Diffusion of New Technology and Complementary Best Practice: a case study*

Ingrid Henriksen
Institute of Economics
University of Copenhagen
Studiestræde 6
1455 Copenhagen K
Denmark

Morten Hviid**
Norwich School of Law
and
Centre for Competition Policy
University of East Anglia
Norwich NR4 7TJ, UK

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Abstract:
During the late 19th century, technologies to measure the quality of the milk in butter production became available, enabling creameries to pay suppliers of raw milk according to quality. Having identified the advantages to the creameries in terms of incentive provision, we demonstrate that the diffusion among the cooperative creameries was relatively slow, particularly relative to other technologies adopted by the same creameries over the same period with a large number dragging their feet. We also observe that late adopters often do not choose the most up-to-date technology and that early adopters who later upgrade their technology in many cases do not choose the current best practice. We consider a number of reasons for the observed patterns, which are at odds with the cooperative creameries being seen as technologically savvy. A proper implementation created both winners and losers among suppliers, and the size of these widened with newer versions of the technology. We show that the slow and inappropriate implementation can be explained by the need to get the technology accepted by a sufficient number of suppliers.

Keywords: Process innovation, diffusion, best practice, cooperative creameries.
JEL classification: L22, P13, Q13, N53, O33

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** Corresponding author. Email m.hviid@uea.ac.uk
1 Introduction

With few exceptions, work on the diffusion of process innovation look at whether or not new technology is adopted rather than how it is adopted. However, the introduction of new technology into the production process does not necessarily imply that the adoption is implemented correctly. In this paper we will look both at the pattern of adoption of a new technology as well as how this was put to use in order to improve efficiency. We do this using a case study of Danish creameries during the early phase of this industry, from 1878 to 1915, focusing on the adoption of machines to measure either the fat or the cream content of the milk. The invention of the continuous cream separator in 1878 enabled large-scale factory production of butter. With the need for a new organisational form to take over from farm production came a number of incentive problems. One of these related to the quality of the milk supplied to the creamery. The new invention we study in this paper was designed to overcome some of these problems by enabling creameries to link the payment for the raw milk to some measure of quality. When studying the adoption of payment systems for milk, which emphasised quality, we look both at the adoption of the technology and how it was used.

The greater the fat or cream content in the milk, the less milk is needed to produce a pound of butter. The majority of costs depended on the quantity of raw milk processed not the amount of butter produced, so the higher the quality of the milk in terms of fat or cream, the better the results of the creamery. To reward high quality raw milk with higher returns, reliable information about the cream or fat content was essential and a technology which enabled this consequently valuable. During the early period of dairy production of butter along factory lines, about 1878 until at least 1886 and possibly later, no reliable and fair mechanism to test for the quality of the raw milk existed and the common mechanism to pay for milk used in Denmark was by weight, using a price pegged to the butter price. For example, Sophus Madsen, a dairy consultant writing in 1889 in Mælkertilidende\(^2\) (vol. 2, p. 521), notes that "payment for the milk equal to the top quotation price for butter for each 28 pounds of milk, ... is currently the most common payment method".

\(^1\) See, for example, Silverberg et al. (1988). Their model reflects that the productivity of a technology realised in practice is not just a function of the presence of the requisite machines, but conjointly requires certain levels of specific expertise and experience both external and internal to the firm. “Hence investments decisions are not merely a question of determining the best practice technology at a given time, but one of weighing the prospects of further development either by acquiring experience with it now to gain a jump on competitors or waiting for a more opportune moment and avoiding possible development costs.” (p. 1041).

\(^2\) Mælkertilidende was the leading weekly magazine for the dairymen. It was distributed widely.
Paying according to quantity gives rise to a number of problems. Firstly it could be perceived as unfair as those with high quality milk contribute relatively more to revenue and relatively less to costs without being rewarded for this. This not only had the potential to create unrest among current suppliers, but also affected the decision to become a supplier. Those with the best quality milk had, if their production was large enough to exploit the economy of scale in factory production, the better outside option of processing it on the farm and hence would be less likely to become suppliers. Thus there was a real danger of adverse selection driving the creameries out of business. Secondly, it distorts incentives to improve the herd appropriately. As long as payment is for quantity, the incentive is to focus on those cows that produce a lot of milk, rather than those who produce very fatty milk. During the period, there was a growing awareness that the propensity to give fatty milk was mainly genetic and that there was no discernible correlation between the amount of milk a cow gave and how fatty this milk was. Thirdly, suppliers have an incentive to adulterate the milk, either by adding water or skimmed milk, or by skimming cream from the raw milk before delivery. In addition, the incentive to extract the last drop of milk at each milking, which is the fattiest, would be weak. All these problems could in theory be overcome once a reliable mechanism to measure the quality was available. From 1886, due to the efforts of ‘Docent’ Fjord, a professor at the Danish Agricultural University, it was. The innovation consisted of two parts, a mechanical device to measure the cream percentage of the milk, and a formula in the shape of a book of tables to translate this into the value of the milk in butter production. Both the measurement and the method of converting the data into a relevant measure were subsequently improved. The paper documents the adoption/diffusion process of both parts.

