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Abstract

The relative success of the Danish and failure of the Irish dairy industries before the First World War is often contrasted given their competition for the lucrative British butter market. The traditional narrative implicitly assumes that Ireland failed because it was unsuccessful at adopting the cooperative institution, and that Irish cooperatives were not as efficient as their Danish counterparts, despite having been explicitly modelled on them. This assumption is, however, untested at the 'firm' level. We seek to rectify this through the analysis of a large microlevel database of creameries in both countries over the period 1898-1903. Using Stochastic Frontier Analysis (SFA), a standard methodology in modern productivity studies, we find no evidence for significant productivity differences on average, although there was a much larger variance in Ireland. This nuances the idea that the Irish were unable to cooperate successfully, although some creameries were certainly productivity laggards.

JEL Codes: N13, N53

Keywords: Dairying, Denmark, Ireland, microdata, productivity

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1 Introduction

The success of Danish agriculture before the First World War owed much to a rapid spread of butter factories and the capture of a sizable share of the important British market (Lampe and Sharp, 2013, 2015, 2019). This is often contrasted with the case of Ireland which, at that point part of the UK, with greater access to coal (Henriques and Sharp, 2016)[1] and as a country with a long tradition of butter production and export, seemed well-placed to enjoy a similar trajectory. Indeed, Irish and British campaigners, notably the Irish Agricultural Organisation Society (IAOS) explicitly aimed to copy the Danish model, which relied on peasant cooperatives and a new technology, the steam-powered automatic cream separator. The result was comparative failure, however, and a number of reasons have been suggested for this. But were the Irish cooperative creameries per se the problem, that is, were they less efficiently managed, and in general less productive than their Danish counterparts? The present work seeks to shed light on this through a large, novel database on microdata for the two countries. We employ Stochastic Frontier Analysis (SFA), a standard tool for the analysis of firm-level efficiency, and find that the Irish creameries were not on average less productive than those in Denmark, although they did suffer from greater variance between them. This has the important implication that it was not the organisation, or the technology employed by the Irish cooperatives, which explains their relative failure, but rather the failure of certain outliers.

We contribute to at least two growing trends within business history. First, regarding the importance of international comparisons. Both have been heavily debated in conferences, workshops and academic writings in recent years, although already in 1976, Chandler wrote that international comparisons are "one of the most promising areas for long-term continuing research in business history. Only by comparing developments of business activities, practices, and institutions in different nations operating under different sets of economic and political constraints and within cultures having different attitudes and values can we understand what in modern business organization results from imperatives of the economic and technological processes and what reflects particular national economic, political, and ideological realities" (Chandler 1976). This was addressed more recently in a special issue of *Business History* in 2012, where it was forcefully argued that comparative studies are particularly important for the study of cooperatives, since they have "cultural, social, political and sometimes religious dimensions which are inseparable from their business identities and practices, but impose a broader contextual reading of their economic activities. …paying due heed to the surrounding climate of conventions and expectation may be regarded as best practice, which 'mainstream' business history does well to emulate" (Webster and Walton 2012).

Second, we contribute to the debate about the quantification of business history, and the move away from case studies of big business with inevitable survival bias, although this is of course nothing new (see e.g., Redlich 1962, Hidy 1972, Jones and Friedman 2011, Decker et al. 2015, de Jong et al. 2015, Jones 2017, Kipping et al. 2017, Toms and Wilson 2017, Wilson et al. 2017). Two special issues of *Enterprise & Society* have been devoted to this very debate, including contributions from Raff (2013) arguing for the importance of "information about a genuine

[1] However, this is contested. Bielenberg (2009) argues that Ireland suffered from a lack of access to coal and that only Belfast was able to take advantage of lower shipping costs.

cross-section of the population", but that "this is rarely obtained in business history." Moreover, Raff (2020) and Scranton (2020) argued for the importance of understanding how decisions are made, which includes understanding the failures, something which might only be covered through largescale comparative studies such as ours. As Jones and Friedman (2011) have argued, "Rigorous analysis of large datasets has been shown to transform our understanding of generalisations based on qualitative research".

