



## Pushing Wheat

### Why Supply Mattered for the American Grain Invasion of Britain in the Nineteenth Century

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Pushing Wheat: Why Supply Mattered for the American  
Grain Invasion of Britain in the Nineteenth Century

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# Pushing Wheat<sup>1</sup>:

## Why supply mattered for the American grain invasion of Britain in the nineteenth century

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**Abstract:** This paper documents the evolution of variables central to understanding the creation of an Atlantic Economy in wheat between the US and the UK in the nineteenth century. The cointegrated VAR model is then applied to the period 1838-1913 in order to find long-run relationships between these variables. The main result is that explanations for the expansion of trade based on falling barriers to trade need to be augmented by another factor: the expansion of US supply. This implies that the growth of the Atlantic Economy cannot wholly be attributed to the decline in transportation costs, as is usually considered to be the case.

**JEL Classifications:** C5, F1, N7

**Keywords:** Grain invasion, wheat, globalization

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<sup>1</sup> I am grateful to Greg Clark for his suggestion of this title!

## 1. Introduction

*Nothing can come of nothing...*

- *King Lear* (I, i, 92)

The development of an “Atlantic Economy” has been seen as central to the history of the pre-First World War “first era of globalization” (see for example O’Rourke & Williamson 1999). As far as the international goods market is concerned, much of the literature concerns the trade in just one commodity: wheat. This is entirely understandable, since the importance of wheat (and to a lesser extent other grains) in the nineteenth century is conveniently witnessed by the fact that related economic variables are very well documented for a large number of countries, making the integration of wheat markets a natural starting point for an analysis of historical globalization.

In this story, at least one fact is undisputed by economic historians: by the 1870s the United States had emerged as a major supplier of wheat, and Europe was the main recipient of that supply. The process which led to this situation has been termed the American “grain invasion” and the dominant explanation for the growth in wheat trade has been that of falling transportation costs, slashing transatlantic barriers to trade. This literature takes as its basis evidence, first presented by Harley (1980), of a sharp decline in the price gap between British and American wheat prices. Since globalization is usually defined by economists as market integration (O’Rourke & Williamson 2002a), which should *ceteris paribus* result in a narrowing of price differentials, this appears to be clear evidence of globalization.

However, Persson (2004) first disputes the comparability of the price series used by Harley, and second, through a careful documentation of the available evidence, finds that the fall in transportation costs was not large enough plausibly to be the only factor involved in the enormous expansion of trade. This, however, leaves us with an apparent paradox. We know that trade did expand greatly in the nineteenth century, but what then caused this? Recently, therefore, there has been an increased focus on the role of falling domestic transportation costs within the US allowing farmers further west to enter the Atlantic economy. This paper does not dispute this, but however suggests another – hitherto ignored, but quite possibly related - factor which might be important.

The focus is narrow: concentrating on the trade in wheat between the UK and the US, but this is common in the related literature. Applying the cointegrated VAR model and the methodology suggested by Juselius (2006) to a database of relevant variables, it turns out that

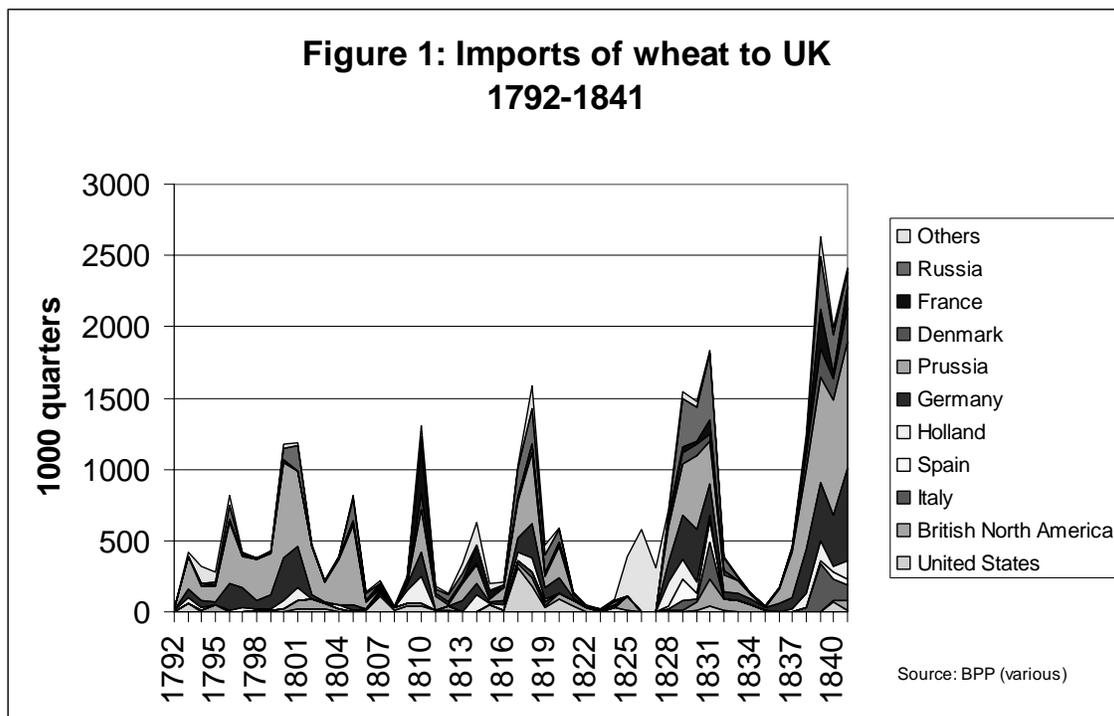
the expansion of British imports of American wheat is almost exclusively attributable to the fact that output in the US expanded. Moreover, this expansion itself was independent of the fall in transatlantic transportation costs, supporting the point made by Persson (2004).

Before showing this, however, it is helpful to take a rather longer term look at the wheat trade of the United Kingdom, and in particular her reliance on imports from the United States.

## 2. The grain invasion of Britain in historical perspective

The idea of a “grain invasion” implies a sudden break with the past. One moment Britain was reliant on domestic supply and that of her near neighbours, and the next American wheat was flooding through her ports. This may indeed be how contemporaries saw it, but the reality was rather different.

