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Incentives, technology and the shift to year-round dairying in late nineteenth-century Denmark[1]

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The grain invasion of the late nineteenth century has attracted a lot of attention from economic historians and political scientists, who have emphasized the distributional consequences of this episode, and the political reactions which it provoked. There is also a substantial literature on Denmark's agricultural transformation during this period, which came as a direct response to growing imports of cheap overseas grain. In particular, the success of the late nineteenth-century Danish dairy industry has been noted by a diverse range of scholars and commentators, including Charles Kindleberger, Horace Plunkett, and H. Rider Haggard.[2] Denmark switched from being a grain exporter to a grain-importing producer of animal products, such as bacon, eggs, and above all butter. Butter exports accounted on average for over 40 per cent of the value of total Danish goods exports between 1895 and 1909, as compared with a share of bacon exports averaging between 18 and 22 per cent over the same period.[3] Denmark's dairy industry grabbed over a third of the rapidly expanding British butter-import market, establishing a reputation for consistent quality that was reflected in high prices in the market place, which in turn translated into high milk prices for the farmers who supplied Denmark's cooperative creameries. For example, average Danish export prices were 13 per cent higher than average Irish export prices between 1905 and 1914.[4]

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[2] Haggard, *Rural Denmark*, Kindleberger, 'Group behavior', and Plunkett, *Ireland in the new century*. See also Ó Gráda, 'Irish creamery system', Henriksen, 'Avoiding lock-in', Henriksen, 'Butter exports to Britain', and O'Rourke, 'Social cohesion', on the development of the Danish and Irish cooperative systems.

[3] Johansen, *Dansk historisk statistik*, pp. 191–2.

[4] O'Rourke, 'Late 19th century Denmark', based on Report on the Trade in Imports and Exports in Irish Ports (various years) and *Statistisk Aarbøg* (various years).

Viewed from the outside, one of the most noticeable features of the Danish dairy industry was its year-round exports of butter. This contrasted sharply with the very seasonal production patterns common elsewhere. For example, in Ireland in 1909, creameries produced just 22 per cent of their annual output in the six months November–April; 45 per cent of annual output came in the three months June, July, and August.[5] Annual reports of the Irish Agricultural Organisation Society (IAOS) are full of complaints about the impact that this had on the movement's ability to market its butter in Britain; the claim was that not only did this mean that Irish butter only sold during the summer, when prices were substantially lower, but that, having lost their position on the British market during the winter months, creameries were forced to 'bribe' their way back into the market in May or June, by offering their product at a further discount. By contrast, Danish farmers benefited from high winter prices, which as we shall see could be over 30 per cent higher than summer prices; and British retailers were able to rely on regular year-long supplies of Danish butter, which made it much easier for the Danish industry to sell its output there. Evidence of the marketing advantages of winter dairying comes in the fact that it was three large butter grocers who organized, in January 1868, the first of a long series of public exhibitions of winter-produced butters in Denmark's second largest city, Aarhus.[6] This exhibition has been described as a milestone in the history of the Danish dairy industry, and it was extensively covered in the local press. Among other things, the importance of early winter calving and winter stall-feeding was underlined at the event.[7]

Why did the Danish industry shift decisively towards a year-round pattern of production, when other major butter producers failed to do so? In 1937, Einar Jensen wrote that

> it is doubtful if Danish farmers consciously have set out to feed the market a regular supply. The real reason seems to be that during the formative period of specialised dairy farming, butter prices during the winter months were so much higher than summer prices that it paid well to develop winter dairying. This fitted in so well with the system of farming that it paid to retain high winter production even after increased supplies from the southern hemisphere changed considerably the seasonal variation in butter prices.[8]

According to this account, Denmark's timing was fortunate: during the 1870s and 1880s, when the Danes were developing their dairy industry and the cooperative movement in response to the grain invasion, the absence of refrigeration meant that globalization was not yet affecting the dairy industry. In addition to keeping average prices high, this implied that there was still a substantial winter premium, which provided the incentive for the switch to winter dairying; path dependence (caused, perhaps, by the capital

[5] *First Report of the Irish Milk Commission*, p. 174.
[6] Axelsen Drejer, 'Mejeribrugets historie', pp. 273–5.
[7] Dybdahl, 'Hans Broge og det jyske Landbrug', pp. 72–7.
[8] Jensen, *Danish agriculture*, p. 328.

investments required for stall-feeding cattle during the winter) ensured that the new system survived after globalization had removed the incentive.

The argument begs several questions. If Jensen is right, then why did winter dairying not develop elsewhere in response to this incentive? Or was the winter premium in fact higher in Denmark than elsewhere during this period? Was it particularly high in Denmark during the 1870s and early 1880s, and did it really decline as suggested above? The Irish cooperative movement was slightly slower to get off the mark than its Danish counterpart, with the first Irish cooperative creamery being set up in 1889, seven years after the foundation of the Hjedding cooperative in Jutland: was it too late by this stage? If the winter premium did in fact decline, was globalization to blame? How important were southern-hemisphere exports during the winter months, and what effect did they have on the winter premium? If the winter premium was in fact similar in different countries, what explains the particularly successful Danish response to the incentive that it represented? And, most fundamentally of all, was the Danish shift to winter dairying in fact as unique as the above discussion has implicitly assumed?

These are important issues in Danish economic history, and in the histories of its economic competitors of the time, such as Ireland. After all, Danish butter exports accounted for roughly 9 per cent of national income in 1900.[9] What is striking about the existing literature is how few data have been brought to bear on the questions outlined above. This paper presents new long-run time-series evidence, taken from primary sources, on the seasonality of production, trade, and prices in the European butter industry, focusing on Denmark, Britain, and Ireland. The data allow us to quantify the Danish shift into winter exports, and compare this with what was happening elsewhere. They allow us to test the Jensen hypothesis, by comparing winter premia and their evolution across countries, and by assessing the importance of southern hemisphere exports and other factors in driving trends in the premium over time. The paper also uses micro-data for 64 Danish creameries, as well as a range of more qualitative evidence, to describe the forces that led Danish farmers to switch to year-round production.

The paper relies largely, but not entirely, on UK trade data to quantify seasonality. For this reason, particular emphasis is given to a comparison between Denmark and Ireland, since exports to Britain accounted for the majority of total butter production in both cases. Exports to Britain accounted for 84.5 per cent of Danish butter exports in 1875–9, 93.5 per cent in 1885–9, and 97.2 per cent in 1895–9.[10] In 1908, exports to Britain accounted for an impressive 76 per cent of Danish production.[11] Similarly, exports to Britain accounted for almost all of Ireland's butter exports, while butter exports accounted for almost half of Irish butter

[9] Johansen, *Dansh historisk statistik*, pp. 191 and 391.

[10] Thomsen and Thomas, *Dansk-Engelsk samhandel*, p. 137.

[11] Johansen, *Dansh historisk statistik*, p. 150, *Statistiske Meddelelser*, 4.rd. 29.bd. pp. 52–3.

production.[12] In the case of other contemporary butter producers, such as France and The Netherlands, the UK trade data might be masking shifts towards domestic consumption, or exports to third countries; this is not an issue for either Denmark or Ireland.

Section I uses new monthly trade data to assess the changing seasonality of British butter imports from Denmark and elsewhere between 1881 and 1914. The evidence shows that the Danish experience was indeed atypical, and the remainder of the paper is devoted to explaining this development. Section II assesses the Jensen argument, by comparing winter premia across countries and over time, using newly collected monthly price data for the period 1870–1914. Section III asks what were the determinants of changing price seasonality over time, focusing on the role of southern exports and Denmark's shift to year-round production, while section IV looks in detail at the low-tech strategies adopted by Danish farmers which made that shift possible. Section V concludes.

I

The first task of the paper is to document Denmark's shift to year-round dairying, and to see whether this was indeed an exceptional event, or part of a broader European pattern. Ideally, what we would like is seasonal data on production in Denmark, and other traditional butter producers such as Ireland, France, and The Netherlands. Section IV will indeed provide some Danish data along these lines, which will confirm the findings of this section, but not surprisingly, such data are not available in a systematic fashion for this period. However, the largest European butter importer of the time, the United Kingdom, did collect monthly data on imports from various countries, and these were published by the British Government in its annual trade returns from 1881. The British import market is a good one to look at for our purposes, since British consumers were very heavily dependent on foreign butter: in 1908, British butter production amounted to just 912,000 cwt.,[13] while imports of butter into the United Kingdom totalled 4,211,195 cwt. Furthermore, Ireland exported 627,000 cwts. of butter in 1908, most of which would have gone to Britain.[14] On the assumption that all UK imports, and all Irish exports, were consumed in Britain, British production accounted for only 16 per cent of British consumption, while imports from outside the United Kingdom accounted for 73 per cent. Imports thus give a good reflection of overall supply in the British butter

[12] In 1908, Irish butter exports amounted to 627,000 cwt., out of a total butter production of 1,285,000 cwt. according to DATII 1912, p. 14 and Solar, 'Irish butter trade', pp. 159–61. Solar's export figure is net; gross exports in 1908 amounted to 751,942 cwt., Report on the Trade in Imports and Exports in Irish ports during the year ended 31 Dec. 1908, pp. 45–6. On the dominance of exports to Britain in total Irish exports, see PP 1910, p. 21.

[13] 490,000 cwt. were sold by farmers, and a further 422,000 cwt. were made or blended in factories. *Agricultural output*, p. 14.

[14] Solar, 'Irish butter trade', pp. 159–60.

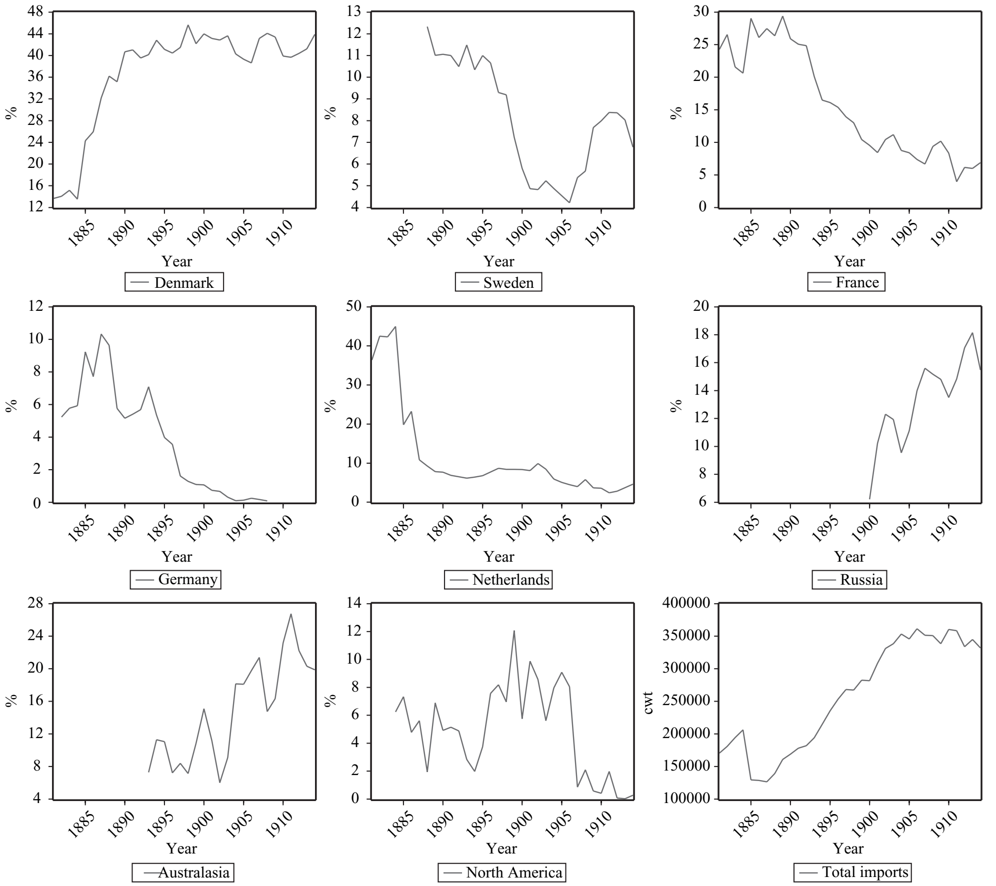

Figure 1. *Average monthly butter imports, 1881–1914*
Source: Annual UK Trade Returns

market. Moreover, as argued above, they give a very good indication of overall Danish output seasonality.