Thus, Henriques et al. (2021) present some of the data used in the present work, but also provide a survey of the debate regarding a "new business history" and some arguments for the relevance of large datasets for the field allowing for the exploration of industries and small firms which might otherwise be ignored. Similarly, Balleisen (2020) called for greater collaborative research in business history particularly in the case of comparative history and the use of data science techniques. Somewhat relating to our work, there have been recent developments in the comparative study of cooperative enterprise, for example Boone and Özcan (2014) who asked why cooperatives emerged when corporations exist, and employed a detailed panel dataset for the county-level founding process of cooperatives in the U.S. ethanol industry from 1978 to 2013, finding that the founding rate of cooperatives decreases in the presence of high, local, corporate ethanol production capacity. Likewise, Irish cooperative creameries faced stiff competition from local proprietary concerns, in contrast to their Danish counterparts. Other examples are Higgins and Mordhorst (2015), who compared British and Danish organisational structures in bacon to analyse why Danish producers enjoyed long-lasting advantages on the British market and Medina-Albaladejo and Menzani (2016), who compared cooperative wineries in Italy and Spain to understand what drove the higher concentration in Italy.

Beyond the realm of business history, and in addition to the economic history we discuss below, we contribute to a literature within regional science on the importance of location for firm performance, see for example the overview presented by Stephan (2011) where it is well-established through the use of microdata that location is a "significant factor", not only for the firm itself, but also for other regional measures such as patents and wages.

The roots of the success of the Danish dairy industry go back more than a century before the foundation of the first cooperative creamery in 1882. Enlightened elites from northern Germany bought up large estates in Denmark from the second half of the eighteenth century and, after introducing new agricultural techniques, including a centralized dairy facility, participated in and in part initiated a radical programme of reform (Lampe and Sharp, 2019; Boberg-Fazlic et al., 2020a), including the abolition of serfdom (Sandholt Jensen et al., 2018) and a more general agrarian reform which established the medium-sized peasant farmers who would go on to found the cooperatives (Boberg-Fazlic et al., 2020b). Over the course of the nineteenth century, educational establishments and extension services teaching best practice including sophisticated accounting techniques were founded (Lampe and Sharp, 2017, 2019), as dairying expanded behind protectionist tariff barriers (Henriksen et al., 2012b). When the centrifugal separator was invented in the 1870s, Danish peasant farmers were well-placed to embrace this technology in order to centralize production similarly to how larger producers had done this for a century. Lampe and Sharp (2019) conclude that Danish success owed more to the long run improvements in agriculture rather than the cooperatives as such, and suggest that this might be the reason that attempts to mimic the Danish model through an explicit focus on the creation of cooperatives, as was tried in Ireland, failed to lead to the success that

was hoped for. Nevertheless, there were certain institutional barriers to forming cooperatives in Ireland, such as conflict (O'Rourke, 2006, 2007),[2] difficulties in enforcing vertically binding contracts between the milk suppliers and the cooperative (Henriksen et al., 2012a, 2015), and, as noted above, a far more competitive (and hostile) proprietary sector in Ireland (McLaughlin and Sharp, 2021). All of these issues could suggest that Irish dairying failed due to inferior and less productive cooperatives, but it may also have been the case that too few were founded, or that Ireland's relative decline might simply have resulted from farmers making a rational choice to sell goods other than butter.

The present work seeks to exclude the trivial explanation that the Irish cooperative creameries were innately inferior. In the following section we provide a brief historical overview of Irish dairying over the relevant period. In Section 3 we present our data and empirical specification, and in Section 4 we give the results of our analysis. Section 5 concludes.

2 An historical overview of Irish dairying

Inspired by the Danish example, the Irish Agricultural Organisation Society (IAOS) was established in 1894 by Horace Plunkett to promote the formation of rural cooperatives, although Irish dairy farmers seem to have been reluctant cooperators who for the most part only established cooperatives when there was no other satisfactory alternative and were not keen on actively participating in cooperative governance once established. Thus, while Denmark had over 500 cooperative creameries by 1888, Ireland had under a hundred, although twice as many proprietary concerns, on a per capita basis the Danes had 10.6 times as many creameries as Ireland. However, by the First World War Ireland had caught up to a certain extent, with 458 cooperatives and 251 proprietary creameries in 1920, compared to over 1000 cooperatives (and very few private creameries) in Denmark (Breathnach, 2012); on a per capita basis the Irish had narrowed the gap to half that of Denmark.