Probably the greatest break with the past came during the last few decades of the eighteenth century, when the industrial revolution and population growth meant that Britain could no longer depend solely on her domestic supply of wheat. British wheat exports soon dwindled to insignificance, and reform of the Corn Laws from 1774 ushered in a period of

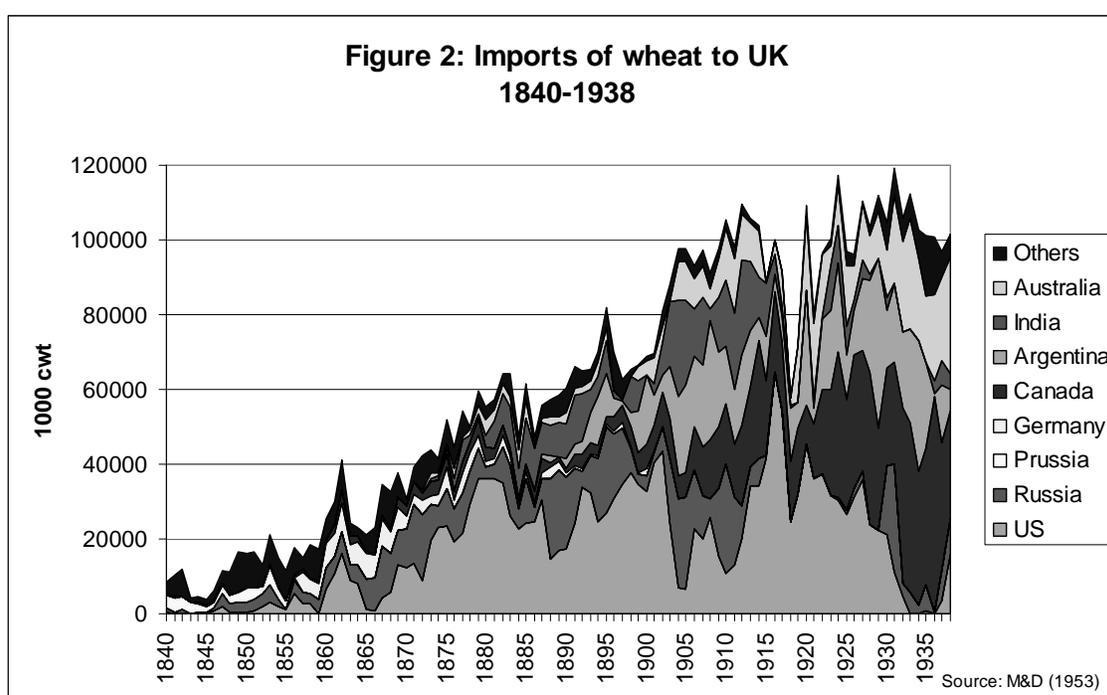


“practically free” trade in grain. (Sharp 2006, p. 3)

Even as far back as colonial times America was an important supplier of wheat and flour (Galpin 1922, p. 24), but this was particularly the case during the Napoleonic Wars, when she supplied both Britons at home and British troops based in continental Europe. (Galpin 1922, 1925) With peace in 1815, however, prohibitive tariffs were introduced in

Britain, but were immediately met with protest and were gradually relaxed from 1825, culminating with the introduction of the more liberal “sliding scale” of 1828.

The pattern of trade for these years is illustrated by figure 1<sup>2</sup>. The rise and fall of wheat imports after 1815 is clearly determined by trade policy and in particular the unusual mechanisms for regulating imports contained in the Corn Laws (see Sharp 2006). What is clear, however, is that until the revision of the Corn Laws in 1842, UK imports of wheat were dominated by European suppliers, principally from Prussia and “Germany”. With the exception of some extraordinary years during and immediately after the Napoleonic Wars (when ports were briefly open due to extremely high prices, which was the only time when imports were permitted), New World producers played a limited, but not insignificant, role.

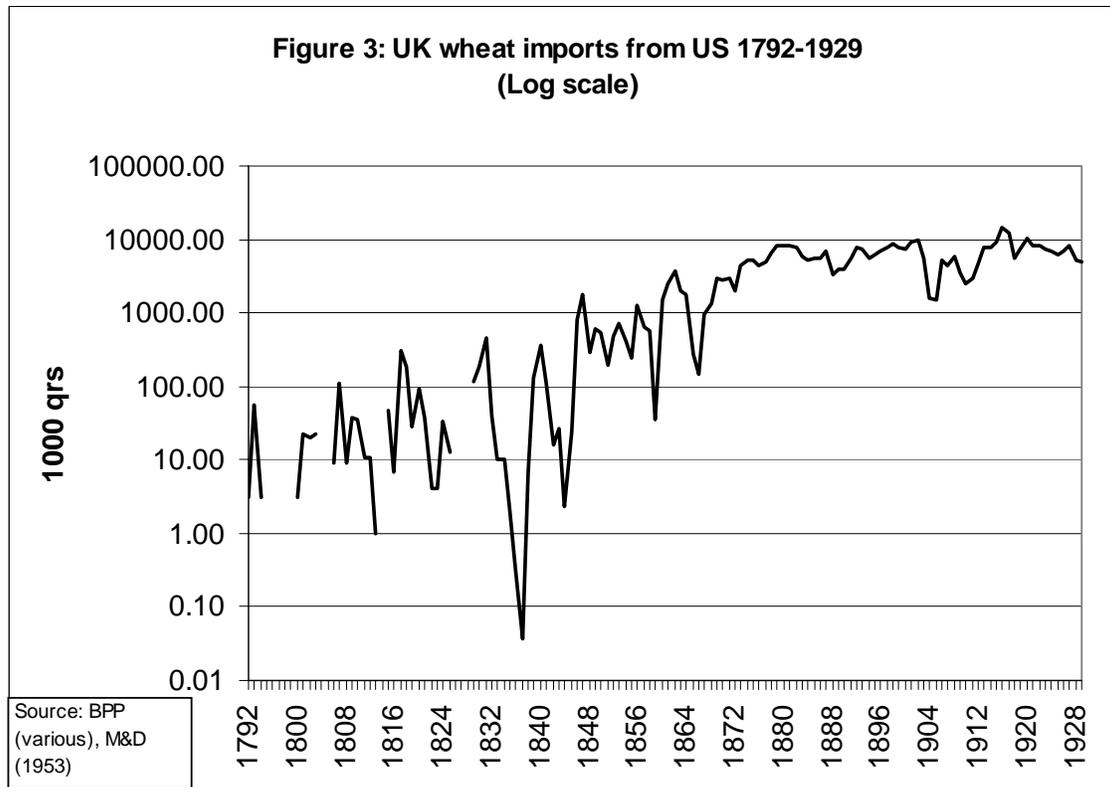


All this changed, however, with the movement to repeal of the Corn Laws, which were relaxed in 1842, 1846 and 1849; and were finally abolished in 1869. Figure 2 illustrates the dramatic entry of New World suppliers and in particular the United States, which for many years supplied over fifty per cent of UK wheat imports. The reason this development became known as the American grain invasion is clear to see.

