the test are reported. The p-value refers to the test probability for the hypothesis that the series is a non-stationary process (the test procedure is described in section 4). The test results clearly indicate that all series are unit root processes.

Appendix table 1: Dickey-Fuller test for unit root

Period	Time series	test-statistic for levels	p-value for levels	test-statistics for FD	p-value for FD	Process (in levels)
1855-1862	Liverpool	-1.98	0.295	-21.98	0.000	Unit root
	New York	0.17	0.970	-17.99	0.000	Unit root
	Copenhagen	-1.92	0.321	-18.59	0.000	Unit root
1885-1885	London	-1.59	0.490	-14.94	0.000	Unit root
	New York	-1.54	0.513	-24.45	0.000	Unit root
	Copenhagen	-2.43	0.132	-14.31	0.000	Unit root

Source: see table 3