This implies that the IAOS had some success, but there were major differences in the way cooperatives were established in both countries. The cooperatives in Denmark arose as a spontaneous, bottom-up affair which required little support from outside agencies, contrasting with a lack of spontaneity in the Irish case, indicated by the fact that around one fifth of the cooperative creameries established up to 1920 were conversions of pre-existing private operators. This proportion was much higher in the south – 33.2% compared to just 7% in the north, which was outside the traditional heartland of Irish dairying and where consequently there were fewer creameries to be converted. The spatial pattern of the private and cooperative creamery sectors provides further evidence that, to a large extent, cooperatives were established where there were no alternatives to private creameries. Private investors were attracted to locations where a plentiful supply of milk offered prospects of high profitability. Milk availability was the key determinant of the location of private creameries, but seems to have had only a minor influence on the location of cooperatives (Breathnach, 2006).

Over time, farmers developed a more positive attitude towards forming, or becoming members of, cooperatives (Doyle, 2019). According to Breathnach (2012), this was because

[2] Although here a counter argument is that the organisational structure established in distributional conflicts may have facilitated the development of cooperatives (McLaughlin, 2015).

they were considered to be better run than their private counterparts, and more prepared for periods of economic downturn. Cooperatives rarely changed hands in the period up to 1920, and were more successful at curbing rogue behaviour (e.g. hygiene and milk adulteration) among suppliers, and paid better prices for milk. Moreover, they were not driven solely by profit and thus could provide a credit system where the payment was extracted over time from a monthly milk cheque. A particular issue in Ireland, however, seems to have been that neighbouring cooperatives were more likely to be bitter rivals competing for suppliers in overlapping territories rather than working together. In addition, the IAOS was under constant financial pressure which limited the level of service that it could provide. This was reflected by the small subscriptions that the cooperatives paid to the organisation.

The worldview of the Irish farmers was profoundly shaped by the socio-economic structures and systems in which they operated. Key to the success of the Danish creamery cooperatives was the restructuring of the Danish landholding system. In the late nineteenth century, most Danish farmers were free of debt and had gained more than a hundred years of experience in developing the productive capacity of their farms. A result of the centralised nature of Danish land reform was the absence of major inequalities in the size of the farms created, which were larger on average than the Irish. This produced a strong sense of common identity, while in Ireland there were deep social divisions created by inequality in farm size. The high level of education of the Danish farmers and a wide range of community-based organisations, such as farmers' associations, credit unions, parish councils and socio-cultural activities also contributed to their success. In Ireland, most farms were still held in tenancies in the late nineteenth century, while the tradition of inheriting farms on the death of the incumbent, coupled with the linking of marriage to inheritance, inhibited innovation in the farming community. The occupiers of holdings generally had little education and few resources, and frequently were indebted to local shopkeepers and moneylenders. In addition, farmers incurred substantial debts with state funded mortgages, over 68 years, that commenced at scale with the 1903 Wyndham Land Act (Foley-Fisher and McLaughlin, 2016).

Jenkins (2004) examined the activities of two groups involved in the establishment of creameries: private capitalists (mainly from the former butter trade or butter retailers based in Britain) and agricultural reformers, organisers and supporters of the Irish Agricultural Organisation Society. He argues that cooperatives worked not purely because of economics but because of culture. The creameries, with their centrifugal separators, had a big impact on the rural economy and social life in Ireland. The adoption of the creamery system was a cultural novelty undertaken by private capital and cooperative interests. He differentiates between "foreign" capitalists with a "free hand" and concerns that strove for "Irish" self-help and cooperation. The creameries became accepted due to micro political conditions but resulted in discussions around issues of cultural identity, economic power, the welfare of rural communities, and wider colonial relationships. The attitudes towards creameries and their legitimacy as "Irish" and "local" businesses were contested, but finally resolved when the Irish Free State chose cooperation as a way to deliver on the new independent government's stated goal of democratic empowerment of farmers. This is something, however, which Moulton (2017) argues the cooperatives were never designed to do, having been founded by local elites: landlords, politicians and Catholic clergymen. Indeed, following independence, some of the Anglo-Irish landlords who had been involved in the cooperative movement left Ireland, including Plunkett himself, who moved to England and devoted himself to the cause of cooperative agriculture around the world.