The quality of the milk was an issue of economic significance. The amount of milk required to produce a pound of butter varied considerably, especially during the period in question. Bøggild (1899) refers to an investigation in 1885 of the milk from 47 suppliers to the private creamery, Grønvang. For the two "best" suppliers, 17.2 and 22.4 pounds of milk was required to produce a pound of butter, while for the two "worst", 41.3 and 45.3 pounds was required. Another illustration comes from an analysis of the milk at the cooperative creamery, Spangs-Bro, for the period May 1891 to May 1892, published in Mælkeritidende (1892, p. 589-595). For example, information from six single-cow herds show a difference of over 100 Kroner between the best and worst cow, a considerable difference given an average value of butter per cow for the six of 175.54 Kroner. Although one might expect that aggregating to

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3 Throughout the paper we use pounds instead of gallons of milk since it is the standard measure in all Danish literature on the subject.
the creamery level would smooth out the differences, a lot of variability still remain. In 1890, the "worst" creamery among the members of the dairy association "Sydjysk Mejeriforening" who reported their results used on average 27.9 pounds of milk per pound of butter, while the "best" used 26.3. Six years later, the worst used 28.1 while the best 25.1.

The first machine capable of measuring the fat content of milk and available in Denmark was designed in 1878 by Fjord.\(^4\) This was quite primitive and could only carry out 12 tests at the time. Since virtually all creameries would receive milk from more than 12 herds and since it was hard to keep conditions the same between each batch of 12 tests, using these to compare the performance of different herds was not appropriate. Due to its potential importance, technological progress was rapid. In 1885, Fjord’s machine was expanded to carry out 54 tests simultaneously and this was further expanded in 1887 to enable 192 simultaneous tests.\(^5\) While insufficient at the level of individual cows, the technology was for almost all creameries useful at the level of individual herds. Thus, by the late 1880s, a fairly extensive testing of the milk from each member or supplier is entirely feasible even where there are a large number of members. Table 1 below summarise the main events:

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1878</td>
<td>First continuous cream separator invented.</td>
</tr>
<tr>
<td>1882</td>
<td>First cooperative creamery formed.</td>
</tr>
<tr>
<td>1886</td>
<td>Fjord invents both a machine to measure the cream content of the raw milk and designs a payment method, referred to as either Fjord’s method, or Faktor 2, the latter because a constant of 2 (actually 2.4) is used.</td>
</tr>
<tr>
<td>1892</td>
<td>Gerber invents a machine which determines the fat content rather than the cream content. For this, a constant of 4.6 is needed for the calibration.</td>
</tr>
<tr>
<td>ca. 1892</td>
<td>Berg constructs laktoskopet, another devise to determine cream percentage. Tests show that laktoskopet require a recalibration of the payment method, yielding a constant of 3.2, but referred to as Faktor 3.</td>
</tr>
<tr>
<td>1893</td>
<td>Berg proposes a new payment method based on differences in cream percentages. This remain largely ignored until 1905.</td>
</tr>
<tr>
<td>1905</td>
<td>The adoption of Berg’s method of paying according to cream or fat percentages takes off.</td>
</tr>
</tbody>
</table>

Many of the issues discussed in this paper are independent of the organisational form of the creamery and we generally talk about "suppliers". Where the organisational form is a

\(^4\) Actually, in 1873 Jakobsen designed a test churn which could churn butter from six different samples simultaneously, see Bøggild (1916, p.222). However this was not commercially viable.

\(^5\) The creameries were well aware of the existence of such improved machines. For example, in an ad in Mælkeproducent, on 27.7.1888 mentions the improved De Laval's Kontrolapparat, which can do 48 tests at the time and each test cycle taking 20 minutes with accuracy improved to 0.1 per cent. A week later an ad for a machine based on Fjords method shows it to be able to process 192 tests at a time.
cooperative, these may be members who are entitled to a share of the profits generated. Where the discussion solely relates to cooperatives, we will specifically say so.