But was this invasion from the US really such a break with the past? As noted in the introduction, the term “invasion” implies a dramatic and sudden increase in the influx of grain. Levels of imports can be misleading, since when starting from a very low level, a

<sup>2</sup> The large proportion for “others” from 1825-27 is due to missing data. For most years the data is for wheat and wheat flour.

constant percentage increase over time can easily be mistaken for a sudden level shift. It is usual in these situations to take the logarithm of the variable and in this way get a better idea of whether the rate of change was increasing over time.



As figure 3 makes clear, there was no sudden break. The increase in wheat imports from the US was exponential until the 1870s, at which point the series levels off. The “missing” observations in the early years represent times of no imports from the US. The large troughs after 1828 and before 1846 are associated with years of prohibitively high tariffs (Sharp 2006). The observation for 1859 seems very low<sup>3</sup> and although it is consistent with that reported in British parliamentary papers, the econometric analysis below reveals that it is almost certainly a measurement or recording error. The final large trough, before the series levels off, is associated with the disruption caused by the American Civil War.

There is an important lesson to be taken from this data. It is clear that, in contrast to the traditional interpretation, the roots of the “grain invasion” can be traced back to the 1830s – possibly even further - and were not simply a phenomenon of the 1860s and ‘70s. We need therefore not necessarily expect the explanation to be sudden changes such as a globalization

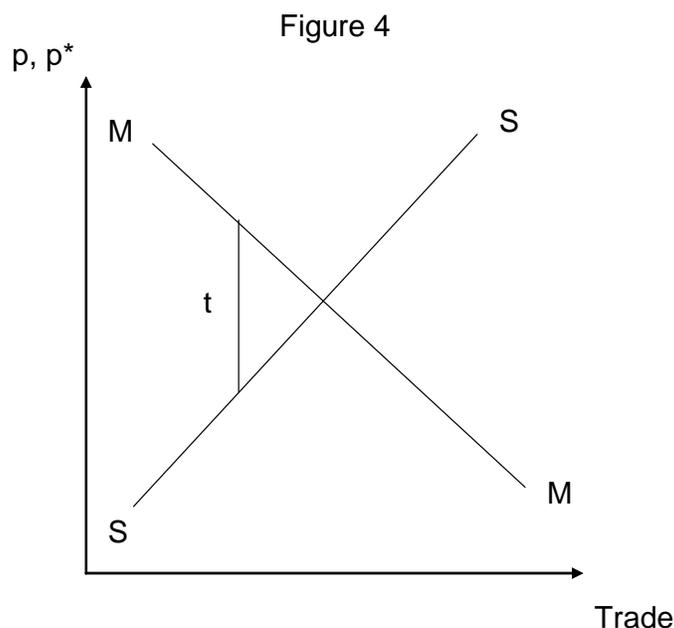
<sup>3</sup> This suspicion seems to be confirmed by the data given in United States (1878) which reports exports of wheat to Great Britain and Ireland of 1,322,718 bushels in 1859 as compared to 1,934,206 bushels in 1860. (Compare to Mitchell and Deane’s 160cwt. in 1859 and 6,497cwt. in 1860.)

“big bang” or “dramatic” falls in transport costs. There were longer term forces for change at work.

### 3. The theoretical background

The most widely used theory for explaining the growth of trade can be summed up by figure 4. The MM schedule is the UK’s home import demand function (i.e. demand minus supply). It is falling with the home market price,  $p$ . SS is the US export supply schedule (supply minus demand) and is increasing in the price abroad,  $p^*$ . The law of one price states that, in the absence of any sort of barriers to trade, then  $p$  should equal  $p^*$  in equilibrium. Any difference in prices would lead to short-term arbitrage, which would return the economy to its equilibrium state. However, with barriers to trade, for example tariffs and transportation costs, a wedge,  $t$ , is driven between export and import prices – the higher the barriers to trade, the larger the wedge.

The popular explanation for the expansion of the transatlantic wheat trade



concentrates on the role of falling transatlantic transportation costs (see for example O’Rourke & Williamson 1999). Harley (1986, p. 238) provides some of the original work on this. His hypothesis is simple and can be understood by imagining an inward shift of the transport cost “wedge” in figure 4. The old import price,  $p$ , now corresponds to a higher price (minus transport costs) for the exporting region. This implies that the quantity supplied by the exporting region will increase. *Ceteris paribus* this will result in excess supply in the importing region leading to a decline in price. At the same time, the old price,  $p^*$ , in the exporting region now corresponds to a lower price in the importing region, thus leading to excess demand and pushing up the price in the exporting region. Import prices have thus fallen, and export prices have risen. Supply in the exporting region will increase and domestic supply in the importing region will decrease.

An alternative is to focus on shifts in the curves. An obvious point is that in the nineteenth century, the United States was experiencing rapid growth of population through immigration and simultaneously the westward expansion of agriculture. An outward shift of SS would also result in increased trade. Simultaneously, UK population was also expanding, implying an outward shift of DD.

#### **4. Selection of data for the econometric analysis**

The simple theory explained in the previous section motivates the inclusion of several explanatory variables: in particular, a test of the theory must include ways of measuring the relative importance of demand factors, supply factors as well, of course, as the gap between British and American wheat prices.

Unfortunately, the model cannot be tested directly. As figures 1 and 2 in section 2 made clear, it is impossible to see the American grain invasion in isolation. More generally, this was a story of increasing wheat imports, only some of which were supplied by the United States. It is therefore not only the British/American price gap that is relevant for analysis, but a multitude of price gaps between the competing suppliers. Moreover, by no means all the wheat consumed in the UK came from abroad. Substantial quantities are still grown today for domestic consumption and were throughout the period. The state of domestic supply is undoubtedly also an important part of the grain invasion story.