3 Data and empirical specification

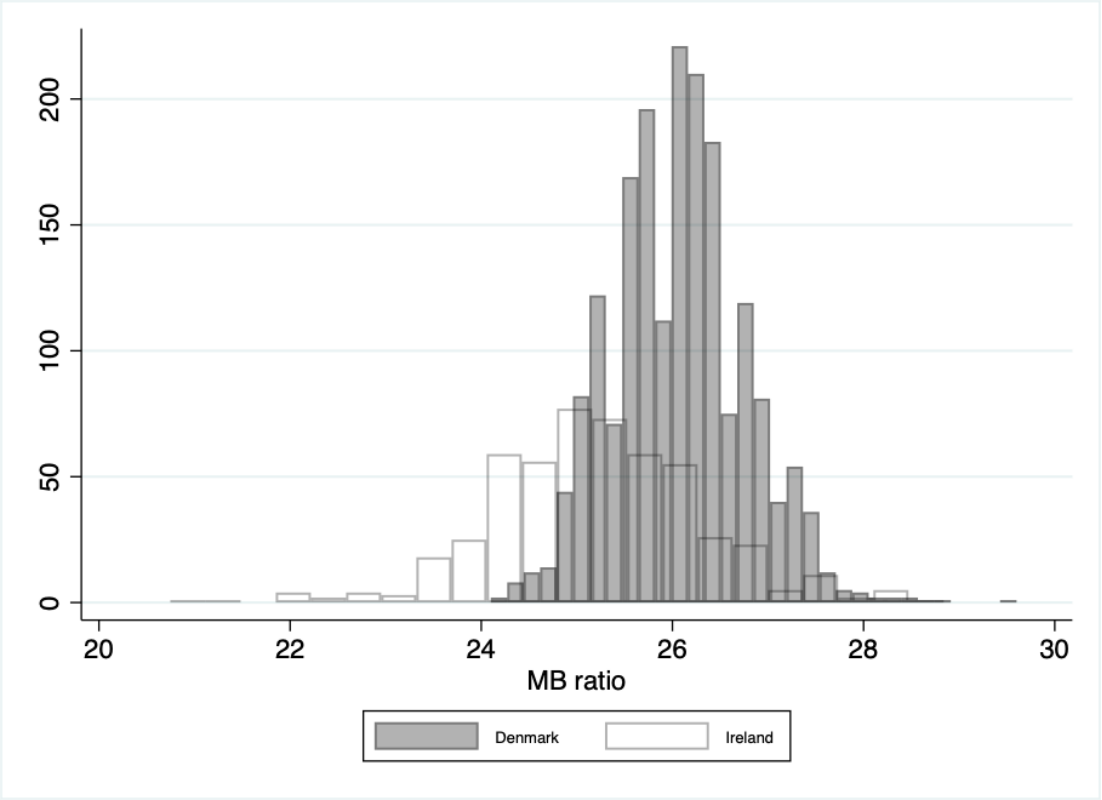
We combine two novel datasets of Danish and Irish cooperative creameries from 1898 to 1903. For Denmark, our data is taken from those collected by the Committee for Creamery Statistics and published as *Dansk Mejeri-Drifts-Statistik* (MDS, 'Operational Statistics for Danish Creameries'). Apart from basic characteristics such as location, year of establishment, number of shareholders etc, the reports also include information on inputs and outputs as well as the technologies employed in the production of (mainly) butter (Henriques et al., 2020). The MDS data are combined with data taken from the Annual Reports of the Irish Agricultural Organisation Society (IAOS) that have similar detailed information on Irish cooperative creameries (McLaughlin et al 2021). The result is an unbalanced panel of 2,391 observations for 712 cooperative creameries: 541 in Denmark and 171 in Ireland, covering the years 1898 to 1903.[3] Table 1 reports some summary statistics, and Figure 1 overlays histograms for milk/butter ratios for the Danish and Irish creameries. The milk/butter ratio was the simple measure of productivity used at the time, describing how many kilogrammes of milk it took to produce 1 kg of butter: by definition, the lower the better. It should be noted here that the Irish creameries were on average more productive than their Danish counterparts, although with a little more variance.[4] This turns out to be potentially important for our empirical analysis and thus we explore this a little more below, where we employ the method suggested by Hadri et al (2003), allowing the variance of technical efficiency to depend on observables.

Unfortunately, comparable data was not published by the IAOS between 1904 and 1912, and we decided to exclude the period from 1913. Interference during the First World War meant that cooperative creameries lost their close association with constructive unionism and began to be linked instead with nationalist politics, especially in comparison with British-owned proprietary creameries. Then, during the War of Independence, creameries were targets of reprisal attacks by Crown Forces who saw them, perhaps, as local gathering-places for a population into which Irish Republican Army members seemed to blend seamlessly. According to one report, some forty-two creameries had been damaged by November 1920, a testament to their significance as community gathering-places in the eyes of the British forces (Bolger, 1977).