The paper is organised as follows. Section two presents the incentive effects of various payment systems for milk. Section three contains a first look at the data, focusing on the adoption of a payment method for quality both from official statistical sources and from the books of minutes of 214 cooperative creameries. The data provide a mixed picture of some initial enthusiasm combined with considerable prevarication by a large minority. Section four takes a closer look at how the new technology was used and in particular focus on whether best practice was followed. Two surprising observations emerge. The new technology adopted was not necessarily the "best" currently available and where technology was updated, best practice with the new technology was not necessarily used. The latter is particularly interesting because it breaks the link between the adoption of new technology and the productivity effect of adoption. Section five returns to the issue of what motivated the adoption by looking at whether it was to curb adulteration. Data does not support this, leaving us with either an argument about long-run effects or a (fair?) redistribution of the gains from joint production. The slow adoption by some could be explained by the transaction costs involved in carried out the tests. Section six present a brief description of how testing was actually carried out and suggests that these costs were seen as non-trivial. Observing that quality pay generated both winners and losers at least in the short run, section seven contains a formalisation of reasons why adoption might be slow. Finally section eight concludes.

2 Payment methods for milk

On order to identify the incentive problems caused by not paying according to quality as well as illustrating the different payment methods on offer and their incentive effects, it is helpful to resort to some notation. We will demonstrate that the incentive problems solely relate to problems with measuring the quality of the raw milk and that these problems are more acute for private creameries who do not return any surplus generated to the suppliers.

The surplus created in a dairy before paying for the raw milk can be approximated by:

\[ \Pi = P_b \cdot \sum_{i=1}^{n} \lambda_i \cdot m_i - C(m) \]  \hspace{1cm} (1)

where \( P_b \) is the price of butter, \( m_i \) is the amount of milk supplied by supplier \( i \), \( n \) is the number of suppliers, \( m = \sum_{i=1}^{n} m_i \) is the total amount of milk processed, \( \lambda_i \) is the butter to
milk ratio of supplier i and $\sum_{i=1}^{n} \lambda_i \cdot m_i \equiv B$ is the total amount of butter produced. The differences in the quality of the milk are measured by differences in $\lambda_i$. Finally, $C$ is the cost of production other than the cost of raw milk. According to contemporary sources, costs depended on the total amount of milk processed, not on the amount of butter produced.\(^6\) While not strictly speaking correct, we will treat the cost function as if it was differentiable. Average costs are approximately U-shaped where the initial increasing returns to scale is caused by the fixed machinery and buildings as well as managerial effort, while the eventual decreasing returns is caused by transportation costs. For most of the relevant range of $m$, average costs, $AC$, are constant.

From (1) it is obvious that the surplus is increasing in $\lambda_i$. Surplus is increasing in $m_i$ if

$$\lambda_i \cdot P_B \frac{dC(m)}{dm} > 0 \quad (2)$$

implying that the creamery should accept as much supply as possible from those with high $\lambda_i$'s.

Assume that $\lambda_i$, can be measured accurately. One simple way to pay each supplier is a fraction of the value added they create, given by the following:

$$w_i = \alpha \cdot (P_B \cdot \lambda_i \cdot m_i - s_i \cdot C(m)) \quad (3)$$

where $\alpha$ is between 0 and 1 and $s_i = m_i / m$. A cooperative would have $\alpha = 1$, while a private creamery might have $\alpha < 1$ if it could get the necessary supply.\(^7\) Each supplier gets a fraction of the revenue he has contributed, $P_B \cdot \lambda_i \cdot m_i$ and similarly pays the same fraction of his average contribution to costs. The latter can be achieved fairly simply by requiring the supplier to receive back the skimmed milk left over once the cream has been extracted at a price roughly equal to average costs. This works because the amount of milk supplied and the amount of skimmed milk produces is extremely highly correlated.

\(^6\) Niels Anton Hansen (*Mælkeritidende* 1889, vol. 2, p.441). The reason for this is that the main parts of costs, such as transportation and energy vary directly with the amount processed. At least the fixed element of managerial salaries also varied with the amount of milk.