Figure 1 gives total annual imports of butter into the UK (in hundredweight), and also the percentages of imports from a number of individual European countries, as well as from Australasia and North America (i.e. the USA and Canada). The sharp decline in total imports in 1885 is an optical illusion, explained by the fact that 'butterine' (i.e. margarine) imports were included in the butter totals until that date; these imports had largely been from The Netherlands, which explains the sharp decline in the Dutch share of imports at that time, as well as the rise in the shares of Danish and French imports. Otherwise, the figure shows the dramatic rise in the quantity of butter imported by rich, free-trading and industrial Britain during this period; the extraordinary success of Denmark which saw its share of the market rise from a quarter to two-fifths during the late 1880s (the decade which saw the establishment of the cooperative creamery movement there);[15] the gradual decline in the shares of traditional European suppliers such as France, Germany, and Friesland, as well as North America; and the rise of new suppliers such as Russia and countries in the southern hemisphere. Among the European suppliers, French exports to the UK declined continually, from over 500,000 cwt. per annum in the late 1880s to less than 300,000 cwt. by the end of the period. German supplies collapsed from the mid-1890s, and were insignificant by the mid-1900s (as were supplies from North America). Dutch supplies had been over 300,000 tons per annum in the mid-1880s, but were less than 200,000 on the eve of the First World War. By contrast, by the end of the period Australia and New Zealand were accounting for between a fifth and a quarter of total imports, with Argentina (not shown) also supplying between 1 and 2 per cent of the market.[16]

Not only did Denmark increase its overall share of the market; it also managed to lower the seasonality of its exports to the UK. Figure 2 provides a simple index of seasonality for the same countries or groups of countries as in figure 1, for the years 1885–1914, namely the coefficient of variation of imports within each year.[17] Three things stand out from this figure. First, the seasonality of imports from Denmark declined throughout this period. At the start of the period, the coefficient of variation fluctuated around about 0.2, while by the end of the period it was fluctuating around about 0.1. The decline was continual throughout the period, rather than being concentrated in a particular sub-period or sub-periods (although the decline is particularly sharp in the late 1880s). Second, this Danish experience was the exception rather than the rule. The seasonality of Swedish exports remained constant, while the seasonality of imports from traditional suppliers in Western Europe such as France, Germany, and The Netherlands, as well as from North America and Russia, increased. Third, this increase in seasonality from traditional suppliers was sufficiently strong that the overall seasonality of imports into the UK increased slightly after the late 1890s.

What was the nature of this changing seasonality? We de-trended the data by dividing monthly imports in each country and year by average monthly imports in that country and year.[18] These data were then regressed against 12 monthly dummies for two decades, 1885–94 (the first decade for which butterine imports were not included in the figures) and 1905–14 (the last decade in the sample).[19] The coefficients on these monthly dummies are plotted in figure 3, for the countries present in the British market throughout the period, plus Australasia. In Denmark, for example, the graph shows that there was a clear peak in July during 1885–94, and an equally clear

[15] These numbers do not reflect exports from Ireland to Britain; including these, Denmark's share of the British market rose from roughly one-tenth to roughly one-third during the 1880s.
[16] Annual UK Trade Returns.
[17] The figure starts in 1885, in order not to contaminate the data with butterine imports.
[18] Thus all Danish monthly imports for 1881 are divided by average 1881 Danish monthly imports, all Danish monthly imports for 1882 are divided by average 1882 Danish monthly imports and so on.
[19] Augmented Dickey-Fuller and Philips-Perron tests indicated that these series were stationary.

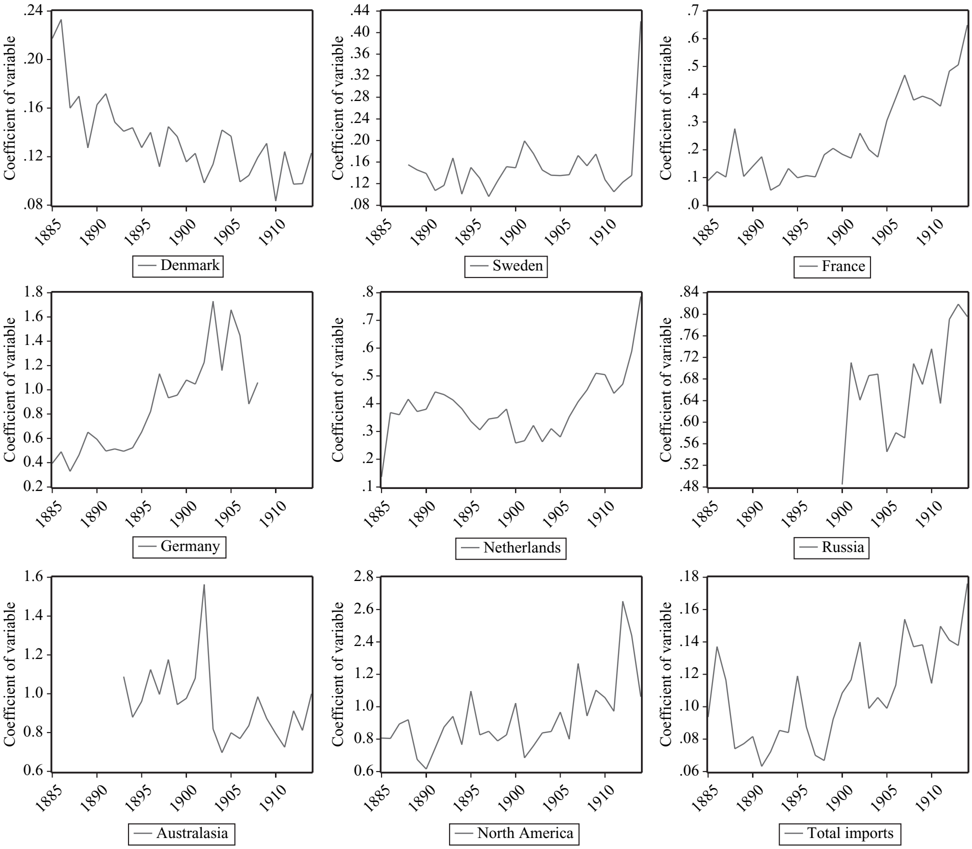

Figure 2. *Import seasonality, 1885–1914: coefficient of variation*
Source: see text

trough in November. By the second period, the peak month had shifted to June, but more importantly the distinction between peaks and troughs had become less pronounced. By contrast, French exports to Britain were fairly evenly spaced between 1885 and 1894, but were highly seasonal in the later period, with pronounced peaks and troughs in July and February respectively. The seasonality of Australasian exports was the opposite of the European pattern, with an 1885–94 peak in December and a trough in August. It is difficult from these figures to say whether Dutch, Swedish or southern hemisphere exports were more or less seasonal in the later period than in the former one, although total imports (which by the last decade before the First World War had clear double peaks in January and July, as well as a trough in November) seem to have become slightly more seasonal, confirming the evidence of earlier graphs.

Figure 4 provides a final look at the changing seasonality of exports from the countries or groups of countries included in figure 3. For each country, a series of rolling regressions (with a window of five years) was carried out,