[3] In the analysis a few creameries are dropped due to lack of data in all years.

[4] One technical issue we had to solve was the conversion from imperial to SI units. This is trivial for most variables. However milk is measured by volume in IAOS and by weight in MDS. This requires a conversion based on the density of milk, which is not entirely constant. We used 1.035 kg/l, as suggested by Jones (2002). The density of milk varies slightly with the fat content and temperature. The range of feasible values is somewhere between 1.027-1.035 kg/l. This is all within a range which does not impact our results in any appreciable way.

Figure 1: Milk/butter ratios for Danish and Irish creameries, 1898-1903



Notes: Sources: (Henriques et al., 2021; McLaughlin et al., 2021).

Table 1: Summary statistics

	Observations	Mean	St.Dev.	Min	P25	Median	P75	Max
Denmark								
Creamery	1881	713.3248	404.5303	2	386	733	1042	1415
Region	1881	10.66348	5.977706	1	5	11	16	21
MB ratio	1881	26.07002	.6885341	24.1	25.6	26	26.5	29.6
Milk	1881	2067072	879340.3	132653.4	1413590	1961401	2599944	6841896
Butter	1881	79448.04	34133.78	5024.75	54555.5	74881	99562	269366
Shareholders	1815	155.9967	73.42173	4	104	142	202	541
Ireland								
Creamery	510	2150.008	148.448	1876	2041	2141	2280	2405
Region	510	35.57843	6.459541	22	31	34	42	46
MB ratio	510	25.20646	1.099182	20.74639	24.48075	25.20687	25.93299	28.83749
Milk	508	1412639	928052.7	42075.81	703186.5	1181473	1970416	7073491
Butter	508	56099.03	37139.87	1763.567	28247.46	46546.74	79275.7	282946.4
Shareholders	509	194.2908	187.7141	7	89	137	226	1472
Total								
Creamery	2391	1019.769	692.7612	2	496	885	1358	2405
Region	2391	15.97783	11.88286	1	6	12	21	46
MB ratio	2391	25.88582	.8691457	20.74639	25.4	25.9	26.4	29.6
Milk	2389	1927913	929162.7	42075.81	1248117	1831400	2498041	7073491
Butter	2389	74483.07	36075.34	1763.567	47837.5	70735.46	96113	282946.4
Shareholders	2324	164.3838	110.3002	4	100	141.5	205	1472
N	2391							

The methodology we employ is Stochastic Frontier Analysis (SFA), which has already been used in the Danish context, although for earlier years and other data, by Henriksen et al. (2011), and Lampe and Sharp (2015). The important contribution of these models is the separation of the error term into a standard stochastic error and an inefficiency term (Kumbhakar and Lovell, 2000). Every producer may attempt to optimize, but not all succeed in their efforts. For example, given the same inputs, and the same technology, some will produce more output than others, i.e., some producers will be more efficient than others. The SFA allows for the fact that deviations of observed choices from optimal ones are due to two factors: 1. failure to optimize i.e., inefficiency and 2. random shocks. The form of the production function, which is the productivity frontier in the model, is given by the relationship between the inputs and the outputs. The inefficiency term shows how far away from the estimated frontier an individual unit is at any point in time. Thus, we can model the output of butter as a function of a vector of input of milk, a trend, and in some cases an indication of the location to account for location specific factors. This provides a baseline model for the production frontier and estimates individual-level inefficiencies for each creamery: in studies on modern data these can then be used to identify who needs intervention and corrective measures can be taken. Here, we can look at average performance to assess whether Danish or Irish cooperatives were most efficient. It is then possible to go one step further and extend the analysis by modelling the inefficiency term. To estimate the individual inefficiencies, we use the model developed by Battese and Coelli (1995), since it allows for the inefficiencies to be explained by specific factors. We can then explain efficiency through whether the cooperative is Danish or Irish, and we also include the number of members (shareholders) of the cooperative as an indicator of size, which is common in related studies.