\(^7\) A private creamery might, as the manager is the residual claimant, be able to increase $\lambda_i$ for each supplier compared to a cooperative and also have lower costs. Thus even with $\alpha < 1$, a private creamery might offer a better deal than a cooperative with $\alpha = 1$. 5
Comparing (1) and (3) note that supplier $i$ has the same incentive to increase $\lambda_i$ as the creamery. Moreover, each supplier is willing to increase supply as long as:

$$P_B \cdot \lambda_i \cdot s_i \cdot \frac{dC(m)}{dm} - \frac{m - m_i}{m^2} \cdot C(m) = P_B \cdot \lambda_i - s_i \cdot \frac{dC(m)}{dm} - (1 - s_i) \cdot AC(m) > 0 \quad (4)$$

If $AC$ is approximately constant over the relevant range, (4) reduces to (2) and hence each supplier has the same incentive as the creamery.

Thus if $\lambda_i$ can be measured accurately, we can design a payment system with appropriate incentive properties. The importance of these properties obviously depend on whether or not the supplier can affect $\lambda_i$ and $m_i$. Firstly, the farmer could improve the quality of the herd, for example by replacing a cow with a high yield ($m_i$) of low quality ($\lambda_i$) with a cow having the opposite qualities, but more generally through selective breeding.\(^8\) This was easier said than done. An example is provided by a Dairy manager in an article in *Mælketidende* (1892, p. 589-595). A relatively large supplier had initially supplied milk with 6 per cent cream. Some years later, as the original herd got replaced, not only did the quality drop to 5 per cent, the quantity supplied also fell. This could clearly not have been something the farmer aimed to do. Secondly, so long as $\alpha$ is close enough to unity, even the supplier with the highest $\lambda_i$ and hence the best alternative use would be prepared to supply. Thirdly, as the last drop of milk from the udder is the richest, the member can increase $\lambda_i$ by ensuring that the cows are milked clean. Fourthly, any incentive to lower $\lambda_i$ for example by skimming some of the cream of the raw milk, are severely limited. Finally, any incentive to increase $m_i$ by adding water or skimmed milk to the raw milk, which would keep $\lambda_i \cdot m_i$ constant and hence lower $\lambda_i$, is also blunted as this would increase both costs and the share of costs but leave revenue unchanged. The last three effects all formally amount to adulteration of the milk, although only the latter two are really potentially detectable and hence only these could alternatively be dealt with through the contractual relationship between dairy and supplier.

\(^8\) We can complicate this by including the cost of feeding the cows, which to some extent determine the amount of milk produced.

\(^9\) The information necessary for selective breeding was slow in coming and not generally available until late in the 1890s. The first association to measure the performance of each cow systematically is set up in 1895 cf. section 5 below. Improvement in the herd through buying and selling would have been feasible throughout the period we study.
2.1 Payment for Quantity

Consider first the case where only the average over the whole creamery, \( \lambda = B/m \), can be measured at the end of a period. If we used the same simple payment method as above, the surplus of member \( i \) would be:

\[
\bar{w}_i = \alpha \cdot (P_B \cdot \lambda \cdot m_i - s_i \cdot C(m)) = \alpha \cdot (P_B \cdot m_i \cdot \sum_{j=1}^{n} s_j \cdot \lambda_j - s_i \cdot C(m))
\]  

(5)

where we use the definition of \( B \) to write \( \lambda = \sum_{j=1}^{n} s_j \cdot \lambda_j \). Comparing (3) and (5) two things are clear: farmers with high milk to butter ratio \( \lambda_i \) may not find supplying profitable and the incentive for suppliers to increase \( \lambda_i \) is now much reduced and if \( s_i \) is small enough, negligible. In appendix A we demonstrate that paying according to (5) rather than (3) imply that those with high quality have a disincentive to supply and that those supplying small quantities may have an incentive to add water to the milk. In summary, using (5) rather than (3) gives bad incentives to suppliers.

Can we do better than (4)? It is worth looking at what the cooperative creameries actually did do. They wanted to balance two objectives, to pay the members as soon as possible (typically every four weeks) and to retain enough to be able to pay the running costs, leaving a small surplus for the end of the accounting year. This net surplus would be distributed according to \( s_i \). From the beginning of the 1880s, they did this in three ways. They used a butter price, \( P_B \), which was lower that the transaction price, they used a national norm, \( \bar{\lambda} \), in place of the average \( \lambda \) and they charged \( P_s \) for the returned skimmed milk.\(^{10} \) In appendix A we show that for cooperatives who can redistribute profits, the payment to suppliers would reduce to (5) with the associated incentive problems, while for private creameries the incentive problems would be worse.