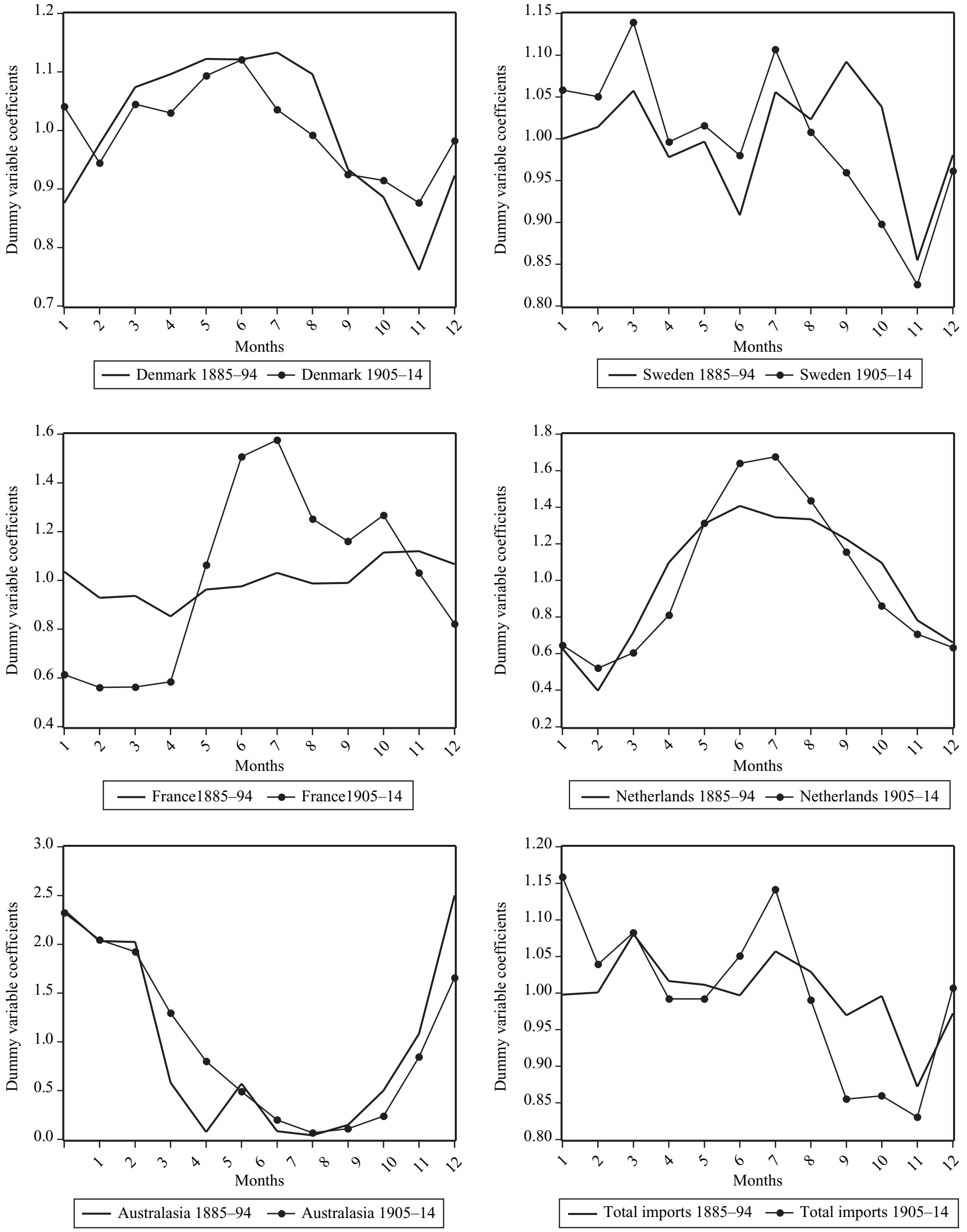

Figure 3. *Monthly dummy variables, 1885–94 and 1904–14*
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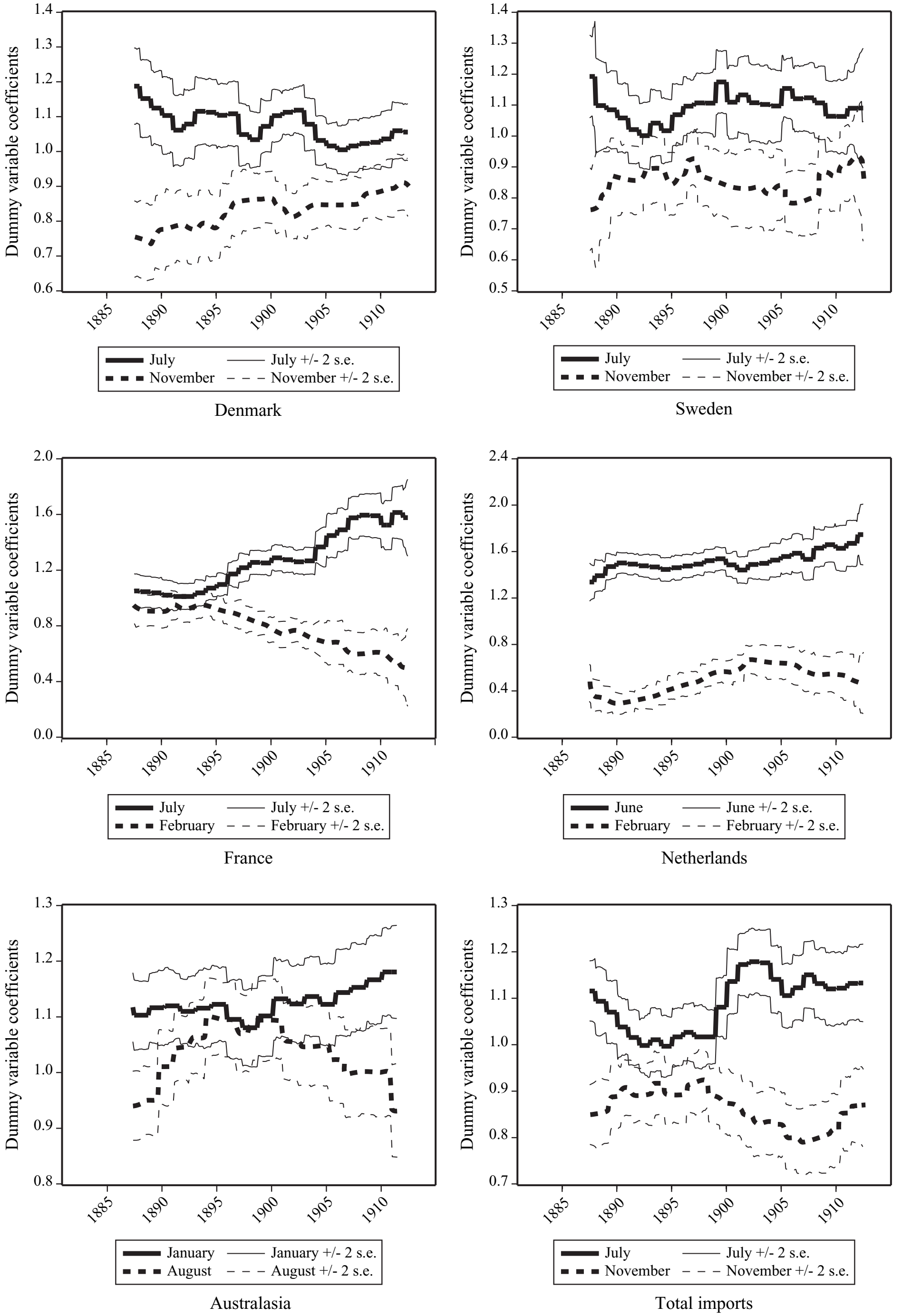

Figure 4. *Monthly dummies, rolling regressions 1885–1914*
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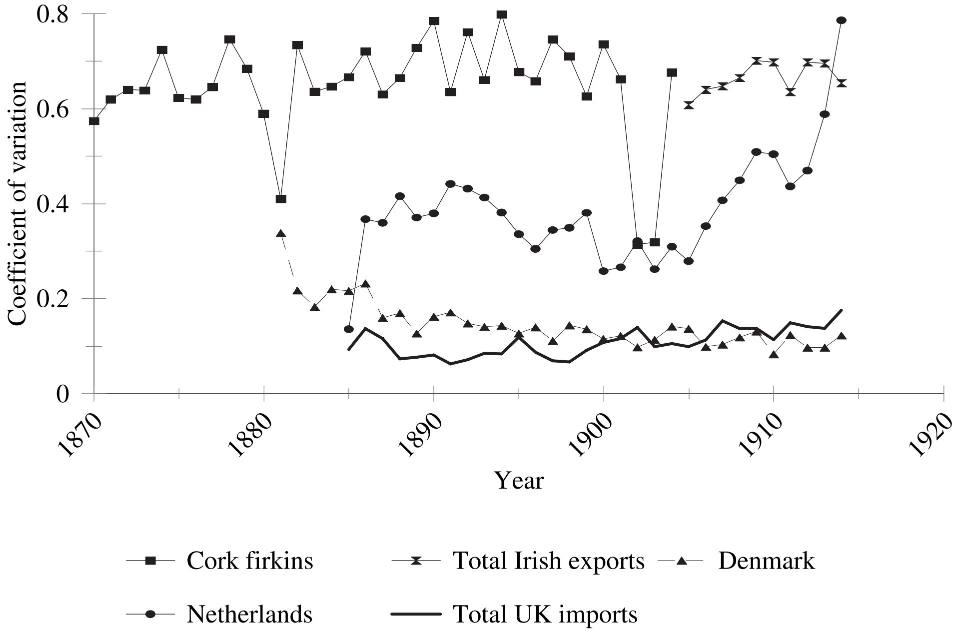

Figure 5. *Irish export seasonality 1870–1914: coefficient of variation*
Source: see text

of detrended monthly imports on monthly dummy variables. Figure 4 plots the coefficients associated with the peak and trough months for each country, along with a confidence interval of plus or minus two standard errors. If exports were evenly spaced throughout the year, all monthly dummies would be equal to one, so declining seasonality will be associated with peak-month dummy variables declining towards one, or trough-month dummy variables increasing towards one. As can be seen from the figure, this is clearly what happens in the Danish case, while once again Swedish seasonality remains reasonably stable, and Dutch seasonality increases. French seasonality increases dramatically, while the seasonality of overall imports also increases somewhat.

Figure 5 gives evidence on the seasonality of production in another major nineteenth-century butter producer, Ireland. From 1870 to 1904, we collected data[20] on the number of firkins entered for sale in the Cork butter market each week; these were then converted to monthly averages. Figure 5 gives the annual coefficient of variation for this series for 1870–1904 (after 1904 information on this variable dries up, presumably because of the decline in the importance of the Cork butter market). Coincidentally, from 1904 on the Government started computing official Irish trade statistics

[20] Published in the *Farmer's Gazette*.

after a hiatus of almost 80 years. Figure 5 graphs the seasonality index for this series as well, and the message which emerges is remarkable: it shows that the seasonality of total Irish butter exports (creamery butter as well as farmers' and factory butter) was extremely similar to the seasonality of the Cork butter market.[21] Moreover, the seasonality index for both Irish series is practically constant over time: on the face of it, Irish agriculture made no headway in eradicating this problem, if problem it was, over a 30-year period. By contrast, the Danish coefficient of variation declined throughout the period, so that by the 1900s it was lower than the coefficient of variation of total UK imports. Lastly, the scale of the Dutch increase in seasonality is apparent here: in 1885 it was lower than Danish seasonality, while by the end of the period it was approaching Irish levels of seasonality.

In summary, while these different measures of seasonality in some cases give slightly different results, several broad features of the data stand out. First, Danish export seasonality declined during the late nineteenth century, but this was not part of a broader European trend. French, German, and Dutch seasonality increased, and Swedish and Irish seasonality remained stable. Overall British import seasonality increased slightly, which is striking given that the arrival on the market of southern-hemisphere exports, as well as the decline in Danish seasonality itself, should both have been acting to reduce it. The next sections will explore the reasons for the decline in Danish export seasonality. We begin with what was happening to the seasonality of butter prices during the same period.

II

Was the unique Danish experience due to winter premia being higher in Denmark than elsewhere; and did the winter premium in fact decline as suggested by Jensen? In order to answer these questions we need seasonal price data. We thus collected price data from primary sources (newspapers and price currents) for three markets: Denmark and Ireland (both major butter exporters), and Britain (a major butter importer).

Weekly data on Irish and London market prices were gathered from the *Farmer's Gazette* for the years 1870 to 1914. While prices were available for a large variety of butter qualities, in this paper we focus on just those butter grades for which price quotations exist over the whole period, or almost the whole period. The Cork butter market, in the south of Ireland, had always been the main source of traditional Irish salted butter, produced by small farmers using non-mechanical methods and sold in wooden firkins. For this market, we collected data on first-class 'ordinary' butter, which would have been heavily salted and produced in the traditional manner (prices were

[21] We have had to rely on the graphs of monthly butter exports published in each year from 1904 onwards. We therefore adopted the highly scientific procedure of using a ruler to read the monthly figures off the (rather detailed) axes provided in the graphs. The alternative measure of seasonality used for other countries also show that Irish seasonality did not decline between 1870 and 1914.

available until 1912 only). For Dublin, we collected data on the prices of first-class 'cools'. For London, we collected prices of butter from Denmark (1873–1914), while Jan Tore Klovland kindly provided us with monthly London prices of butter from Friesland (1870–1914) (another traditionally important supplier). Lastly, weekly prices of the highest grade of Danish butter on sale in Copenhagen were collected from *Mæglernes Pris-Kurant Udgiven af Stadens Mæglere* (The Brokers' List) (1870–1914).

We next converted these data into monthly averages, to take account of the fact that there were frequently missing observations for individual weeks. Lastly, we calculated a variety of measures of price seasonality for these markets. Figure 6 plots the annual coefficient of variation of butter prices (for years in which there were price data for all 12 months). Figure 7 repeats the analysis of figure 4 above; that is, the series are first de-trended by dividing each observation by the annual average price; a series of rolling regressions with moving five-year windows are then performed, regressing the resulting de-trended series on monthly dummies. The figure shows the January and May coefficients for the three series for which there were sufficient data to carry out the procedure, together with associated confidence intervals. Lastly, figure 8 plots the raw January to May price ratio for each year.

The clearest evidence of narrowing price premia comes from Figure 7, which shows that the gap between January and May prices started declining sharply in the 1890s, and was much lower in 1910 than in the 1870s. However, there is some suggestion from the Danish data that the gap widened in the 1870s, before narrowing again. This impression that price seasonality may have become greater during the 1870s is reinforced by the coefficient of variation data for the Danish, Dublin, and London Friesland series, while the two series for Cork butter suggest an increase in seasonality during the 1880s (figure 6). Lastly, figure 8 also suggests some increase in price premia during the 1870s and early 1880s, before premia narrowed again, especially during the late 1880s and 1890s.[22]

[22] There are in principle several possible reasons why the winter premium initially increased. One possibility is that the costs associated with winter dairying (e.g. animal feed and labour costs) might have increased in the 1870s and 1880s, relative to the price of butter, before declining again. This, however, does not appear to be the case. We have British imported animal feed prices from 1880: it seems that if anything animal feed prices fell relative to butter prices in the early 1880s, and only started to rise from the mid-1890s. This should have produced movements in price seasonality that were the opposite to those actually observed. Moreover, the ratio of agricultural wages to butter prices in Ireland was relatively constant until the mid-1890s, at which stage it too started to rise (animal feed prices are taken from the NBER Macro History Database; the wage data are from P.P. (1909), p. 213). Another possibility is that demand-side forces caused the rise in price seasonality, with rising living standards in Continental Europe leading to consumers there eating more winter butter, and to the seasonality of supplies arriving in Britain increasing. However, our data suggest that total British import seasonality remained constant (figure 2) or actually *declined* (figure 4) until the mid-1890s or so, before rising again. A third, more likely possibility is that the fresh, unsalted butters which consumers were increasingly switching to during this period kept less well than traditional salted butter; this would have led to an increase in price seasonality until refrigeration and southern hemisphere supplies started smoothing out annual prices once more. Testing these hypotheses is however beyond the scope of this paper.