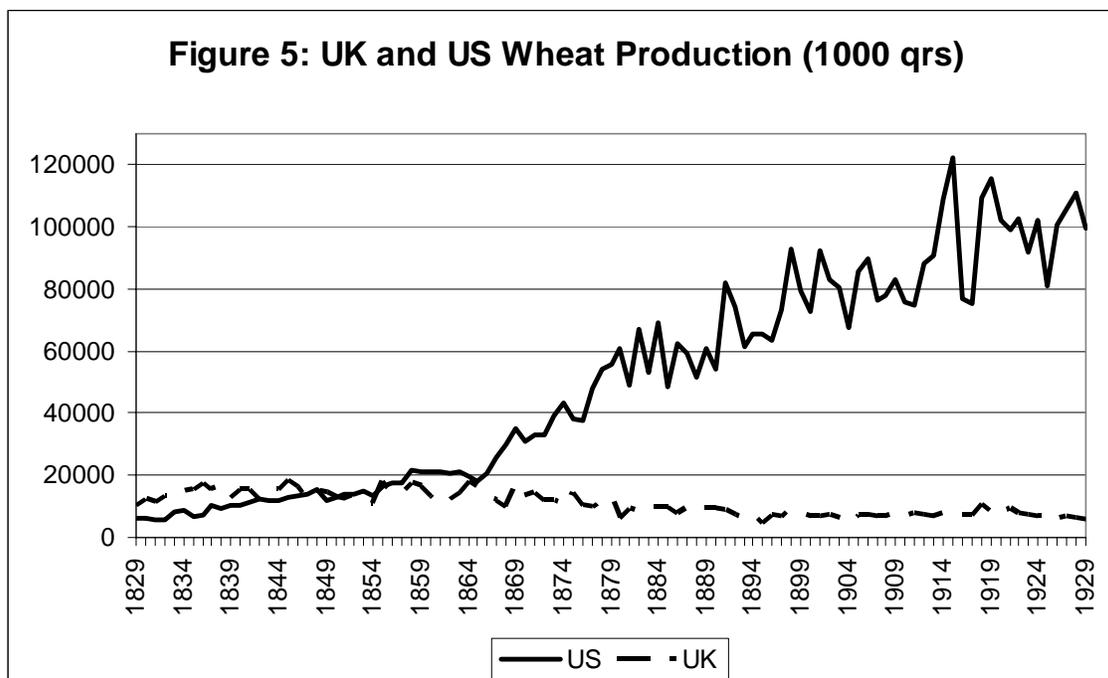
Any relevant econometric investigation of the grain invasion must, therefore, include data on wheat production in the US and the UK. I have thus attempted to reconstruct wheat production data for both countries for the century from 1829 to 1929.

Although official estimates for the UK are only available from 1884 (Mitchell & Deane 1962, pp. 86-7; see Coppock 1956 for a background on these estimates), unofficial estimates are given by Gilbert & Lawes (1893, appendix table II) for the years 1853-83<sup>4</sup>. Contemporary estimates are not available for earlier years, but are given by Fairlee (1969, p. 114) for 1829-52<sup>5</sup>.

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<sup>4</sup> They report their estimates in “harvest years” e.g. 1852-3 – I have used the second of the pair in each case.

<sup>5</sup> She does not give an estimate for 1842, since her estimates are based on multiplying the quantity of wheat sold in “inspected markets” under the Corn Laws by a constant fraction, which changes from 4 to 14/5 in 1842, since the number of inspected markets increased from 150 to 290 on April 29, 1842. It is not too hard to use Fairlee’s method to get a rough estimate of wheat output in 1842. Using BPP (1842, p. 177) we find that 970 thousand quarters of wheat were sold in inspected markets until April 29. Multiplying this by Fairlee’s factor of four gives 3,880 thousand quarters. After April 29, 8,739 thousand quarters were sold. Multiplying this by Fairlee’s factor of 14/5 gives 8,740 thousand quarters. Adding the two together gives an estimate of 12,620 thousand quarters produced in 1842.



Prior to 1866 the only official estimates for the US are those from the decennial census. These estimates from 1839 can be found in United States (1975, pp. 511-2). Other (sometimes contradictory) estimates exist from various sources for other years. The most complete of these is from Guetter & McKinley (1924, p. 29), which has data for some years back to 1790<sup>6</sup>. I have used their estimates for the years 1840-58, 1860 and 1862-65. This still leaves missing observations for 1829, 1831-38 and 1861. Thorp (1926, pp. 113-145) gives descriptions of the state of the wheat harvest for most years from 1790 to 1925. Wheat crops are given various descriptions such as “failure”, “poor”, “abundant”, “record” to name a few. His descriptions seem to follow the data from Guetter & McKinley very closely, e.g. his description of a “record” crop corresponds to historical highs. The levels for these years have been based on these descriptions<sup>7</sup>.

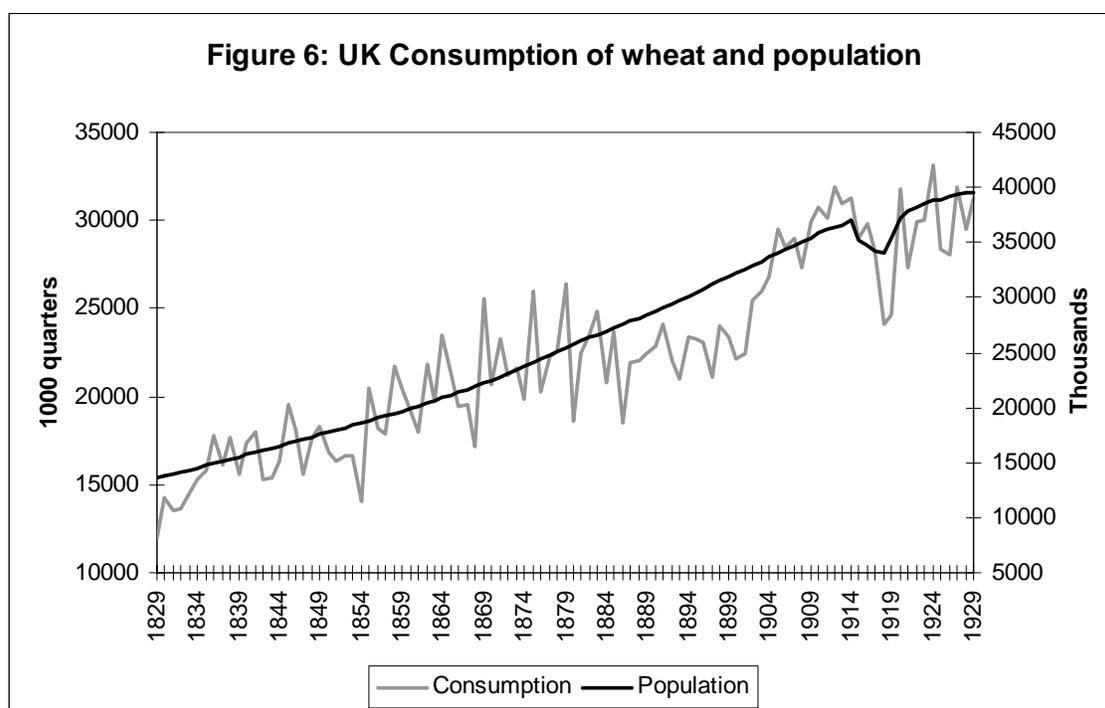
Figure 5 reports the production series for the US and the UK, and makes for fascinating reading in itself. The story of the American supply is one of increase throughout the period, rapidly overtaking that of the UK. Rothstein (1965, pp. 62-63) attributes the expansion of