As costs depended on the quantity of milk processed, it would make sense to require that suppliers pay for the cost through a levy on the milk supplied. The incentive effects of this is explored more formally in the appendix, where we find that in a cooperative where the supplier get his share of the net surplus, the payoff for the individual member is still given by (5) and the incentive problems remain. A private creamery would still face a greater incentive

\(^{10} \) E.g. they paid the top quotation for butter per 28 pound raw milk supplied and charged 3 øre per 4 pound skimmed milk returned. Of this, the latter contributed the most. Take as an example a creamery where they used 27 pounds of milk per pound of butter, got a price of 4 øre over top (\( \approx 1.04 \text{ Kroner} \)) and processed 2 mill pounds of milk. For simplicity, assume that they had 2 mill pounds of skimmed milk. Then the contribution from the skimmed milk is 15,000 Kroner, while the contribution from the other two together are 5,608 Kroner.
problem than a cooperative, but it would be less acute than those arising from the more common payment method.

The incentive problems identified in the section relate solely to using the average butter per pound of milk ratio, \( \lambda = \sum_{j=1}^{n} s_j \cdot \lambda_j \), as a proxy for the quality of the raw milk of individual suppliers.

### 2.2 Payment for Quality

The mechanical apparatus developed by Fjord and others could not measure \( \lambda_i \) directly. They either measured \( \delta_i \), the cream percentage of member \( i \) (Fjord's Apparatus and Laktoskopet), or, \( \phi_i \), the fat percentage of member \( i \) (Gerber's apparatus). These measures were correlated with \( \lambda_i \), but a method to use this data to estimate \( \lambda_i \) was required. For example for Fjord's apparatus, Fjord demonstrated that a difference of 1% cream on average implied a difference in the amount of butter produced from 4 pounds of milk of 2.4 kvint, or 0.024 pounds.\(^{11}\) Thus the extra amount per pound of milk is 0.006. Let \( \Delta \) be the average cream percentage defined as: \( \Delta = \sum_{i=1}^{n} s_i \cdot \delta_i \) and define the average fat percentage \( \Phi \), similarly. Depending on the apparatus used, the estimated butter per pound of milk ratio is given by:

\[
\tilde{\lambda}_i = \begin{cases} 
\lambda + (\delta_i - \Delta) \cdot 0.006 & \text{For Fjord's Apparatus (Faktor 2)} \\
\lambda + (\phi_i - \Phi) \cdot 0.0115 & \text{For Gerber's Apparatus (Gerbering)} \\
\lambda + (\delta_i - \Delta) \cdot 0.008 & \text{For Laktoskopet (Faktor 3)}
\end{cases}
\]

Note that for all three measures, \( \sum_{j=1}^{n} \lambda_j \cdot m_j = \sum_{j=1}^{n} \tilde{\lambda}_j \cdot m_j \) and hence the estimate redistributes around the (weighted) average of \( \lambda_i \). Apart from the constant (and whether or not it is cream or fat percentage), the payment methods are then the same. You pay each supplier as in (3), but use the estimated values in (6).

\[
\tilde{w}_i = \alpha \cdot (\tilde{\lambda}_i \cdot m_i \cdot P_{il} - s_i \cdot C(m))
\]

From (7), the better is the estimate of \( \lambda_i \), the closer are the incentives to the ideal surplus maximising method of paying for the raw milk.\(^{12}\)

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\(^{11}\) The relationship between the difference in the measure of cream content of the milk and the difference in amount of butter produced from a pound of butter is non-linear.

\(^{12}\) Note that a cooperative with \( \alpha = 1 \), which charged for the returned skimmed milk and redistributed surplus according to \( s_i \), would give the same final surplus of member \( i \) as in (7).
Another payment system, which was independent of the measurement apparatus used was based on converting the supply of each farmer into the amount of milk with 1% cream, $m_i \cdot \delta_i$ (or fat, $m_i \cdot \phi_i$) and then pay for the milk according to each supplier's share of that.\(^{13}\)

So far we have used $s_i$ to redistribute profits in the cooperatives. Once the relevant information is available, quality-adjusted shares of milk, such as $\tilde{s}_i$, could clearly be used instead. As pointed out by various authors in *Mælkeritidende*, the correct method for dividing the net surplus depends on how the surplus has arisen. If the main driver in retaining earnings to pay for the costs were related directly to milk, for example through the payment for the returned skimmed milk or a levy on the milk, the surplus should be shared according to milk. In reality, the main contribution to covering costs came from the sale of skimmed milk and from Johansen (1893), we learn that 53 out of 63 creameries shared the surplus according to the amount of milk supplied and only 8 according to the computations for quality pay. Thus the overwhelming majority did not use the new data to distribute net surplus.