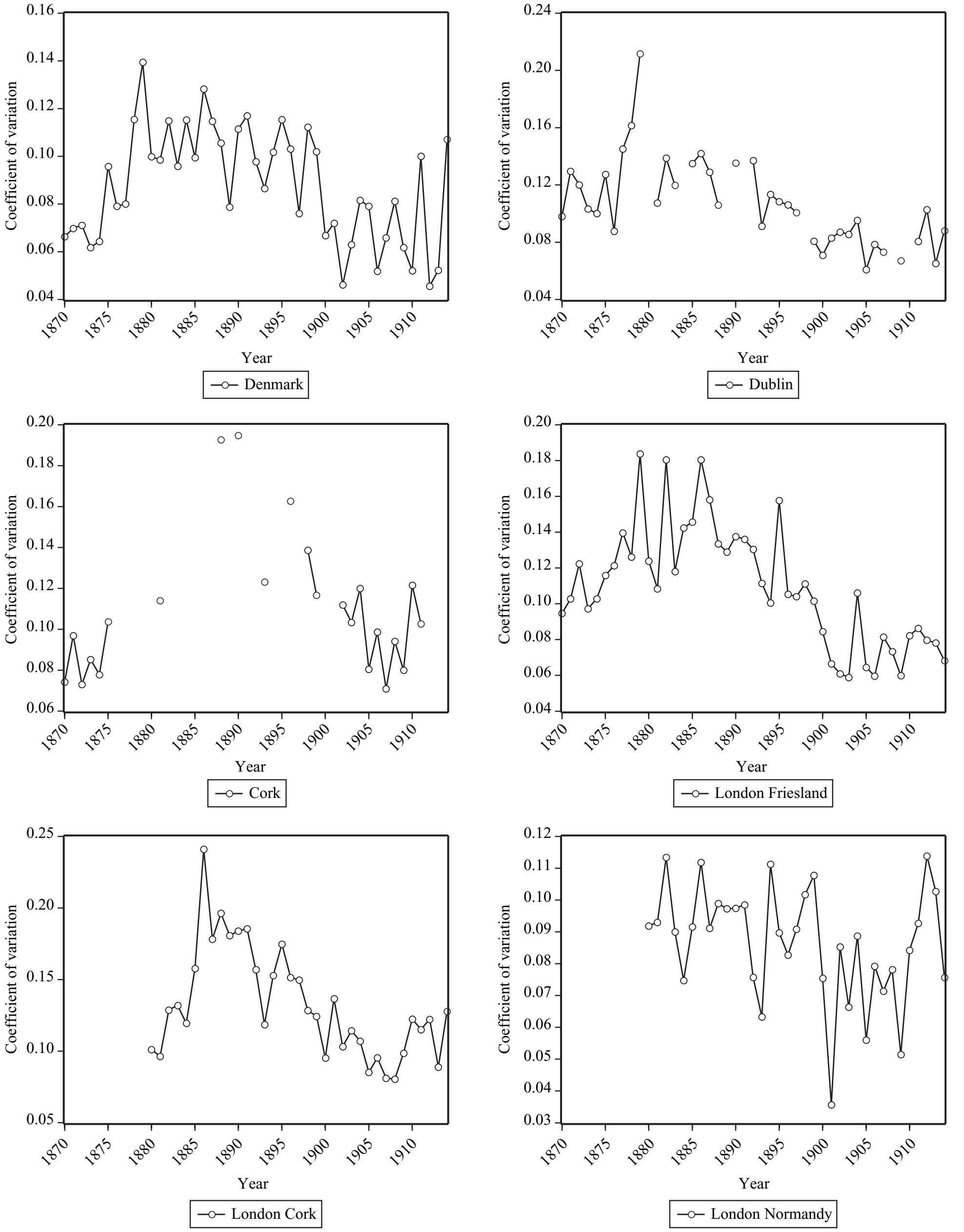

Figure 6. *Price seasonality 1870–1914: coefficient of variation*
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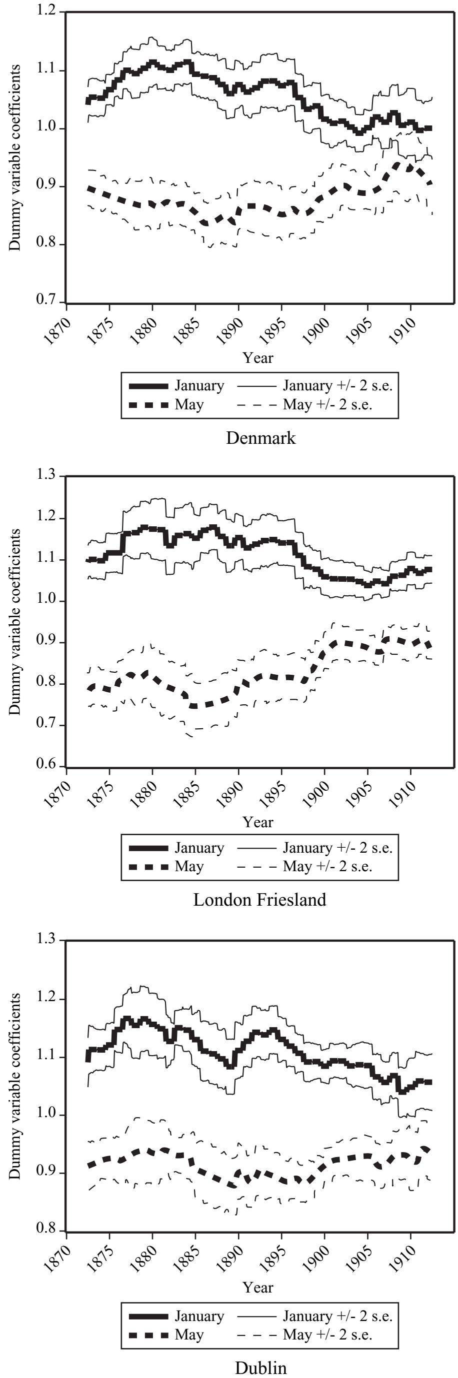

Figure 7. *Monthly price dummies, rolling regressions 1870–1914*
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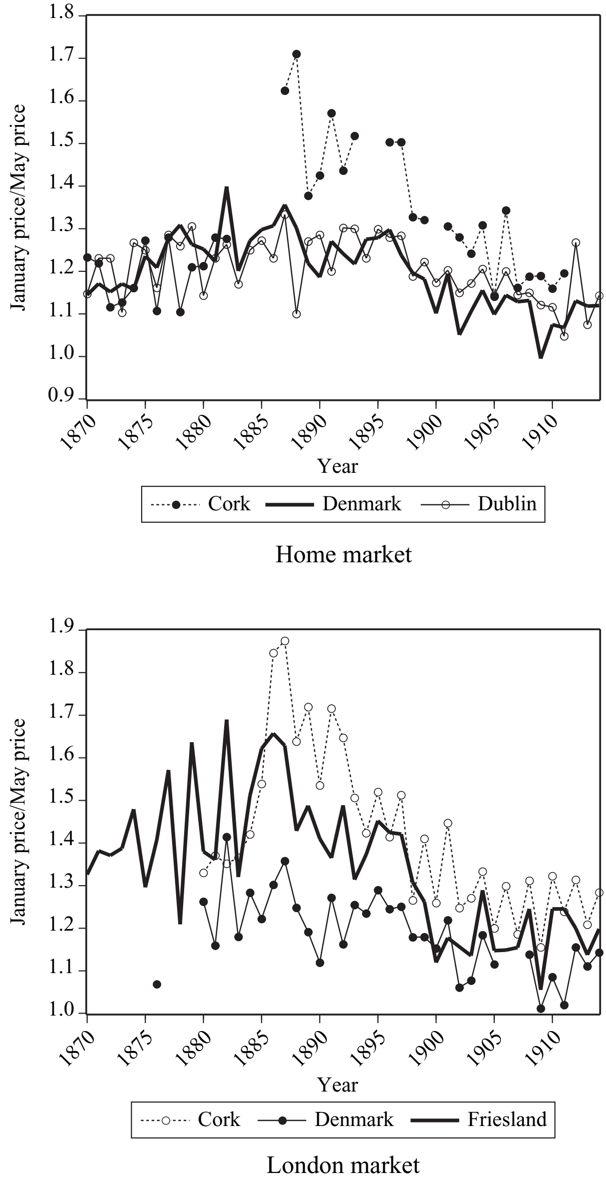

Figure 8. *January/May price premium, 1870–1914*
Source: see text

Figure 8 also suggests that price premia in Denmark were no higher than in Ireland, while the Danish winter premium on the London market was lower than the premia enjoyed by Dutch or Irish butter. The Cork winter premium was particularly high, probably reflecting the relatively seasonal production of Irish farmers' butter. It is not the case that Danish farmers

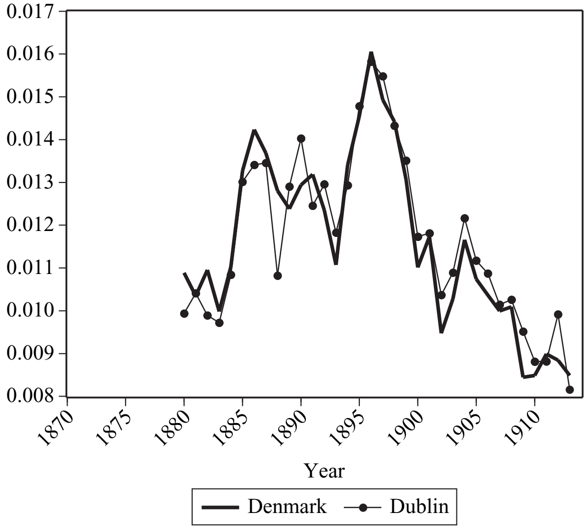

Figure 9. *January–May price premium, divided by animal feed prices, 1870–1914*

Source: see text

Note: Graph shows the ratio of the January to the May price in each country, divided by the British imported animal feed index (1900 = 100)

faced a price incentive to develop winter dairying that did not exist elsewhere. Figure 9 shows this very clearly: it plots the January to May price premium, relative to the British price of imported animal feeds, in Dublin and Denmark. (As will be seen later, if the price premium represented the benefit from producing in the winter, animal feeds represented an important cost of such a strategy.) The ratio of benefit to cost was almost identical in both countries; moreover, it rose steadily until 1896, and only started declining after this date. The Jensen hypothesis on its own will not do, therefore, in explaining the different path taken by Danish farmers. Nor is it the case that the price incentive had vanished by the late 1880s or early 1890s, when the Irish cooperative movement took off. However, the price evidence does suggest that there was an increase in the winter premium precisely at the time that the Danes began to develop an intensive dairying sector, based on winter production and cooperative creameries. While the incentive on its own was not sufficient (since it also existed in Ireland and presumably elsewhere in Europe), Jensen may be right in his assertion that price incentives were important in the Danish case, and that they presented Danish farmers with a moment of opportunity that was seized with both hands. Lastly, it is true that by the early twentieth century the incentive to develop winter dairying was indeed much lower than it had been in the late 1880s and early 1890s; to that extent, traditional suppliers such as France may indeed have been crowded out of the British winter market (although this declining premium did not lead Danish farmers to retreat from winter dairying: as section V shows, they continued to smooth out production into the 1900s).[23] The following section will discuss the reasons for this decline in the winter premium.

III

What caused the decline in the winter premium from the 1890s onwards? Goodwin, Grennes, and Craig[24] attribute the decline in the American premium, which occurred at the same time, to the adoption of mechanical refrigeration. While not excluding this possibility, in this section we explore two alternative hypotheses. The first is the Jensen argument that the rise in southern hemisphere butter exports to Europe in the late nineteenth century played an independent role in smoothing out price fluctuations, by augmenting the supply of butter during the winter months. Obviously, this North–South trade could not have existed without mechanically refrigerated steam ships, and thus was ultimately as a result of similar technologies to those emphasized by Goodwin, Grennes, and Craig. However, whereas their article emphasizes the intertemporal arbitrage effects of refrigeration, the hypothesis explored here is that refrigeration affected price seasonality via interregional arbitrage. The second hypothesis is that price smoothing may have taken place because of the Danish shift to year-round dairying.

The evidence in section I that the overall seasonality of imports into Britain actually increased between 1881 and 1914 suggests that refrigeration probably played a role in smoothing out prices in Europe. Of course, the fact that these are only import data—albeit import data for the biggest market in Europe—means that we cannot say anything with certainty about what was happening to the overall seasonality of supplies, either in the British market, or in Europe more generally. However, if these data are reflective of the supply situation in Britain generally, then there was a very small increase in overall supply seasonality during this period. If price seasonality declined, then this must have been as a result of a reduction in the seasonality of demand as consumers found it easier to store butter for longer periods, and one likely candidate explaining this is cold-storage facilities, in the larger British ports such as London or Newcastle, or in the larger British grocery chains, such as Maypole or the Cooperative Wholesale Society.

However, this does not mean that the decline in Danish seasonality, or the emergence of the southern hemisphere as a major source of supply, was irrelevant: far from it. Figure 10 shows the percentages of British imports during the winter months (defined as November through March inclusive) coming from these two sources, as well as from France. From the turn of the century, Denmark and Australasia accounted for over 60 per cent of

[23] Note also that as France and Germany industrialised, they may have directed an increasing share of their winter production towards their domestic markets, heightening the seasonality of their exports to Britain.

[24] Goodwin, Gennes, and Craig, 'Mechanical refrigeration'.