<sup>6</sup> For background information and a discussion on the reliability of the early US estimates, see Benedict (1939), Ebling (1939) and Gallman (1963).

<sup>7</sup> For 1861 his description is “good”, which is the same as for 1859 and 1860, which both have a production of 173 million bushels. I have thus chosen a level of 173 for 1861. Thorp does not give a description for 1829, so I have chosen the level for this year on the basis of linear interpolation between 1820 and 1830. I have then assigned levels to 1831-8 using linear interpolation between 1830 and 1840. When the description is “failure”, “short” or “shortage”, I have subtracted 15% from the interpolated series. When the description is “good”, “large” or “excellent”, I have added 15%. Other descriptions result in the use of the standard interpolated series.

American agriculture after 1850 to the completion of the acquisition of easily exploitable new territories with victory in the Mexican War and technological innovations in agriculture and transportation, a point already noted by Anon (1934, p. 293) for the period after 1870. More recent work has stressed biological innovations. (Olmstead & Rhode, 2002) Indeed, the last year when UK production exceeded that of the US is 1855. This demonstrates that the supply side of the grain invasion story must be taken seriously.

The data for UK production are no less interesting: British agriculture certainly does not give up immediately. The largest crop is recorded for 1845 with over 18 million quarters, but a similar level is also reached in 1864. Even by the early 1870s, UK crops are not noticeably below their long-term average level, but a noticeable decline sets in soon after, falling to about half their historical average by the end of the period. By the 1920s, the UK was producing only about 6 million quarters per year, whilst the US was producing regularly in excess of 100 million quarters.



The supply side must of course be seen in the light of the demand side. This is illustrated in figure 6, which shows the increase in population from 1829-1929<sup>8</sup>. (Mitchell & Deane, 1962, pp. 8-10) Consumption is also illustrated, and is assumed to be equal to total UK production (as above) plus total imports (from Mitchell & Deane, 1962, pp. 97-99). Both series are increasing over time, although *per capita* consumption of wheat is declining,

<sup>8</sup> The observations for 1915-20 are for civilians only.

presumably as income increased and more diverse bundles of food found preference. But it is clear that even if UK wheat output had not been falling, the import demand curve in figure 4 was shifting outwards.

The final piece of the jigsaw is the price gap between US and UK wheat, about which more later, but before looking at this it is necessary to consider more carefully what exactly is going to be tested for in the econometric model. Obviously, it is necessary to look at the role of falling transport costs and trade policy. However, while the increasing demand in the UK is certainly an important part of the grain invasion story – without the demand, there would have been no invasion – this seems so obvious that it would be useful to be able to simplify the econometric analysis by abstracting from this. What would then remain is to test whether supply factors or “globalization”, i.e. a decrease in the price gap, is mostly responsible for the increase in trade.

With this in mind, the analysis starts with the idea of a representative UK consumer. He consumes American and British wheat. If he chooses more US wheat, then imports will increase, and if he chooses UK wheat, then imports will decline. In order to reflect the relative importance of the two sources of supply, these variables are expressed in *per capita* terms – note that this implies that US output *per capita* means per head of **UK** population. Expressing imports in *per capita* terms as well, we get an import demand function for the representative consumer:

$$m = f(x_{UK}, x_{US}, z),$$

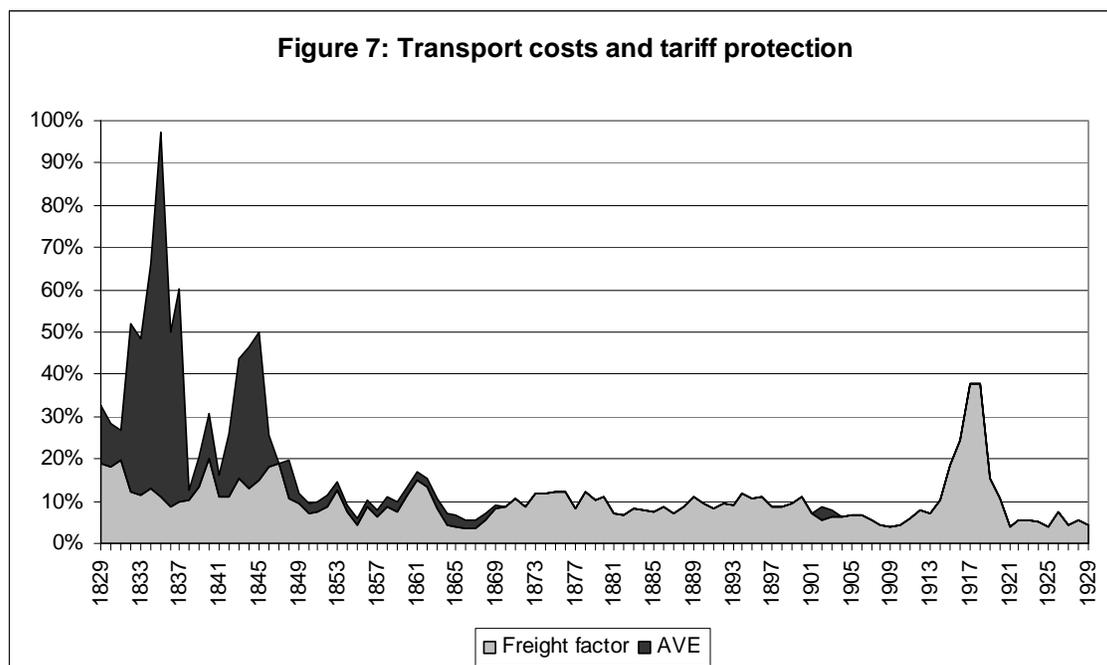
where  $m$  is the logarithm to the total imports of wheat from the US to the UK in thousands of imperial quarters *per UK capita*,  $x_{UK}$  is the logarithm to the total output of wheat in the UK in 1000s of imperial quarters *per capita*,  $x_{US}$  is the logarithm to the total output of wheat in the US in 1000s of imperial quarters *per UK capita*, and  $z$  is a measure of the gap between the price of British and American wheat.