This section has demonstrated that payment according to quality, such as (7) had several advantages. It gave suppliers with the best milk an incentive to supply, it gave individual members better incentives to improve their herd, it provided strong disincentives to cheat and it provided a fairer distribution of the surplus of the creamery. All these were important for both current profitability and future growth and prosperity. Moreover, the better the estimate of $\lambda_i$, the stronger these positive effects would be. At the same time, (7) increases the risk faced by each supplier as compared with (3). Given the uncertainty about the future quality of the herd, it may be important to share the risk between the creamery and the suppliers. In the following we will consider how these effects affected the adoption of payment for quality. The section has also made clear that diffusion is not just about the technology which enabled more or less accurate measurement of $\delta_i$ or $\phi_i$, but also about the way in which this information was translated into information about $\lambda_i$.

### 3 Adoption of new payment methods

The desirability of payment according to the quality is already evident in a 1879 report from "The Patriotic Society of Funen" which in translation reads.

"The fat or butter content of the milk, upon which its value in the main depends, can, even when the milk is healthy, vary, depending on the individual cow or its feeding. As the milk naturally ought to be paid for according to its

\(^{13}\) See, Appendix (iii) for the implication.
true value, it would be proper not just to pay for weight but also quality. We are however not blind to the fact that there are practical problems caused by such an assessment and the resultant pricing, at least at the moment, and we thus refrain from providing firm guidance in this matter. If in doubt the milk can always be analysed, and in any case, creameries should only get involved with honest suppliers." (Betænkning angaaende de Fynske Fællesmejerier afgivet til Fyens Stifts Patriotiske Selskab, Odense 1879, p 12-13)

However, because inexpensive and reliable methods were not initially available most Danish creameries paid for the milk according to its weight, i.e. as described in section 2.1 above. By 1886, Fjord had developed both a mechanical apparatus to measure the cream content as well as a method to estimate the quality of the milk for butter production and the first adoption by eight creameries, two private and six cooperatives, take place in 1886. Of these, four are from Ribe Mejerikreds, 14 two from Aarhus Mejerikreds and one from each of Fyn and Sydjydsk Mejerikreds.

3.1 The rate of diffusion according to official statistics

There is a number of statistical investigations carried out at the time from which we can get a varied, if patchy, impression of the diffusion of the process innovation of paying for quality. Note that four of the eight early adopters are from the region around Ribe, which also saw the establishment of the first cooperative in 1882. A survey by Johansen (1893) to investigate how creameries paid for the milk focused on this county, which is located in the southwest of Jutland and on Vejle a county in east Jutland. During 1893, Johansen collected information from 104 creameries (half from each county) of the approximately 134 creameries in the area, of which 11 were private creameries, the rest cooperatives. By 1893, 63 of these 104 creameries used Fjord’s method to pay for quality, the rest paid according to weight. The implied rate of adoption of 61 per cent overstates the true level of adoption. Johansen clearly states that the missing creameries were relatively small creameries who on the whole paid according to weight, so the true rate may have been as low as 47 per cent. Compared to the diffusion of the use of commercial starters, 93 per cent in seven years (see, Leisner 2004), a diffusion rate of about 50 per cent in 7 years for quality pay is not particularly rapid. 15

Johansen's data allows us to break the diffusion rate down further, table 2.

14 Denmark was divided up into various Mejerikredse, that is creamery districts, which more or less followed county boundaries.

15 Two other studies confirm this. One relates to cream pasteurisation, a technique available from 1891, which by 1896 was adopted by 93 per cent of all creameries (Jensen and Jensen 1950, p. 407). Branding of Danish butter provide a final example. The Lur brand was designed in 1900 and was by 1906 adopted by all but very few creameries (Drejer 1925-33, pp. 406-407).
Table 2. *Adoption by year.*

<table>
<thead>
<tr>
<th>Year</th>
<th>Ribe</th>
<th>Veje</th>
<th>Potential Fraction per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1886</td>
<td>6</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td>1887</td>
<td>12</td>
<td>3</td>
<td>55</td>
</tr>
<tr>
<td>1888</td>
<td>6</td>
<td>13</td>
<td>85</td>
</tr>
<tr>
<td>1889</td>
<td>5</td>
<td>3</td>
<td>93</td>
</tr>
<tr>
<td>1890-93</td>
<td>3</td>
<td>10</td>
<td>104</td>
</tr>
<tr>
<td>No date</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>

*Source:* See text.