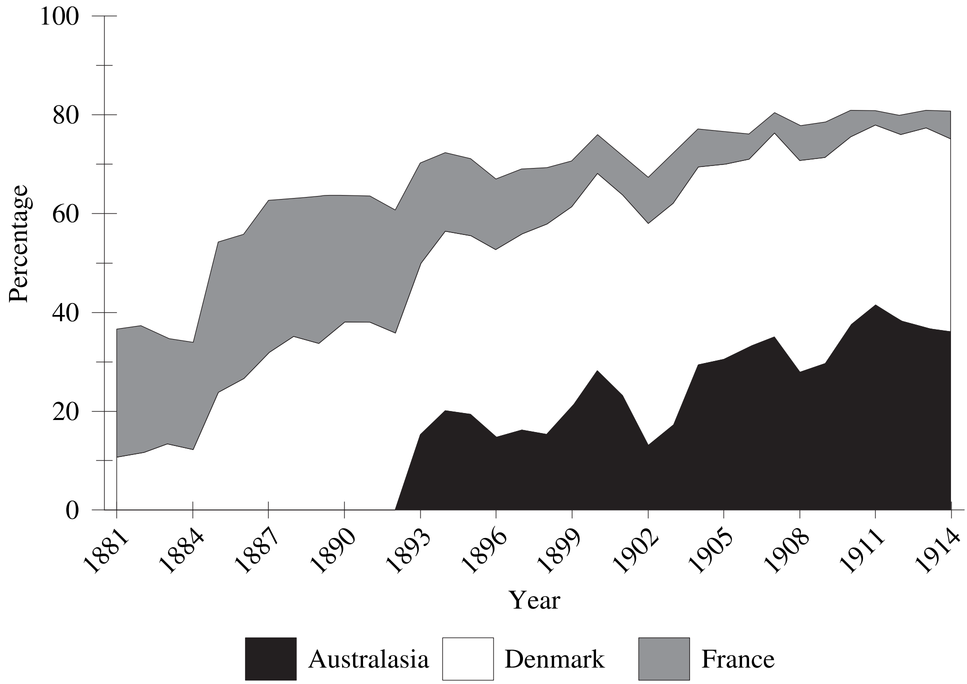

Figure 10. *Winter import 1881–1914: percentage of imports, November–March*
Source: Annual UK Trade Returns

winter imports; the figure was over 70 per cent by the eve of the Great War. (By contrast, in the early 1880s France accounted for twice as many winter imports as Denmark, and Australasia was not supplying butter to the British market at all.) In the absence of the revolution in Danish production methods, and the development of the North–South butter trade, the seasonality of import supply in the British market would have grown much more sharply, and the winter price premium would not have declined by as much as it actually did.

By how much would price seasonality in Britain have increased if Danish and Australian winter supplies had been withdrawn from the market? Obviously the answer will depend on elasticities of demand and supply, as well as on the size of alternative sources of supply. Table 1 reports regressions using monthly data from 1885 to 1913, which yield an import supply elasticity of 2.415, and an import demand elasticity of –0.508.[25] We consider the following simple relationship:

[25] The dependent variable is total monthly UK imports, and the butter price is the average price of imports, both variables being taken or derived from the Annual UK Trade Returns. All nominal variables in the regression were deflated by the Sauerbeck wholesale price index, kindly provided by Jan Tore Klovland. Income was proxied by monthly rail freight receipts, which were taken from the NBER

Table 1. *Monthly butter imports: demand and supply elasticities*

(Dependent variable: monthly butter imports)

	Demand	*Supply*
Constant	9.898	18.049
	(14.622)	(10.191)
Own price	–0.508	2.415
	(–2.282)	(3.556)
Lagged deflated freight receipts	0.201	
	(1.838)	
Real wheat price	–0.065	
	(–0.611)	
Real animal-feed price		–1.212
		(–3.526)
January		0.103
		(2.752)
February		0.028
		(0.609)
March		0.159
		(2.774)
April		0.039
		(0.716)
May		0.088
		(1.391)
June		0.166
		(2.373)
July		0.256
		(3.587)
August		0.187
		(2.773)
September		0.040
		(0.703)
October		–0.006
		(–0.120)
November		–0.139
		(–3.712)
Time trend	0.003	0.005
	(11.673)	(12.683)
AR(1)	0.632	0.497
	(14.869)	(10.638)
R-squared	0.892	0.791
Adjusted R-squared	0.890	0.781
S.E. of regression	0.124	0.175
F-statistic	565.141	97.853
Prob(F-statistic)	0.000	0.000
Mean dependent variable	12.423	12.423
S.D. dependent variable	0.373	0.373
Sum squared residuals	5.232	10.119
Durbin-Watson statistic	2.066	2.164

Note: Equations estimated using two-stage least squares with AR(1) correction instruments include all exogenous variables and lagged regressors. All variables measured in logs
Source: see text

$$W + S(p) = D(p) \tag{1}$$

where W represents winter imports from Denmark and Australasia, a parameter whose value will be changed exogenously; S represents all other exports to the UK, which are taken to depend on the domestic price p; and D represents UK import demand (i.e. domestic demand minus domestic supply), which also depends on p. Totally differentiating this expression yields the following expression (after some manipulation):

$$dW/S + dS/dp(p/S)(dp/p) = dD/dP(p/Q)(dp/p)(Q/S) \tag{2}$$

where Q is the total amount supplied to the UK market (i.e. $Q = W + S$). Solving this for the percentage change in prices yields

$$dp/p = (-dW/S)/[E_S - E_D(Q/S)] \tag{3}$$

where E_S and E_D represent elasticities of supply and demand respectively.

We can now use this formula to calculate the monthly butter prices that would have obtained if Danish and Australasian supplies had not been present on the British market. In each case, Q represents total actual imports in the month in question, S represents Q minus the amount being withdrawn from the market, and $-dW$ represents the amount being withdrawn from the market (i.e. Danish and/or Australasian supplies). We calculated two counterfactual price series: the prices that would have obtained had Australasian supplies been withdrawn, and the prices had both Danish and Australasian supplies been withdrawn.[26] Obviously, reducing overseas supply in this manner would have increased average British prices, but our focus here is on the impact on price seasonality. Figure 11 thus presents the annual coefficients of variation of these actual and counterfactual price series. The seasonality of actual (average) import prices remained fairly constant throughout the period, at around 0.05. By contrast, withdrawing Australasian supplies would have led to the coefficient of variation roughly doubling over the period, rather than remaining constant; and withdrawing both Danish and Australasian supplies would have led to the coefficient of variation roughly trebling rather than remaining constant.

Clearly the advent of southern-hemisphere butter on the European market had a large impact on European price seasonality; and Denmark's swimming against the tide, and shifting into winter dairying despite Australasian competition, added to the impact. To this extent, Denmark may have benefited from a first-mover advantage of sorts, in that its own

Macro History Database, as were monthly wheat prices and a monthly animal-feed price index. All variables are either stationary or trend stationary. Both supply and demand equations include a time trend; the supply equation also includes monthly dummy variables. Estimation is by two-stage least squares, with an AR(1) correction for serial correlation; instruments include all exogenous variables and lagged regressors.

[26] The latter two series are only computed from 1893 on, the date from which Australasian import data become available.

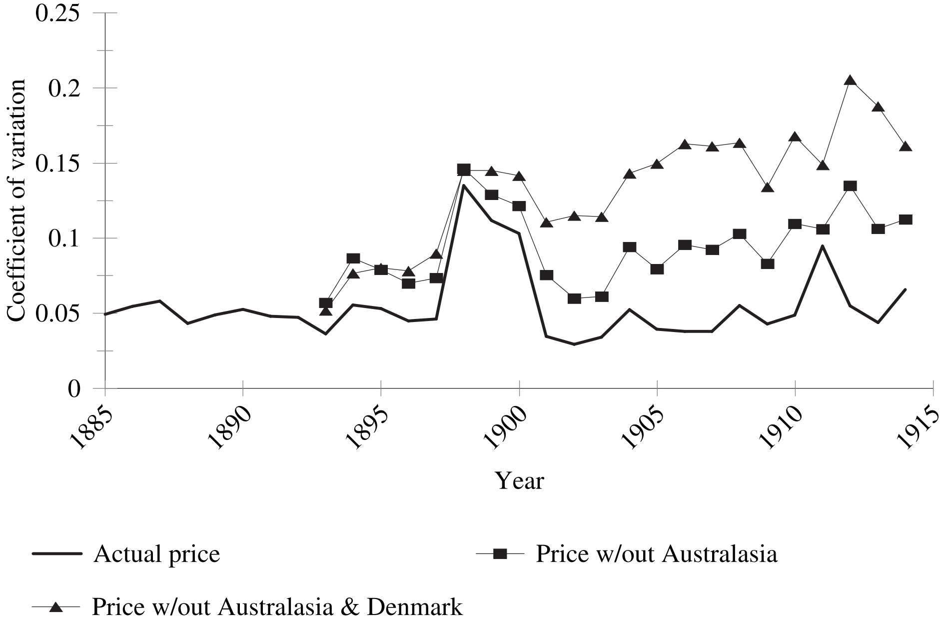

Figure 11. *Actual & counterfactual prices: annual coefficient of variation*
Source: see text

shift to winter dairying made a similar shift less attractive for others. But what were the forces that underlay this Danish shift in the first place?

IV

Figure 10 demonstrated an impressive increase in the amount of Danish butter being shipped to the British market during the winter months. It is not the case that mechanical refrigeration was a force behind the early acceleration in winter exports of butter from Scandinavia to Britain. Mechanical refrigeration was only diffused in the Danish dairy sector during the second decade of the twentieth century[27] and storage facilities in Danish harbours could not have accounted for any large intertemporal arbitrage on the Danish side of the North Sea. Rather, this smoothing of exports from Denmark was the result of a conscious effort by Danish dairy farmers to raise production in the winter months.

We would have liked to supplement the data in figure 2 on trends in the seasonality of exports with corresponding official data on trends in the seasonality of Danish milk production. Not surprisingly, this cannot be done. However, reliable information from a large number of ordinary farms was

[27] Etwill, *Teknologi og innovation*, pp. 112–13.

Table 2. *The annual distribution of milk production, Denmark*
(percentage of annual production)

	Nov.	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*	*Aug.*	*Sept.*	*Oct.*	
Period	1	2	3	4	5	6	7	8	9	10	11	12	13
1898	6.03	6.61	6.86	6.95	7.52	8	8.97	10.5	10.2	9.15	8.15	7.11	6.74
1908	6.66	7.06	7.23	7.52	7.97	8.47	8.98	9.58	9.17	8.2	7.39	6.89	6.67
Diff.	0.63	0.45	0.38	0.57	0.45	0.47	0	–0.9	–1	–1	–0.8	–0.2	0

Sources: Danmarks Mejeri-Drift-Statistik 1899 and 1909

collected on the initiative of the cooperative creameries from 1898 onwards. Participating in this survey was optional, and the rate of participation grew rapidly over time. It appears that the creameries which sent in their data were a fairly representative sample of cooperative creameries generally.[28]

We have collected information on the annual distribution of milk production for 64 creameries in 10 counties, representing a variety of geographical environments within Denmark. Each of the creameries had 100–175 members. Some creameries reported their annual production in 13 four-week periods (probably for reasons of accountancy) whereas others reported monthly production. The information is summarized in table 2.[29] We compare the average seasonality in the first year for which this is possible with the average 11 years later, in 1908. Even at this relatively late stage we see that the creameries were making progress in smoothing-out production. This is consistent with the finding earlier that the seasonality of Danish exports declined continuously from 1881 to 1914. In 1898, the ratio between the share of production in the peak month (June) and the trough month (November) was 1.7; by 1908, this ratio had declined to 1.4. To put the achievement in context, the scattered evidence that we have suggests that seasonality had historically been a serious problem in Denmark. For example, in the 1830s just 1 per cent of the annual production of a farm in Fyn took place in December, January, and February, while 56 per cent took place in June, July, and August, an even higher proportion than the 45 per cent cited earlier for Ireland in 1909: 'it was [then] considered the trick to overwinter the cows with as little concentrates as possible' one author tells us.[30] By contrast, in Denmark in 1908, creameries produced 45 per cent of their annual output during November–April, and 27 per cent in June, July, and August.