Ideally,  $z$  should be the relative price of wheat in the two countries, but unfortunately it is not possible to create such a variable. Wheat is by no means a homogeneous good, and qualities and types of wheat differ considerably both between the wheat produced in each country, and within each country’s own output. Even if it was possible to construct a UK and a US price series for an identical variety of wheat, it is by no means clear that this price gap would be representative of the entire wheat trade. Instead, a simpler measure is made use of, defining  $z$  as

$$z = \log(ave + ff),$$

where *ave* is the *Ad Valorem* Equivalent of the UK tariffs and *ff* is the freight factor. *z* is thus a measure of the “explainable” gap between the prices of British and American wheat.

*z* is illustrated in figure 7. The AVEs are taken from Sharp (2006). They are calculated as the tariff revenue on wheat in each year divided by the value of wheat imports. The freight factor for wheat is defined as the transport cost per unit of wheat divided by the value of a



unit of wheat<sup>9</sup>. The idea is thus to express both as *ad valorem* barriers to trade, but in doing so it is necessary to specify a valuation of the good in question. The “best” valuation would be the cif price at British ports, but this is not available, and, as noted in Sharp (2006, p. 16), meaningful valuations of imports are not compiled in Britain prior to 1854. It is thus necessary to value the wheat at the American price, or at the British price.

Here it has been chosen to evaluate the wheat at an average of the British price – the so called *Gazette* average. Using the American price to value the imports would of course increase the estimates – to unrealistically high levels in the case of the tariff barriers – but the

<sup>9</sup> From 1884 the series is that described by Federico & Persson (2006) and is for New York to London. Freight rates are not reported for 1918, since shipping was controlled by governments and the rates were not made public. (United States 1919, p. 347) The freight factor in 1918 is thus assumed to be the same as in 1917. Prior to 1884 the series is based on my estimates (which follow Federico & Persson’s closely for most years, but have less missing observations). The wheat is valued using the US price (see 2. above). From 1866 to 1883 the transport costs for New York to Liverpool are taken from United States (1901). These are reported as (UK) pence per (presumably US) bushel. These have been converted to shillings per quarter using the ratios given under 2. above. Freight rates for the years 1829-32 and 1844-65 can be found using North’s (1958, pp. 550-1) “(East Coast) American Factor” for wheat, by multiplying this with the *Gazette* price for each year. I have not been able to find freight rates for 1833-43. I have thus estimated these by assuming that the freight rate for wheat followed the same pattern as North’s (p. 549) “American Export Freight Rate Index” after 1832, an assumption which is not too far from the truth for most years.

present method enjoys several advantages. First, it employs a consistent series of prices of a fairly standardized quality of wheat. This is not the case for the available American series. Second, as demonstrated in Sharp (2006, p. 17), the published valuations from 1854 seem to have valued imports using the *Gazette* price, so doing so here makes the estimates consistent with other work using these valuations. Third, the resultant interpretation of  $z$ , as the proportion of the UK price payable as freight costs and duty, fits in well with the interpretation of the demand equation given above, as the demand of a representative UK consumer.

It is quite clear that barriers to trade declined substantially – initially of course due to the repeal of the Corn Laws, but later due to a decline in transport costs, although these fluctuate quite substantially; the peak after 1914 being due to the First World War.

If it is found that it was predominantly supply changes that influenced imports of US wheat to the UK, then it would provide evidence for the theory put forward by Persson (2004), who suggested, in the light of his finding a fairly modest decline in transatlantic transport costs, that

*...the growth in world grain trade [could have been] driven by a downward shift in the New World supply schedule and/or a change in the supply schedule – its becoming more price-elastic as nations with practically unlimited supplies of land were populated by immigrants. (p. 142)*

Additional evidence would be that the supply of wheat in the US was not impacted on by the transatlantic price gap, since if the theory is correct, then the supply increase was exclusively a product of immigration.

An obvious criticism of the variables chosen above is that they do not take account of the role played by the improvement in US domestic transportation, especially the development of a railway network. The reason for neglecting this aspect is quite simple: the data for domestic transportation costs are not available before the 1850s. However, if, as seems likely, the relationship runs both ways between the western expansion of agriculture and the extension of the rail network, then this is not so important. The supply increase was quite obviously dependent on the western expansion of agriculture, which in turn was related to the expansion of domestic transportation improvements, so the supply variable captures this aspect. Moreover, it is not clear that the transportation improvements meant reduced costs of getting the wheat to the east coast, since it had to travel longer distances as the centre of gravity of wheat production moved westwards.

## 5. The econometric approach

The analysis here uses the cointegrated VAR model and the methodology described by Juselius (2006). To model the long-run relationships the following model is estimated:

$$\Delta X_t = \alpha\beta' X_{t-1} + \Gamma\Delta X_{t-1} + \mu + \Phi D_t + \alpha\beta_0' t + \varepsilon_t, \quad (1)$$

where  $X_t = (m_t, z_t, xuk_t, xus_t)'$  as described in the previous section, and  $t$  is the trend.

This model assumes that the  $p = 4$  variables in  $X_t$  are related through  $r$  equilibrium relationships with deviation from equilibrium  $u_t = \beta' Z_t$ , and  $\alpha$  characterizes the equilibrium correction. It holds that  $\alpha$  and  $\beta$  are  $p \times r$  matrices and the rank of  $\Pi = \alpha\beta'$  is  $r \leq p$ . The autoregressive parameter,  $\Gamma$ , models the short-run dynamics, and throughout it is assumed that  $\varepsilon_t \sim iid.N_p(0, \Omega)$ .

$D_t$  is a vector of dummies, which is discussed in the next section.