We see that adoption rates are faster and slightly higher in Ribe County. Unfortunately, we do not have the age of each creamery, only the age distribution of the creameries in the combined sample, from which we have constructed the fourth column (the number of potential adopters, i.e. active creameries, in the two counties) and the fifth column (adopters as a fraction of potential adopters). Even allowing for growth in the number of creameries, column five shows a very rapid early growth in adoption. Johansen also collected information about the number of members/suppliers, the number of cows, the annual amount of milk and the milk per pound of butter ratio. Interestingly, there are no significant differences in these averages between those who pay for quality and those who do not for either of these four measures. It is, however, noticeable that of the 11 private creameries, only two pay according to quality, although from section 2, these potentially had more to gain. Unfortunately, we are not supplied with the name of the creameries, so we cannot link his data with any of the other sources. In 1900, Johansen (1900) gather information from 66 creameries in the county of Ribe and find that 44 (71 per cent) paid according to quality.

The agrarian journal, which mentioned the eight early adopters, estimated that the year after, 1887, a further 50 of the roughly 800 private or cooperative creameries had adopted payment for quality. The implied diffusion rate of 7.3 per cent is quite a bit lower than that found in table 4, giving us the first hint that diffusion was not homogeneous across the country. Chr. Korsgaard carried out a national sample of creameries during 1892 and reported the results in *Mælkeritidende* in 1893. Table 3 contain information on the number of creameries in the sample, the number of adopters, the rate of adoption and finally how much lower milk per butter ration \((1/\lambda)\) the adopters had.
Table 3. Adoption of quality pay by 1892.

<table>
<thead>
<tr>
<th>Area</th>
<th>Creameries</th>
<th>Quality Pay</th>
<th>Quality Pay per cent</th>
<th>less M/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeland</td>
<td>33</td>
<td>21</td>
<td>63</td>
<td>0.1</td>
</tr>
<tr>
<td>Lolland-Falster</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Funen</td>
<td>37</td>
<td>21</td>
<td>57</td>
<td>0.0</td>
</tr>
<tr>
<td>East Jutland</td>
<td>32</td>
<td>15</td>
<td>48</td>
<td>0.0</td>
</tr>
<tr>
<td>West Jutland</td>
<td>30</td>
<td>13</td>
<td>43</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>141</td>
<td>70</td>
<td>50</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Dansk Mejeristforenings Spørgtevle 1892

Notes: East Jutland: Vejle, Aarhus, Randers, Aalborg, West Jutland: Viborg, Ringkøbing, Ribe. Column 4 shows the decline in the pounds of milk to make 1 pound of butter.

Consistent with the picture from the two counties in table 2, by 1892, on average half of the creameries had adopted payment according to quality. However, the geographical distribution is not even and the aggregate regions in the table conceal further differences. For example, from table 3, the adoption rate in Ribe was close to 60 per cent while for the region to which it belongs, West Jutland, it was 43 per cent. This geographical variation remains throughout the whole period we are looking at. There is no accounting for this pattern in the official regional statistics. Looking, for example, at the milk per butter ratio it was highest on Funen and Lolland-Falster, two regions with very diverse speeds of diffusion. The last column reports on how much lower the milk per butter usage was in those creameries who paid according to quality. While we do not know anything about statistical significance, the economic effect is modest, except possibly in West Jutland, supporting the evidence from Johansen (1893) above. Several reasons can be offered for this. It may for example be that the main motivation for introducing quality pay is the long-term improvement in the herd, in which case the difference would not show up yet. Alternatively, the main concern may have been curbing adulteration and those who did not adopt simply had other means of securing honest behaviour, (Henriksen and Hviid 2004), see Section 3.3 below.

From vol. 7 (Nov. 1902 - Nov. 1903) onwards, Mejeri-Drifts-Statistikken (MDS) include information about payment method, partly in an attempt to widen diffusion. The data is based on voluntary self reporting from cooperatives and, especially when it comes to the introduction of new technology, one might be concerned that the sample is biased towards those who are more progressive and technologically advanced, giving us a potentially

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16 According to the official statistics the milk per butter ratio of all creameries declined by a modest 4 per cent between 1899 and 1914 with all the improvement taking place between 1899 and 1906 (Statistiske Meddelelser 4,49,1, p. 43). Detlefson (1993, p. 99) finds that the quality improvement measured by the fat per cent from the 1890’s to the 1980’s was about 20% from3.4% to well above 4%.