We start with the following specification to model the production function and the inefficiency term for each country separately:

$$ln(Butter)_{it} = \beta_0 + \beta_1 ln(Milk)_{it} + \beta_2 Trend + \beta_3 Region + v_{it} - u_{it}\,, \qquad (1)$$

where the main input ln ($Milk_{it}$)in the production function is the amount of milk used in kg and $Trend$ captures yearly changes in butter production. This first specification includes regional changes represented by $Region$ that show association-specific differences related to butter production. v_{it} is the noise error term, while u_{it} is the inefficiency term.

$$u_{i,t} = \delta_0 + \delta_1 ln(Shareholders)_{it} + w_{it}\,, \qquad (1')$$

where the inefficiency term includes the number of shareholders, indicating the size of the creamery.

Another approach would be to calculate the frontier for both countries and add a dummy for whether the creamery was located in Denmark (0) or Ireland (1):

$$ln(Butter)_{it} = \beta_0 + \beta_1 ln(Milk)_{it} + \beta_2 Trend + v_{it} - u_{it}. \qquad (2)$$

The inefficiency term can be written as:

$$u_{i,t} = \delta_0 + \delta_1 \, ln(Shareholders)_{it} + \delta_2 Nation_i + w_{it} \,, \qquad (2')$$

where the inefficiency term now again includes the number of shareholders, and the dummy for whether the creamery was located in Denmark or Ireland, which is our main coefficient of interest. If it is insignificant, we can say that there were no efficiency differences between Danish and Irish creameries on average. However, this might implicitly impose a strong restriction on the variance of the inefficiency term, which matters since the model is estimated using maximum likelihood on a truncated normal distribution (Battese & Coelli, 1993). In this case, the parameter might be large, not because of mean differences but because of differential variances across borders. As such this estimate still shows cross-border differences, just not in the expected efficiency of the creameries. One simple way around this is to rely on models separately estimated for each nation. This allows for everything, including variances, to vary across borders, while the production process is similar. It also allows us to roughly compare efficiencies. Another approach is to explicitly model a heteroscedastic error- and inefficiency-term. We demonstrate both in the following section.

4 Results

Table 2 reports the results of our estimations. Column (1a) shows the results based on Equation 1 for 541 Danish cooperative creameries, while Column (1b) reports results for 171 Irish cooperative creameries using again Equation 1. In this first specification, we attempt to explain the inefficiency term by the size of the creameries captured by the number of shareholders. In Column (2) we use specification 2 to explain the inefficiency term by nation.

Table 2: SFA results

	lnButter		
	(1a)	(1b)	(2)
Frontier			
lnMilk	1.004***	0.988***	0.992***
	(0.00160)	(0.00278)	(0.00128)
Trend	0.00626***	0.00577***	0.00609***
	(0.000343)	(0.00101)	(0.000373)
Region	0.000111	-0.000828**	0.00114***
	(0.0000935)	(0.000296)	(0.0000737)
Constant	-3.325***	-3.021***	-3.174***
	(0.0230)	(0.0438)	(0.0189)
Technical Inefficiency			
lnShareholders	0.0483	-0.0314	-0.472
	(0.0878)	(0.0291)	(0.810)
Ireland			0.638
			(1.159)
Constant	-0.847	0.129	-0.105
	(1.163)	(0.0687)	(0.592)
σ_u	0.090	0.038*	0.162
	(0.058)	(0.021)	(0.142)
σ_v	0.020***	0.037***	0.028***
	(0.001)	(0.002)	(0.001)
λ	4.463***	1.032***	5.88***
	(0.057)	(0.022)	(0.142)
γ	0.952	0.516	0.972
Observations	1815	507	2322
Creameries	541	171	712

Standard errors in parentheses. * p<0.05, ** p<0.01, *** p<0.001 The years included are 1898-1903.

We see productivity growth of around 0.6 per cent per year in Denmark and 0.57 per cent in Ireland. The coefficient on ln *milk* implies (approximately) constant returns to scale, although the coefficient is significantly different from 1 in all specifications. The strongly significant λ shows the presence of inefficiency in the process of production, validating the use of the stochastic frontier model.