This approach enjoys many advantages. In particular, all the variables are considered in a very general model in which they are all initially treated as endogenous. This means that any potential relationship between the variables can be modelled, in contrast to other modelling techniques which usually assume a theoretical model and attempt to fit the data into this structure. The relationships found between the variables can thus be considered “sophisticated stylized facts” (Juselius & Franchi, 2007) which the theory model has to replicate before it can claim empirical relevance. Another advantage is that the cointegrating equilibrium relationships between the variables are by definition invariant to the addition of other variables to the model. This implies that, although other relevant variables might be considered to be of importance for the econometric analysis, their omission will not impact on the interpretation of the equilibrium relations that are uncovered: this is a very convenient property for many econometric analyses using historical data.

## 6. Empirical analysis

The results presented here were obtained using CATS in RATS, version 2. The period used for estimation is 1838 to 1913, thus avoiding extreme periods such as the mid-1830s, when the UK was actually re-exporting wheat to the US, and the First World War. Besides, the data for wheat production in the US is very unreliable before 1838, and the start date ties in well with evidence that the UK can be treated as an open economy from 1838 (O'Rourke & Williamson 2005, p. 14 and Sharp 2006, p. 22).

## 6.1 Extreme observations and measurement errors

The model is well specified under the assumption that the residuals are iid. and normally distributed. This assumption is conclusively rejected for the baseline model: the Doornik & Hansen (1994) test for normality is rejected with a p-value of 0.0004.

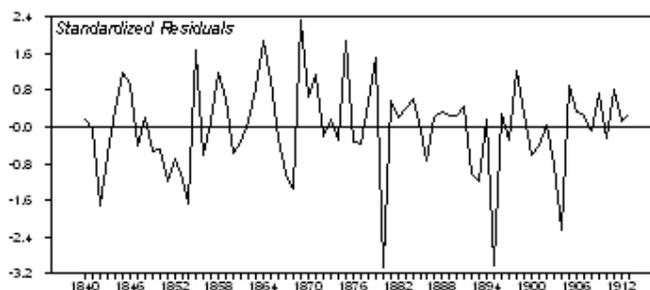
The reason for this is that special events and measurement errors might affect the interrelationships between imports, the price gap and wheat supply in the two markets in ways which are not captured by the four variables. By controlling for these it is possible to uncover the underlying long-run model for “normal” observations.

These special events will show up as large residuals in the equation for the relevant variable. Special events which have only transitory effects, from period  $T_0$  to  $T_x$  can then be modelled by dummies of the form  $Di_t = 1_{\{t=T_0\}} - 1_{\{t=T_x\}}$  and will be apparent as two large consecutive residuals of opposite sign. A dummy of the form  $Dp_t = 1_{\{t=T_0\}}$  allows for the special event to have permanent effects on the levels of the variables and will show up as a single large residual, as will special events which involve level shifts in the cointegrating relations, which are modelled by dummy variables of the form  $C_t = 1_{\{t \geq T_0\}}$ .

Dummies are used to control for various special events, in particular for years of unusually high tariffs. Although 1838 can be considered to mark the decisive shift towards free trade in wheat, with the duty on wheat equivalent to a 2 per cent *ad valorem* tariff, by 1842 it was equivalent to a 15 per cent tariff and it remained high for most years until 1849 when the notorious Corn Laws “sliding scales” were abolished. (Sharp 2006, p. 7) The import trade was particularly hard hit in 1844. Imports are also extremely low in 1859, but the residual analysis shows it to almost certainly be an error in the data.

The residuals associated with the equation for UK wheat production are illustrated in figure 8. The large negative residuals in 1880, 1895 and 1904 are all associated with harvest failure. What is interesting about this result is that harvest failures in the UK clearly have permanent level effects, since the large negative residuals are not followed by large positive residuals.

**Figure 8: Spot the harvest failures: standardized residuals of  $Dxuk$**



Scholars have previously puzzled over why it took so long after the repeal of the protectionist Corn Laws in 1846 for agricultural supply in the UK to start falling; leading some to conclude that legislative protection had no impact on UK wheat supply (see for example Kemp 1962). It seems, however, that it took major harvest failures before farmers were forced off the land, or until they possibly diversified into non-wheat growing activities.

## 6.2 Specifying the model

All subsequent analysis relies on the choice of lag-length of 2 in the model in equation (1) being correct. Using information criteria, it is found that  $k=2$  lags are in fact sufficient to characterize the systematic variation in the model. This assumption was verified at various points during the subsequent analysis.

After introducing the dummies, the model appears to fulfil the iid.-normality assumption. The F-test for (no) autocorrelation up to second order is accepted with a p-value of 0.31. The Doornik & Hansen (1994) test for normality is accepted with a p-value of 0.55. The univariate tests for the individual variables are likewise accepted.

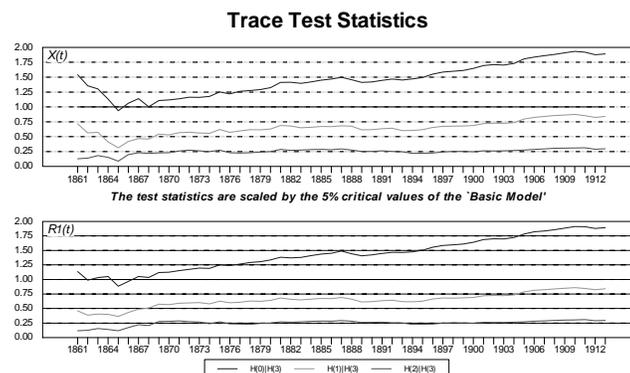
Before determining the cointegration rank, weak exogeneity of  $XUS_t$  was tested for. Weak exogeneity corresponds to a zero row in  $\alpha$ , since this implies that this variable contains no information about the long-run parameters in  $\beta$ . The test is calculated for  $r = 1, \dots, p - 1$  and is accepted with a p-value close to 0.30 in all cases, but rejected for the other variables. In the following, therefore,  $XUS_t$  is restricted to being weakly exogenous and the maximum rank of  $\Pi$  is correspondingly reduced by 1. This is consistent with the theory postulated in section 4 implying that US wheat supply was probably more a function of immigration and domestic price considerations, as suggested by Harley (1978).

A crucial step in the analysis is to determine the number of equilibrium relationships,  $r$ . The models are therefore estimated in the nested sequence

$$H(0) \subset \dots \subset H(r) \subset \dots \subset H(3),$$

where  $H(0)$  is the VAR in first differences and  $H(3)$  is

**Figure 9: Determining cointegration rank**



the unrestricted VAR in levels. Whilst the LR rank test for  $r = 2$  against  $r = 3$  (full rank) is rejected at the 5% level with a p-value of 0.04<sup>10</sup>, recursive estimation of the trace test statistics, as illustrated in figure 9, shows that given more observations the test would be accepted.