How was this decline in the seasonality of Danish milk supply achieved? Note first that the fact that Danish seasonality had historically been high

[28] Based on a reading of 215 minute books of cooperative creameries, it appears that some elite creameries did not report until late on, while some less successful creameries reported at an early date. Whether creameries participated in the survey or not appears to have been to some extent random according to Henriksen and Hviid, 'Contracts in the governance', p. 5.

[29] App. A gives the figures for individual creameries in both years.

[30] Krarup, *Fyn med Omliggende Øer*, p. 245.

implies that there was no immutable geographical reason forcing Danish farmers to produce all year round. Such was the argument of an Irish commentator of the mid-twentieth century, Beddy, who stated that Denmark's 'rainfall and general climatic conditions did not point the way to grazing', and that her agricultural policy thus

> involves the growing of large quantities of cereals and forage crops for animal fodder which is supplemented by imported feeding-stuffs of high protein content . . . Climatic conditions are such that animals must be housed for a comparatively large part of the year and hence extensive farm buildings are required not only for this purpose but for the storage of fodder. This constant care of livestock is associated with that regular, as opposed to seasonal, production of livestock products which is so important a feature of marketing.[31]

However, the evidence shows that there was a shift in production structures away from an Irish-style seasonality, which remains to be explained. One possibility is that Denmark's transition to intensive dairying may have been facilitated by relatively low wages. In 1870, unskilled urban male wages in Ireland were 49 per cent of British wages in 1905, and Dutch wages were 57 per cent; Danish wages were just 36 per cent. In 1890, the figures were 75 per cent, 83 per cent, and 57 per cent respectively; it was only in the following decade that Danish wages overtook wages in the other two countries, but by that stage the transition to cooperative winter dairying had already taken place.[32] Furthermore, the increased labour requirements of dairy farming, that is the milking work and the work related to the growing of root crops for animal feed, was first met by women who had until then been underemployed. However, low wages on their own were neither sufficient nor necessary, since otherwise Denmark would have shifted to winter production even earlier, and perhaps abandoned the strategy in the twentieth century, by which time her wages were amongst the highest in Europe.

Another argument is that capital may have been relatively abundant in Denmark; a Danish expert visiting Ireland in 1909 argued that

> For the Irish butter exports to be tolerably distributed over the year the present system will have to be revolutionized. The calving is timed in the spring for the sake of raising the young calves. Should this be changed byres will have to be built and feed stuffs imported . . . Purchase of feeds and building of byres requires big outlays and, in addition to that, the whole working of the farm must be changed from permanent grass to arable land. The Irish farmer lacks the funds for making this transformation and unlike the Danish farmer he does not reckon the manure to be of value. Since he owes the whole purchase sum of his farm no money can be raised unless the government will lend it to him. And the crux of the matter is, I suppose, whether butter is more profitable than beef. A change towards whole year butter production necessitates the growing of roots [beets] and these plants take, besides some experience, more labour.[33]

[31] Beddy, 'Principal economic features', pp. 196–7.
[32] Williamson, 'Evolution of global labor markets,' pp. 178–9 and O'Rourke and Williamson, 'Around the European periphery', pp. 156–8.
[33] Schou, 'Landbrugsforhold i Irland', p. 266

It is unlikely that capital was scarcer during this period in the United Kingdom, of which Ireland was a member, than it was in Denmark; after all, Britain was the world's foremost capital exporter of the time, and the available evidence suggests that Ireland was exporting capital as well.[34] It is possible, though, that capital markets may not have worked sufficiently well to channel investment funds to Irish farmers. Credit cooperatives never really took off in Ireland as they had done in Germany;[35] while in Denmark small local savings banks to a large extent fulfilled the same task as credit cooperatives elsewhere, supplying credit to people with little or no security for loans.[36] Besides, the cooperative creameries in Denmark in some instances granted credit for the purchase of feed stuffs (see below). Furthermore, the transfer of land from landlords to farmers was taking place in Ireland during the period, whereas in Denmark land reform had taken place much earlier: already by 1835 there were 41,695 peasant proprietors in Denmark, as opposed to 24,795 tenant farmers.[37] In addition to occupying peoples' energies and fuelling agrarian unrest, this may have locked-up Irish farmers' capital in the purchase of their own land, as the above quotation suggests, when it might have been more usefully employed in various productive investments, including facilities for stall feeding.[38]

Regressions explaining creamery numbers in Ireland find some explanatory role for the number of bank branches per county, per 100,000 of population, which is consistent with the argument that imperfect capital markets hampered agricultural investment there.[39] However, a comparison with Holland suggests that agrarian calm and the availability of capital were not sufficient to ensure a shift towards winter dairying, since both conditions were present in this traditional dairy producer,[40] and yet, as figure 2 showed, Dutch exports to Britain became more seasonal during the late nineteenth century, not less so.[41]

[34] O'Rourke and Williamson, *Globalization and history*, ch. 11.

[35] Guinnane, 'Failed institutional transplant'.

[36] Guinnane and Henriksen, 'Danish credit cooperatives', pp. 52–4.

[37] Jensen, *Danish agriculture*, pp. 125–6.

[38] More useful, that is, for total agricultural output, but not necessarily for individual farmers' incomes. On the Irish Land Wars, see also Solow, *Land question*, and Guinnane and Miller, 'Limits to land reform'.

[39] O'Rourke, 'Social cohesion'. But see Ó Gráda, *Ireland: a new economic history*, p. 356, who concludes on the basis of qualitative evidence that the traditional image of over-cautious Irish financial institutions is unwarranted.

[40] Dutch farmers borrowed heavily to finance purchases of fodder, artificial fertiliser and cattle during the crisis of 1880–1900. On the other hand, by 1890 they were sufficiently heavily indebted that their borrowings were seen as a serious problem impeding the further development of the industry, see Van Zanden, *Transformation of European agriculture*, p. 133. As in the Irish case, therefore, there may have been some problems with the way in which Dutch capital markets worked in practice.

[41] A note of caution is appropriate here. We do not know what happened to the seasonality of Holland's exports to Germany during this period, which were a significant proportion of total Dutch exports, see, Smidt, 'Dutch and Danish exports', p. 142. Dutch exports to Germany were worth just over twice as much as Dutch exports to Britain in both 1893 and 1913; in 1913 exports to Germany accounted for 53% of total Dutch exports, and 26.8% of Dutch production, see, Knibbe, *Agriculture in The Netherlands*, pp. 264–7; Mitchell, *International historical statistics*, p. 610 and Lando, *Die Organisation des Dänischen Buttergrosshandels*, p. 82. It is also possible that Dutch winter production largely supplied the domestic market.

The key factor in the Danish case was technology: not the 'high-tech' technologies associated with refrigeration, but new ways of feeding cattle, which were transmitted rapidly throughout Danish agricultural society. It was the systematic creation of knowledge based on experimentation and observation by practitioners and academics, and the diffusion of that knowledge, which were crucial. First, it was found that by feeding in the winter, the milking period could be prolonged by the same number of months, thus maximizing lactation. The increase in winter production was thus closely correlated with a rise in total production. A cow that calved in, for example, November would continue to give milk throughout the summer after it was put out to graze in April or May, and would only go dry in September or October. Left to itself, the active milking period of an animal in the northern hemisphere would typically be from May to about September–October. Popular understanding of this fact apparently dates far back in time. According to a textbook edited in 1875,

> it was said, more than twenty years ago that a cow that calves in March calves twice . . . Consequently you lost none of the summer's production by bringing the cow to produce something also in the winter. By now, however, there has been a further demand on the cow's nutrition and production and the time of calving has been pushed further forward so that now the proverb says it is a Christmas cow that calves twice.[42]

Textbooks recorded the results of various experiments speaking to this issue. Thus, Buus[43] reported an annual surplus production of between 23 and 31 per cent per animal, depending upon breed, for cows that calved in February compared with April.

Second, a correlation was established between the amount of concentrates, in the form of grain, bran, and oilseed cakes, fed to a milch cow, and the amount of milk it yielded at any time. Not only could cows give milk over a longer time period as a result of winter feeding, they could also give more milk at any time as a result of more fodder. This corresponded with the experience of some large dairy farmers and agricultural schools, but did not go unquestioned until well into the 1880s. A series of scientific experiments that started in 1887 supervised by the Agricultural University provided the evidence. The main result[44] was that within a fairly wide interval there was a close correlation between the input of various feeds of equivalent nutritional value, and the output of milk per period of the experiment (table 3). Furthermore, as indicated in the footnote to table 3, these experiments provided the basis for substituting various fodder materials for each other.

What was needed for this to have an effect on the behaviour of dairy farmers was convincing evidence of the economy of this measure. In order to make their point to the reader, Danish textbooks on dairy farming from

[42] Buus, *Malkekøernes behandling*, p. 52.
[43] Ibid., p. 78.
[44] Summarized in 'Samlet Oversigt' p. 731.

Table 3. *Feed and output*

No. of feed units	*Fat per cent*	*Kilos of milk*	*Kilos of butter*
154	3.21	102	3.70
168	3.22	110	3.82
184	3.21	122	4.24

Note: 1 feed unit in this particular context was equal to 0.5 kilo of grain, 0.5 kilo of oilseed cakes, 0.5 kilo of bran, 5 kilos of beets, 6.25 kilos of turnips, 1 kilo of hay, and 2 kilos of straw
Sources: The experiments on which the table is based started in the second half of the 1880s and the results were communicated through lectures in agricultural associations. They were summarized in *Mælkeritidende* 1895, p. 731

the 1870s onwards introduced the pedagogical concepts of 'maintenance' and 'production' fodder. The first served only to keep the animal alive during the winter season, whereas the second served to expand milk production. Translated into economic terms, the argument for winter stall-feeding was that the maintenance cost and other fixed costs of a cow were so large that minimum average total costs were only obtained at a much larger scale of production than that applied by most farmers. Thus, Svendsen,[45] in the most influential textbook of the late nineteenth century, compared the practice quoted by Buus with his own. By adding 36 per cent more fodder he obtained an increase in production of 71 per cent. To put it another way, sparse winter stall-feeding implied under-utilization of the farmer's animals, which formed an important part of his capital equipment. One further advantage was that a highly recommended ingredient in the cows' winter feed, rapeseed cakes, demonstrably had a good effect on the texture and taste of the butter.[46]

Three pieces of empirical evidence support the argument that winter stall-feeding was the crucial factor in reducing the seasonality of Denmark's butter output, and in improving Danish milk yields. First, Danish farmers stall-fed their cattle much more than their Irish counterparts: in the early twentieth century the figures for imported feed stuffs were 372 kilos per cattle unit for Denmark, but only 28 kilos for Ireland.[47] Second, the seasonality of butter imports from several European countries increased dramatically in 1914 (figure 2), when imports of overseas fodder to Europe decreased. Denmark was an exception during the first years of the war, when Britain facilitated a continuation of imports to Denmark. (In 1917, however, the Danish luck ran out, and during the last years of the war, milk production per cow decreased by 39 per cent.)

Third, table 4 contrasts the development of winter stall-feeding in Denmark and Holland; it gives the use of or the imports of[48] oilseed and

[45] Svendsen, *Fodringslæren*, p. 270.
[46] Ibid., p. 112.
[47] Schou, 'Landbrugsforhold i Irland,' pp. 266–7.
[48] Which in the Danish case are identical.