Table 3: Technical efficiency, by nation

	Count	Mean	St.D.	Min	Median	Max
Denmark						
(1a)	1815	.9872865	.0072925	.9108388	.9893125	.9958048
(1b)	0	.	.	.	.	.
(2)	1815	.989298	.0041299	.9418159	.9902678	.9950754
Ireland						
(1a)	0	.	.	.	.	.
(1b)	507	.9768322	.0111774	.9198009	.9800449	.9925219
(2)	507	.9853623	.0107945	.8984788	.9884598	.9968575
Total						
(1a)	1815	.9872865	.0072925	.9108388	.9893125	.9958048
(1b)	507	.9768322	.0111774	.9198009	.9800449	.9925219
(2)	2322	.9884387	.0064326	.8984788	.9900028	.9968575
N	2322					

The years included are 1898-1903.

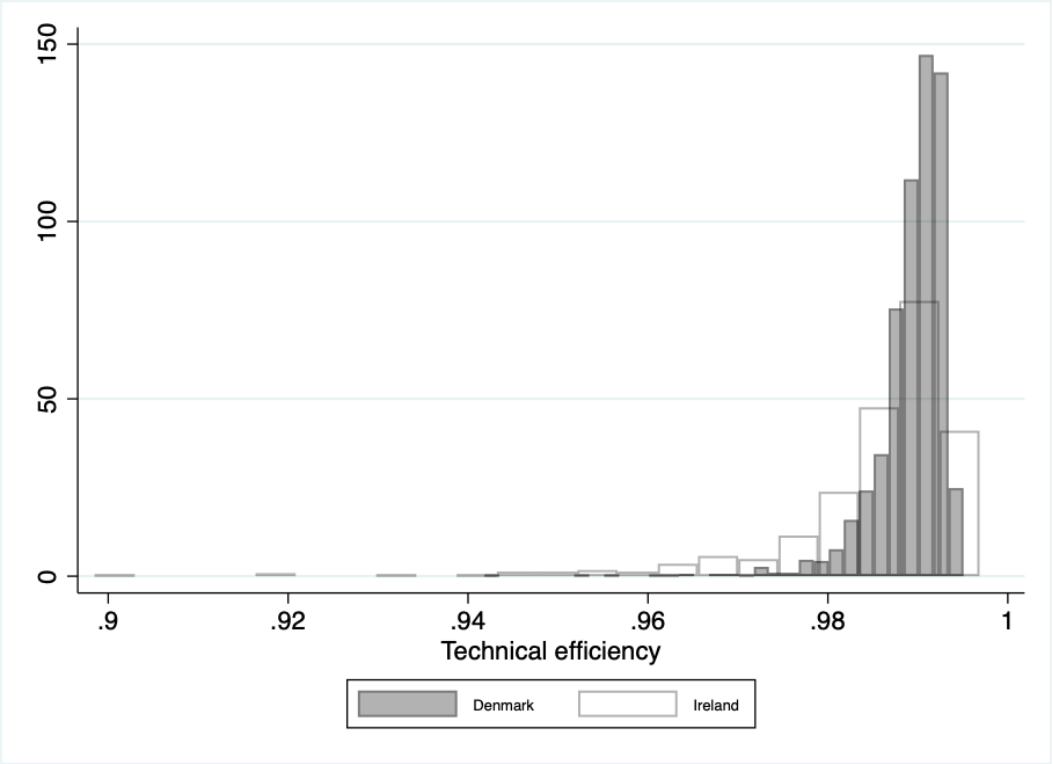
(1a) and (1b) and (2) represent the specifications as reported in Table 2.

The technical inefficiency term of columns (1a) and (1b) is estimated using equation 1'. We explain the inefficiency of creameries using the number of shareholders to indicate the size of the creamery. In Denmark, the estimated coefficient is positive and therefore indicates that creameries with more members were more inefficient, while in Ireland the opposite was the case. However, both coefficients are not statistically significant. It seems very unlikely that size does not matter, and it also seems unlikely that the number of shareholders does not reflect the size. But measuring the impact of size as a log-linear function might not be the most efficient way to capture the complex nature of scale productivity. It suffices, however, as a control for size in our application.

Thus, from column 2, we get an estimate that compares efficiency between Denmark and Ireland. The coefficient is positive, implying that the average inefficiency of Irish creameries is larger than the Danish: in fact Ireland produces 63 percent less butter, which can be attributed to inefficiencies. However, as the coefficient is not statistically significant, this means we cannot find *statistical* evidence for there being a significant difference between the productivity of creameries in Ireland and Denmark, although Figure 2 demonstrates that there was considerable heterogeneity in both countries, with this being somewhat greater in Ireland, as was already apparent in Figure 1. Even when letting everything except the specification vary across borders, we find the same results: Ireland is less efficient than

Denmark, but not significantly so.[5] Likewise, for this specification we find evidence that larger creameries (as measured by the number of shareholders) are more efficient. A one percent increase in number of shareholders is associated with a 0.47 percent increase in efficiency in terms of butter output. Again, however, the coefficients are statistically insignificant.