### 6.3 The long-run relations

Proceeding with the assumption that  $r = 2$  and normalizing on UK output and imports gives the results reported under  $H_0$  in table 1. In the adjustment matrix,  $\alpha$ , imports and UK wheat output are clearly endogenous and it therefore makes sense to normalize on these variables.

In order to assess the significance of the  $\beta$  coefficients, it is necessary to impose identifying restrictions. This is done by restricting insignificant coefficients to zero. Table 1 reports the results of some of the models estimated, with H3 being the final model chosen.

Table 1

	H0				H1				H2				H3			
	alpha(1)	alpha(2)	beta(1)	beta(2)	alpha(1)	alpha(2)	beta(1)	beta(2)	alpha(1)	alpha(2)	beta(1)	beta(2)	alpha(1)	alpha(2)	beta(1)	beta(2)
M	0.2104 [10.8]	-0.02 [-1.2]	-3.73	1	-0.18 [-0.5]	-0.86 [-6.1]	-0.26 [-10.1]	1	-0.28 [-0.7]	-0.90 [-5.4]	-0.31 [-12.9]	1	-0.29 [-0.7]	-0.89 [-6.0]	-0.27 [-11.6]	1
Z	0.02 [1.8]	-0.01 [-1.3]	-1.05	2.32	-0.24 [-1.1]	-0.15 [-2.0]	0.02 [0.2]	0.32 [1.8]	-0.26 [-1.2]	-0.17 [-1.89]	0	0.31 [2.4]	-0.24 [-1.1]	-0.15 [-1.9]	0	0.33 [2.55]
XUK	-0.01 [-2.1]	-0.04 [-6.8]	1	20.88	-0.78 [-6.9]	-0.20 [-5.0]	1	0.11 [0.34]	-0.81 [-6.9]	-0.25 [-5.3]	1	0	-0.81 [-6.9]	-0.21 [-5.1]	1	0
XUS	...	...	10.86	-8.07	...	...	0.53 [2.6]	-3.00 [-9.0]	...	...	0.69 [2.68]	-2.98 [-5.2]	...	...	0.59 [3.3]	-3.1 [-13.5]
C(1880)	...	...	-2.85	5.28	...	...	0	0.85 [3.7]	...	...	-0.04 [-0.4]	0.82 [3.1]	...	...	0	0.80 [4.3]
C(1904)	...	...	-3.42	-2.01	...	...	-0.37 [-3.1]	0.86 [3.5]	...	...	-0.41 [-2.8]	0.88 [2.7]	...	...	-0.37 [-3.2]	0.84 [4.0]
t	...	...	0.04	0.59	...	...	0.03 [6.01]	0	...	...	0.02 [4.5]	-0.00 [-0.2]	...	...	0.03 [6.6]	0

Asymptotic t-values are in parentheses.

Since all variables are in logarithms, the coefficients in the  $\beta$  matrix can be interpreted as elasticities. Additionally, the exogeneity of  $XUS_t$  implies that causality runs from this variable (Granger causality). The relation for  $XUK_t$  reveals that, in equilibrium, a 1 per cent increase in the US wheat supply implied a 0.6 per cent decrease in the UK wheat supply. The expansion in the US was thus directly responsible for the decline in the UK, as long suggested by economic historians. However, this relation also implies that a 1 per cent increase in imports from the US was associated with a 0.27 per cent increase in UK wheat supply. This is (statistically) a very significant result, but is difficult to interpret. A possible explanation could be that a common explanatory variable has been omitted, for example an increase in demand for both which is not controlled for by expressing the variables in *per capita* terms. The sign is the opposite of that suggested by Harley (1986).

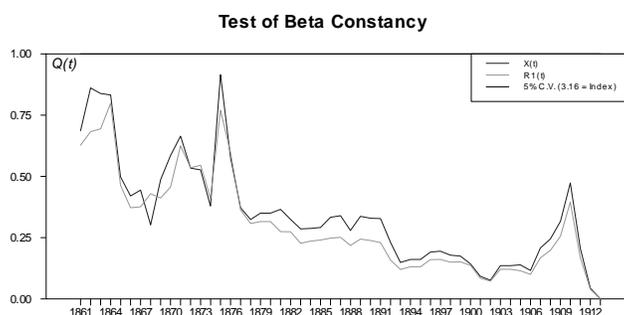
<sup>10</sup> The asymptotic distributions of the tests depend on the deterministic variables and the presence of a weakly exogenous variable. The asymptotic p-values are therefore based on a simulated asymptotic distribution from CATS.

The second relation can be interpreted as a long-run relationship for the level of imports from the US. A 1 per cent increase in the price gap corresponds to a 0.33 per cent decrease in the level of imports, and a 1 per cent increase in the US wheat supply caused a 3.1 per cent increase in the level of imports. It might be noted that the latter is a very robust result, supported both by the identified models in table 1, but also by alternative specifications of the model, including those with differently specified and additional variables (not presented here).

Finally, further tests were made to check the assumptions of the model such as parameter constancy, which did not give reason to question the validity of the estimation results. The result

of a recursive test for beta constancy (see Juselius 2006, p. 159) is illustrated in figure 10, where it is accepted for all sample lengths.

**Figure 10: Checking the assumptions of the model**



## 7. Conclusion

The result that the increase in UK imports was mainly driven by the increase in the American supply is so robust that it seems legitimate to state it as a Juselius-Franchi “sophisticated stylized fact”. Intriguingly, this seems to imply that the grain invasion was, at least in part, *not* due to “globalization”, as defined by O’Rourke & Williamson (2002a, p. 25), which for them is market integration, or a decline in the “wedge” illustrated in figure 4. The “first era of globalization” might therefore have more in common with the “overseas trade boom” of 1500-1800 (O’Rourke & Williamson, 2002b), than has previously been suggested.

Domestic transportation improvements were almost certainly a factor in permitting the westward expansion of agriculture. However, since the level of imports from the US expanded gradually over a long period of time, there seems to be good reason to believe that sudden improvements in transport technology were not the main reason for this. But what is quite clear is that the enormous increase in production in the US could not have taken place without the substantial immigration she enjoyed throughout this period. Interestingly, this means that we can perhaps again conclude that globalization played an important role for the expansion of trade, but through the integration of labour markets, rather than of commodity markets. This is surely a promising area for future research.

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