Table 4. *Cows and oil cakes, 1877–1910*

	The Netherlands		*Denmark*	
Year	*Number of cows*	*Use of feed cakes*	*Number of cows*	*Imports of oil seed cakes*
1877[a]	100	100	100	100
1893[b]	96	150	125	310
1903	107	359	135	1352
1910	117	429	143	1803

Note: a average 1875–79 for Denmark; *b* average 1890–94 for Denmark
Sources: Knibbe, *Agriculture in the Netherlands*, pp. 155 and 264–5; Bjørn *et al, Del danske landbrugs historie*, p. 262; Johansen, *Dansk historisk statistik*, pp. 204–5

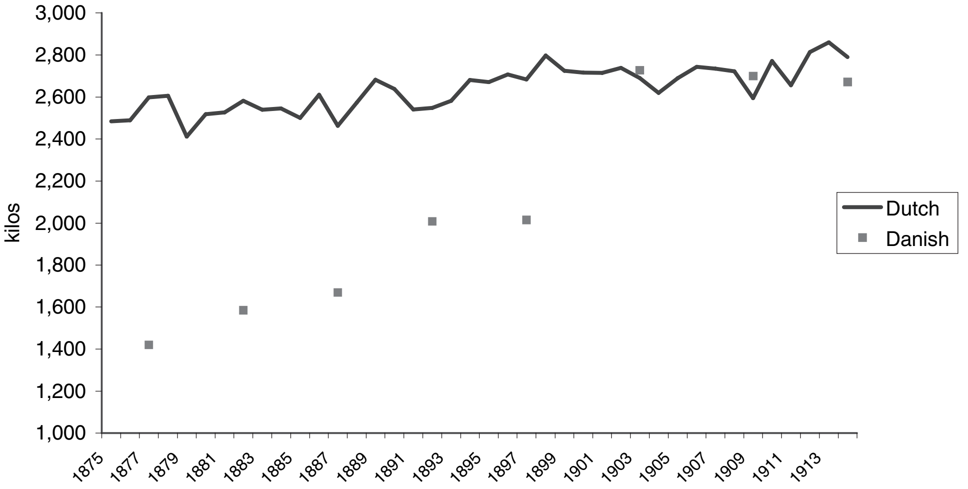

Figure 12. *Milk (per cow) in Denmark and the Netherlands, 1871–1914*
Sources: see text

oilseed cakes, because these were mainly stall-fed to milch cows. It shows that both countries expanded production by having more animals and by feeding them better. It also shows that the use of this specific feed-stuff accelerated considerably faster in Denmark than in The Netherlands. This fits well with the development of the relative seasonality of their butter exports that can be observed in figure 2. However, note that the countries were starting from different positions. Figure 12 indicates that Dutch dairy farmers initially had higher yields, perhaps as a result of better breeds of animals, or alternatively the higher use of oilseed cakes (in 1875–7, the Dutch used roughly three times as many oilseed cakes as the Danes). On the other hand, Danish farmers used considerably more grain per cow.[49] In

[49] See, Knibbe, *Agriculture in the Netherlands*, pp. 282–5, Bjørn *et al, Del danske landbrugs historie*, p. 262, and Johansen, *Dansk historisk statistik*, pp. 147–9.

1914 the difference in annual yield per cow was small. Danish dairy farmers had increased their annual production, mainly through added winter production, associated with stall-feeding.

To further convince dairy farmers of the advantages of winter production, the seasonal variation in product prices was brought in as a strong argument, consistent with Jensen. The product in question was light-salted butter that fetched the highest price but would not keep for very long in the absence of cold storage. Information first came to the dairy farmers from merchants who traded on the British market, for example via the butter exhibitions mentioned earlier. The textbooks then diffused this knowledge about winter prices more widely; for example, Buus[50] sets the winter premium as high as 30 per cent in the early 1870s, slightly higher than the premia apparent in figure 8. What is striking in the Danish case, therefore, is the way in which technical information was sold to farmers on the basis of hard-headed commercial considerations.

The ways in which this scientific and commercial knowledge was diffused to dairy farmers cannot be fully documented. We can observe formal channels of information: journals and books, the teachings of agricultural schools and, most importantly, the Danish agricultural extension service. It is difficult to quantify the effectiveness of these channels in Denmark compared with in other countries. The number of agricultural advisers in cattle and dairy farming was not particularly impressive: 37 advisers in cattle farming and 8 in dairy science was the maximum during this period, attained in 1905. However, Denmark was fortunate in that three factors facilitated communication: a high rate of literacy, a homogenous population, and a small geographical area. In this context, one person would have a wide audience.

The various agricultural associations that flourished from the 1860s were probably most influential in the diffusion of knowledge. Among the associations, the cooperative creameries were crucial.[51] Not only did they impart knowledge by inviting agricultural advisers to give lectures, and sometimes by handing out leaflets to the members; most of them forced specific feeding practices on their members. The statutes of the cooperative creameries invariably made provision for winter production by stall-feeding. To take one example, the Dybdal cooperative on the island of Bornholm simply bought the prescribed amount of rapeseed cakes and sold it on to the members. The price was deducted from the members' payment for their milk supply. Another, more typical, model was found in Sæby, Northern Jutland. The acquisition of feedstuffs was left to the individual farmer, but he had to present the invoice for rapeseed cakes at the request of the cooperative board. Failing to do so was penalized. Just like individual farmers, or even more so, the cooperative had a strong incentive to utilize

[50] Buus, *Malkekøernes behandling*, p. 56.
[51] In 1903 the cooperatives processed the milk from 81 per cent of all Danish milch cows.

its capital equipment and its skilled staff at an optimum scale throughout the year.

The creamery statutes on feeding only applied to cows that were actually giving milk in the winter months. This extra feed would have been wasted on dry cows. Consequently, there must have been an inducement for dairy farmers to start production in, for example, November, in the first place. It is highly likely that the explanation was the easier access to economies of scale in marketing, including the winter premium, offered by the cooperatives.[52] Being in a cooperative offered dairy farmers a safer return on their investment. Small and medium-sized farmers were dependent on a guaranteed outlet for their milk in the winter before they ventured into winter stall-feeding. Big farmers were big enough to have a personal reputation with the grocer, and therefore could reap the potential winter premium anyhow. (The evidence we have on the early encouragement of winter production by butter grocers tells us that big farmers were their main initial target group.) There are no written records on the fate of individual private creameries in Denmark (since they were not associations and were therefore not faced with the obligation to hold meetings and to write minutes), and so it is difficult to quantify the extent to which cooperatives were more successful than private creameries at stimulating winter production. However, a jubilee publication by a cooperative on the island of Funen tells us of the private precursers to cooperatives in that region that 'in summer the quantity of milk could be satisfactory but in the winter it would decline to a minimum'.[53] The records of another small private creamery in Eastern Jutland tell us of a summer production that was more than five times the winter production in the late 1870s.[54]

We end this section with some econometric evidence regarding the determinants of reduced seasonality in Danish dairying. Equations (1) and (2) in table 5 make use of the survey data on Danish cooperatives alluded to earlier; they regress the yield per cow on the seasonality of milk production in both 1898 and 1908.[55] Consistent with our argument, there is a very strong relationship between these two variables in 1898 (that is, yields were higher where seasonality was lower), with variations in seasonality across cooperatives accounting for a third of the variation in milk yields in the sample. The elasticity of milk yields with respect to seasonality is smaller in 1908, and the equation only explains about 14 per cent of the variation in milk yields. This is presumably because there was less variation in seasonality across creameries: equation (3) shows that declines in seasonality

[52] See Rashid, 'Quality in contestable markets'. The quality problem can be overcome when small sellers collude.

[53] *Bregninge Andelsmejeri*, p. 2. Presumably private creameries might have made contractual provisions for winter production. Since, however, for other reasons, the number of cooperatives grew remarkably fast in Denmark they took upon themselves the task of promoting winter production among small and medium sized dairy farmers.

[54] Rykind-Eriksen and Reindahl, *Andelsmejerier*, p. 13.

[55] All variables in the regressions reported in tab. 5 are entered in log format.

Table 5. *Yields and seasonality, 1898–1908*

	(1)	*(2)*	*(3)*	*(4)*	*(5)*
Dependent variable	Yield in 1898	Yield in 1908	Decline in seasonality		
Seasonality in 1898	−0.287***		0.628***	0.627***	0.599***
	[6.37]		[6.20]	[6.41]	[4.63]
Seasonality in 1908		−0.163***			
		[3.04]			
Newspapers per capita				0.116*	0.180**
				[1.77]	[2.57]
Savings banks per 100,000 population					0.175
					[1.43]
Male wage					−0.283
					[0.39]
Female wage					1.175*
					[1.71]
Constant	7.959***	8.298***	1.328***	1.564***	−3.172
	[103.98]	[77.95]	[8.28]	[8.27]	[0.68]
Observations	64	63	64	64	64
R-squared	0.33	0.14	0.47	0.5	0.51

Note: Robust t statistics in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Dummy variables accounting for method of data collection included; coefficients not reported. Yield in pund per cow per year (2 pund = 1 kilogram); seasonality of production measured by coefficient of variation. All variables are measured in natural logarithms
Sources: see text

between 1898 and 1908 were higher in creameries where the seasonality had initially been higher: i.e. there was a convergence across creameries during this period.[56]

Lastly, equations (4) and (5) in table 5 try to test what other factors may have been correlated with declining seasonality, by entering several county-level variables which measure the spread of literacy (as measured by average newspaper circulation per capita),[57] the development of capital markets (as measured by the number of savings banks per 100,000 population),[58] and wage costs.[59] Consistent with our discussion above, neither wage costs nor savings banks show up as significant determinants of declining seasonality; by contrast, newspaper circulation was positively and statistically significantly associated with declining seasonality, confirming the role of literacy and of the print media in rapidly circulating new, low-tech technologies to Danish farmers.

[56] The regressions in equations (3)–(5) include three dummy variables to account for any impact of different reporting methods among creameries (i.e. creameries could report data for either 12 or 13 periods, in both years). The coefficients are not reported in the table. We also experimented by including numbers of pupils in country high schools and agricultural schools, but these variables were not statistically significant.

[57] Thomsen, *Dagbladskonkurrencen 1870–1970*, pp. 897–917, *Statistiske Undersøgelser* nr.10, p. 43.

[58] *Statistiske Meddelelser: De danske Sparekasser 1898*, p. 73 and 1908, p. 81.

[59] *Statistiske Meddelelser: Tyende- og Daglejerlønnen i Landbruget 1899*, p. 8.

V

Moving to winter dairying allowed Danish farmers not only to reduce the seasonality of their supply, but to increase overall output, by making maximum use of their fixed capital. What have we learned about the reasons for Denmark's success?

Seasonal price data show that the incentives to shift into winter dairying were particularly high in the 1880s and 1890s, which is precisely when the Danish shift took place. Furthermore, several factors served to lower the winter premium from the mid-1890s; not just refrigeration, the factor stressed by Goodwin, Grennes, and Craig, but also the emergence of southern-hemisphere exports, and the Danish shift to winter dairying itself: in the case of the latter factor, the Danes benefited from a first-mover advantage, in that once they had entered the winter market, it was less attractive for others to follow suit.

Jensen is probably right therefore to stress the price incentives faced by Danish farmers; indeed, as we have seen, those price incentives were stressed by Danish agricultural reformers. However, these incentives cannot on their own explain the Danish shift, since our price data show that farmers elsewhere faced winter premia that were every bit as high as the Danish premia. Prices may have created a demand for innovation, but the supply of innovation varied across countries. The crucial factor in Denmark was the generation of empirical knowledge by a combination of the private and public sectors systematically analysing the empirical evidence; the rapid diffusion of this knowledge in a highly educated society via lectures, exhibitions, and written materials, as well as by institutions such as the new cooperative sector; and a willingness to absorb this knowledge by profit-maximizing farmers.