Figure 2: Technical Efficiencies for Danish and Irish creameries, 1898-1903



Notes: The results are as reported in specification (3) of Table 2.

One of the assumptions behind our use of Stochastic Frontier Analysis is constant variance across countries. However, as already noted, this might not be the case as the variance of productivity seems to be different between Danish and Irish creameries. To account for this, we use the method proposed by Hadri et al (2003) that allows for heteroscedasticity in the error term, i.e. it takes into account this variance in the error term when estimating the technical efficiencies. We specify explanatory variables for both the inefficiency error as well as the idiosyncratic error variance using the following functions:

$$\sigma_{wit} = \exp(\alpha_0 + \alpha_1 \ln (Milk\ for\ butter)_{it})^6$$

$$\sigma_{uit} = \exp (\gamma_0 + \gamma_1 Nation_it)$$

The results for this model are presented in Table 4, where column (2) explicitly models the

[5] From table 3, we can construct confidence intervals (CI) of the Danish and Irish average efficiencies. When doing so, the CI of Danish creameries overlap the average Irish creameries and vice versa.
[6] The two-sided error term is likely to be affected by size-related heteroscedasticity (Hadri et al 2003). The best measure of size in our case would be the amount of milk used (how large supply is).

difference between the variance in productivity of Danish and Irish creameries. Our results are qualitatively unchanged. Clearly, however, the variance on inefficiency (σ_u) is indeed lower in Denmark. The interpretation is clear: Irish creameries were not on average less efficient, but production in Ireland carried a seemingly higher risk of operating inefficiently.

Table 4: SFA allowing for heteroskedasticity in the error term

	(1) lnButter	(2) lnButter
Frontier		
lnMilk	0.993***	1.000***
	(0.00130)	(0.00127)
Trend	0.00611***	0.00627***
	(0.000374)	(0.000346)
Region	0.00103***	0.000818***
	(0.0000561)	(0.0000614)
Constant	-3.182***	-3.285***
	(0.0194)	(0.0185)
Efficiency		
lnShareholders	-1.922	-7.831
	(24.23)	(.)
Constant	0.405	-22.15
	(4.219)	(18.27)
σ_u		
Ireland		-2.434***
		(0.563)
Constant	-2.356	-0.597
	(12.69)	(0.349)
σ_w		
lnMilk		-0.718***
		(0.0500)
Constant	-7.147***	3.067***
	(0.0502)	(0.708)
N	2322	2322

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5 Conclusion

Using a detailed microlevel database of Danish and Irish creameries, we have demonstrated that there was no statistical difference between the productivity of the cooperatives in the two countries, although on average Irish creameries were less efficient due to a greater variance in productivity, which is apparent both from simple milk/butter ratios, but also when we apply more advanced statistical methods. A tentative conclusion based on this might be that the relative Irish failure was not due to an inability of Irishmen to employ the cooperative institution or the new technology – at least on the very local level we have considered here – although it seems that they were unable to do this as consistently as the Danes. A clear limitation to our analysis is of course that we do not have information on the important proprietary sector in Ireland, which was perhaps if anything more efficient, although competition for milk supplies with cooperatives might have led to inefficiencies.

Our finding suggests that future work should consider reasons for the relative failure of Irish dairying beyond a simple inability to cooperate, such as legal or competitive barriers to the spread of Irish cooperatives, or simply that Irish farmers considered other activities, such as rearing cattle for live export or condensed milk manufacturing for the military to be a more profitable enterprise. For example, Ireland benefited from (non-tariff) protective barriers to the British market for live cattle imports from 1869 onwards (McLaughlin, 2015, p.88), and thereafter Irish farmers consistently held a dominant share of British cattle imports (Perren, 1971). Thus, according to official statistics, livestock exports constituted 42.33 percent of all exports from 1924-28, whereas butter exports were a mere 9.28 percent. In contrast, Denmark faced tariff and non-tariff barriers on live cattle exports to Germany, its traditional market, from 1879 (O'Rourke, 2017, p.44), coinciding with both the Danish reorientation towards Britain and towards dairying.

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