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APPENDIX A

The distribution of milk production by 13 four-week periods or by month (%) 1898

Creamery	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Baaring	6.9	7.3	7.7	7.3	8.5	8.7	9.6	10.4	9.6	8.4	8.1	7.5	
Engholm	6.4	6.6	6.8	7	7.4	8	9.8	9.8	9.1	8.6	7.9	6.5	6.1
Guldbjerg	6.1	6.6	7.5	7.8	8	8.2	8.5	9.6	8.8	7.8	7.5	6.8	6.8
Holmstrup	6.8	7.1	7.7	7.2	8.2	8.2	9.7	10.3	9.7	9.2	8.1	7.8	
Jægersminde	5.4	5.7	6.1	6.3	6.5	7.1	8	10.7	10.5	9.6	8.9	8	7.2
Kappendrup	6.1	7.1	7.7	8.3	8.6	8.9	9	9.4	9.2	7.4	6.5	6	5.7
N. Lyndelse	6.2	6.2	6.3	6.8	7.1	7.3	7.8	9.3	9.8	9.3	8.9	8	7
Skovgaarde	6.2	6.9	7.3	6.8	7.9	8.4	10.6	11.2	10.4	9.3	8	7	
Skydebjerg	6.3	7	7.1	7.3	8	8.4	10.4	10	8.7	7.7	6.9	6	6.2
Tallerup	5.7	5.7	6	6.6	6.5	6.9	8	10	10.1	9.8	9.3	8.4	7
Tarup	6.3	6.7	7.2	7.6	8	8.3	8.5	9.6	8.9	7.9	7.5	6.9	6.6
Ubberud	6.4	6.8	7	6.5	8	8.3	10.1	11.1	10.3	9.6	8.6	7.3	
Baarse	6.5	6.9	7.2	6.8	8.2	8.5	10.3	10.8	9.9	9.7	8.2	7	
Stensved	5.1	5.5	6.2	7	7.8	8.6	9.1	10.9	9.9	9.4	8.6	6.8	5.1
Sydstevns	7.4	7.9	8.3	7.8	8.6	8.6	9.2	9.1	8.7	8.7	7.9	7.8	
Brørup	6.3	6.6	6.9	6.9	6.9	6.9	7.2	9.7	9.8	8.9	8.1	7.3	8.5
Helgenæs	7.2	8.4	6.9	7.4	8.1	8.4	8.4	10.4	9.3	7.9	6.4	5.5	5.7
Aarrehus	6.9	7.2	7.3	7.2	7.1	6.5	9.4	9.9	9.1	8.3	7.3	6.5	7.3
Andst	5.6	5.9	6.2	6.3	6.4	6.9	9.4	10.9	10	9.3	8.4	7.6	7.1
Birkehøj	5.8	6.5	7.7	9.8	10.2	8.3	8.9	10.9	9.5	9.8	7.5	5.1	
Hunderup	7.4	7.1	7.1	6.2	6.7	6.8	8.8	10.3	11.6	10.5	9.2	8.3	
Kjærbybro	6	10	6.3	7	6.9	7	7.2	11.6	12	8.2	6.3	4	7.5
Bækmarksbro	6.4	7.5	6.6	6.6	6.8	6.8	7.8	10.3	10.3	9.3	7.2	6	8.4
Phønix	7.1	9.4	7.7	7.6	9.2	8.6	7.2	12.9	9.5	7.4	7.3	6.1	
Bjørnskilde	6.5	6.6	6.5	6.3	8.4	8.9	10.4	10.7	10.6	10.1	8.1	6.9	
Boslunde	6.5	8.7	7.4	7.4	8	10.2	9.1	9.5	10.4	8.1	6.9	7.8	
Harrested	6.6	6.4	6.7	7	9.7	8.6	12.2	8.7	9.9	10.5	7	6.7	
Kobberdal	6.6	7.1	7.4	7	7.9	8.2	9.7	10.2	9.7	9.8	8.7	7.7	
Lundshøj	6.4	7.3	8.3	7.9	9.2	9.3	10.6	10.5	9.2	8.4	6.6	6.3	
Vemmelev	5.3	6.2	6.7	7	7.4	8	8.3	9.8	9.5	8.9	8.6	7.1	7.2
Aunslev	5.5	6.1	6.4	6.7	7.3	7.8	8	9.7	9.6	9.2	8.6	7.4	7.7
Heden Vantínge	5.4	5.9	6.2	6.4	6.7	7.2	7.9	9.8	9.6	9.4	9.6	8.5	7.4
Jordløse	6.8	6.5	6.7	7	7.1	8.4	9	8	9.1	8.6	8.1	7.9	6.8
Rosvang	6.1	6.6	7.3	7.7	8	8.5	8.8	9.7	9	8	7.5	6.7	6.1
Aastrup	6.3	7.3	8.5	7.8	9	8.9	9	9.1	8.2	7.3	6.5	6.2	5.9
Barrit	4.9	5.2	6	6.3	6.6	7.3	8.2	11.4	12	10.3	9	7.3	5.5
Brovad	5.6	5.3	5.2	5.6	5.8	6.2	6.5	9.5	11.2	11.1	10.4	9.5	8.1
Drenderup	4.8	5.8	6.3	6.3	6.1	6.9	8.5	11.1	10.5	9.3	8.7	7.6	8.1
Egtved	4.4	4.3	4.4	4.3	4.3	9.1	10.9	12.6	12.6	10.1	9.3	7.5	6.2
Hatting	5.3	6	6.6	7.1	7.5	7.8	8.2	10.6	10.7	9.3	8.1	6.7	6.1
Højrup	6.9	7.6	8	7.2	8.2	8.1	10.3	10.3	9.5	8.6	7.6	7.7	
Sdr.Stenderup	6.3	7.3	7.9	7.1	8	8.1	10.5	11	10.2	9.3	7.6	6.7	
Smidstrup	5.5	6	6.5	6.9	5.5	7.6	8.5	11.1	10.9	9.5	8.4	7.1	6.5
Stenderup	6.7	4.6	5.9	6.1	6.9	7.7	8.1	11.4	11.5	9.9	8.4	7	5.8
Vestrup-Hjejls	5.7	6	6.3	6.6	6.8	7	8.2	10.9	10.4	9.2	8.3	7.5	7.1
Viuf	5.1	5.6	5.8	6.1	6.4	7.2	8.6	10.6	11	9.8	9.1	7.7	7
Ødsted	4.8	5	5.5	5.9	5.9	6.2	7.3	9.9	11.1	10.5	10	8.7	9.2
Ølstedbro	3.9	4.5	5.1	5.9	6.7	7.6	8.5	12	12.8	11	9.5	7.4	5.1
Aadal	5.7	6.7	7.4	7.2	8.7	8.7	9.3	11	9.4	9.2	11.6	5.2	
Vattrup	5.9	6.8	7.2	7.7	7.8	7.8	8.7	10.1	10.3	8.7	7.4	6.1	5.5
Økilde	7.4	8.3	8	7.5	6.3	8.3	9.4	11.1	10.3	9.1	7.4	6.9	

APPENDIX A *Continued*

Creamery	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Alhøj	6.5	6.8	6.8	7	7.5	7.5	8.8	11.1	10	9	10	9.1	
Egedal	5	5.3	5.9	6.4	6.6	7.6	8.3	11.1	11.2	10.3	9.1	7.3	5.9
Kildevang	6.9	9.2	7.8	8	8.2	10.5	8.4	9.1	9.9	8.7	6.5	6.8	
Lystrup	5.7	6.2	8.3	6.5	6.7	9	9.2	10.9	12.2	8.7	7.7	8.3	
Nonnebjerg	5.6	6	6.7	7.1	7.4	7.8	9.6	11.2	11.1	9.8	9	8.7	
Skovly	5.8	6.3	7	6.9	8.7	9	10.9	11.8	10.5	9.2	7.4	6.5	
Søkilde	4.9	5.7	6.5	6.6	8.2	8.7	10.6	12.9	11.9	10.2	8.1	5.7	
Søvind	4.9	5.6	6	6.7	7	7.9	8.3	10.7	10.5	9.7	9	7.5	6.2
Tranbjerg	6.6	6.7	6.7	7.2	7.6	7.7	8.4	10.1	9.1	8.2	7.7	7.1	6.9
Tørring	6	6.8	7.5	7.1	8.3	8.2	9.9	11.8	10.9	9.4	7.3	6.8	
Viruplund	7.5	8.1	7.6	7.2	8.5	8.7	9.8	10.4	9.4	8.4	7.3	7.1	
Aale	5.8	6.3	6.9	7.2	7.5	7.8	8	9.8	9.6	8.7	7.9	6.9	7.6
Aastruplund	5.4	5.7	6.2	6.7	7.2	7.2	8.1	9.8	10.9	10	9.1	7.5	6.2

1908

Creamery	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Baaring	7	7	7	8	8	8	8	9	9	8	8	6	7
Engholm	7	7	7	7	7	8	9	9	9	8	8	7	7
Guldbjerg	7	7	7	8	8	9	8	9	8	7	7	8	7
Holmstrup	7	7	7	8	8	8	8	9	9	8	7	7	7
Jægersminde	6	6	7	7	8	8	9	10	10	9	8	6	6
Kappendrup	7	8	9	9	9	9	9	8	7	7	6	6	6
Nr. Lyndelse	7	7	7	7	8	9	9	9	8	8	7	7	7
Skovgaarde	6	7	8	8	9	9	10	10	9	9	8	7	
Skydebjerg	6	7	7	8	8	8	9	9	9	8	8	7	6
Tallerup	6	7	7	7	8	8	8	10	9	9	8	7	6
Tarup	7	8	8	8	8	9	10	10	9	8	8	7	
Ubberud	6	6	6	7	8	9	10	10	10	8	7	7	6
Baarse	6	6	6	7	8	8	9	10	10	9	8	7	6
Stensved	7	7	7	7	8	8	9	9	9	8	8	7	6
Sydstevns	7	8	9	7	7	10	8	9	10	8	7	10	
Brørup	6	7	7	7	7	8	8	10	10	8	8	7	7
Helgenæs	8	8	8	8	7	8	10	12	10	8	6	7	
Aarrehus	7	7	7	7	7	7	7	8	10	9	8	8	8
Andst	7	7	7	8	9	9	10	11	10	9	7	6	
Birkehøj	7	7	7	8	8	8	9	9	10	8	7	6	6
Hunderup	6	6	6	7	7	7	8	9	11	10	8	8	8
Kjærbybro	7	7	8	9	9	9	8	9	9	8	6	5	6
Bækmarksbro	7	7	8	8	7	8	8	11	9	8	7	6	6
Phønix	8	8	8	7	8	8	11	11	10	8	6	7	
Bjørnskilde	7	8	6	7	8	8	8	9	9	8	8	7	7
Boeslunde	8	8	8	8	9	9	10	10	8	7	7	8	
Harrested	5	6	6	7	8	9	9	10	10	9	8	7	6
Kobberdal	8	7	6	9	9	11	11	8	8	7	7	9	
Lundshøj	7	8	8	8	9	10	10	9	9	8	7	7	
Vemmelev	6	7	8	8	8	8	9	9	9	8	7	6	7
Aunslev	6	6	6	7	7	9	10	10	9	8	8	7	7
Heden Vantínge	7	7	7	8	8	8	8	10	9	8	7	6	7
Jordløse	6	7	7	7	8	8	10	8	9	9	8	6	7
Rosvang	7	8	8	8	8	8	9	9	8	8	7	6	6
Aastrup	7	7	8	8	8	8	9	11	10	9	7	8	
Barrit	6	7	7	7	8	8	9	10	10	8	8	6	6
Brovad	6	6	6	6	7	7	8	9	10	10	9	8	8
Drenderup	6	7	7	7	8	8	8	10	9	8	8	7	7

APPENDIX A *Continued*

Creamery	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Egtved	6	7	7	8	8	8	9	10	9	8	7	7	6
Hatting	6	7	7	7	8	8	9	9	9	8	8	6	8
Højrup	7	7	7	8	8	8	8	9	9	8	7	7	7
Sdr.Stenderup	6	7	7	7	8	9	10	10	9	9	6	6	6
Smidstrup	6	7	7	7	8	9	9	10	9	8	8	6	6
Stenderup	7	7	7	8	8	9	9	9	8	8	6	7	7
Vestrup-Hjejls	7	7	7	8	8	9	10	9	8	8	7	6	6
Viuf	6	7	7	7	7	8	9	10	9	8	8	7	7
Ødsted	6	6	7	8	8	9	9	10	10	9	9	9	
Ølstedbro	5	6	7	7	8	9	9	11	10	8	6	6	6
Aadal	7	8	9	8	9	9	10	10	9	7	7	7	
Vattrup	7	7	7	7	8	9	9	10	9	8	7	6	6
Økilde	6	7	7	7	7	7	8	10	10	8	7	7	9
Alhøj	8	8	9	9	9	9	10	10	8	7	6	7	
Egedal	6	7	7	8	8	9	10	10	9	8	6	6	6
Kildevang	8	8	9	9	9	9	9	9	8	8	8	6	
Lystrup	7	8	8	8	7	9	9	10	11	9	8	6	
Nonnebjerg	7	7	7	7	8	8	9	10	9	8	7	6	7
Skovly	7	8	7	7	9	9	10	10	9	8	7	9	
Søkilde	5	6	6	7	7	8	8	10	10	9	9	8	7
Søvind	6	7	7	8	8	9	9	9	9	8	7	7	6
Tranbjerg	8	8	9	9	9	9	9	9	8	8	8	6	
Tørring	7	7	7	7	8	9	10	10	10	9	8	8	
Viruplund	8	7	8	8	8	8	8	9	8	7	7	7	7
Aale	7	7	7	7	8	8	8	9	9	8	8	7	7
Aastruplund	6	6	6	7	7	8	8	9	10	10	9	7	7

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