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upwards biased picture of the rate of diffusion. Comparisons with other sources do lend some limited support for this concern. While MDS imply that 85 per cent had adopted payment for quality by 1904, the Danish Statistical Bureaux, using a much more extensive sample of both private and cooperative creameries, estimated that only about two thirds of all creameries paid according to quality in 1905 and that this had only reached 90 per cent by 1909. However, the larger sample contained 22 per cent non-cooperatives who had a very much lower rate of adoption and hence underestimate the adoption of cooperatives.

Table 4 summarises the information on diffusion from both MDS and the Office of Creamery Statistics (Kontoret for Mejeristatistik: KfM).

<table>
<thead>
<tr>
<th>Year</th>
<th>Source</th>
<th>Seeland</th>
<th>Funen</th>
<th>Jutland</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1902</td>
<td>MDS</td>
<td>67.2</td>
<td>87.3</td>
<td>78.6</td>
<td>77.2</td>
</tr>
<tr>
<td>1903</td>
<td>MDS</td>
<td>70.5</td>
<td>89.4</td>
<td>79.7</td>
<td>79.0</td>
</tr>
<tr>
<td>1904</td>
<td>MDS</td>
<td>77.0</td>
<td>91.2</td>
<td>86.0</td>
<td>84.7</td>
</tr>
<tr>
<td>1905</td>
<td>MDS</td>
<td>81.8</td>
<td>96.0</td>
<td>93.1</td>
<td>90.9</td>
</tr>
<tr>
<td>1906</td>
<td>MDS</td>
<td>87.9</td>
<td>96.3</td>
<td>97.8</td>
<td>95.1</td>
</tr>
<tr>
<td>1907</td>
<td>MDS</td>
<td>86.5</td>
<td>96.1</td>
<td>89.3</td>
<td>89.9</td>
</tr>
<tr>
<td>1908</td>
<td>MDS</td>
<td>86.1</td>
<td>99.1</td>
<td>90.6</td>
<td>90.9</td>
</tr>
<tr>
<td>1909</td>
<td>MDS</td>
<td>91.7</td>
<td>99.1</td>
<td>94.0</td>
<td>94.3</td>
</tr>
<tr>
<td>1910</td>
<td>MDS</td>
<td>90.0</td>
<td>96.6</td>
<td>94.9</td>
<td>94.0</td>
</tr>
<tr>
<td>1911</td>
<td>MDS</td>
<td>92.5</td>
<td>99.2</td>
<td>95.4</td>
<td>95.3</td>
</tr>
<tr>
<td>1912</td>
<td>MDS</td>
<td>93.1</td>
<td>98.3</td>
<td>94.9</td>
<td>95.0</td>
</tr>
<tr>
<td>1908</td>
<td>KfM</td>
<td>86.2</td>
<td>96.3</td>
<td>86.9</td>
<td>88.2</td>
</tr>
<tr>
<td>1910</td>
<td>KfM</td>
<td>86.6</td>
<td>97.4</td>
<td>88.1</td>
<td>89.1</td>
</tr>
<tr>
<td>1914</td>
<td>KfM</td>
<td>89.7</td>
<td>96.2</td>
<td>92.5</td>
<td>92.3</td>
</tr>
</tbody>
</table>

Comparing first tables 3 and 4, we see that while diffusion rates may at least in some areas have been rapid in the first seven or so years, for the next 10 they are modest and from 1902 to 1914 fairly slow. It is only really for the island of Funen that the process is complete by 1905, almost 20 years after the first adoption took place. The data from MDS may also overstate the rate of diffusion as compared to the much larger sample in KfM. A lot of the diffusion in MDS is down to a growth in the number of creameries submitting information, most of whom are paying according to quality. Table 4 show big differences between the regions, and the aggregation hides an even greater spread within each of the counties. For example, for Seeland, non-adopters are almost solely found in the area of Præstø, Sorø and Maribo. The latter comprise the islands of Lolland and Falster and is particularly slow to adopt. As late as 1914, 34 per cent had not adopted payment for quality.

Looking at tables 2-4, a picture emerges of a significant number of enthusiastic early
adopters followed by a large group dragging their feet. This picture is partial, because we do not have consistent date for the whole country from the start. By the time we can put together a panel in 1902, a large part of the action has already occurred.

3.2 Data on diffusion from the minute books

We have read the books of minutes from Board and General meetings from 214 Danish cooperative creameries. These books of minutes contain a wealth of information about both adoption and the process, which led to adoption of various payment methods for the raw milk for 214 creameries. While they are not systematic and at times vague about exactly what the adopted method of pay for quality involved, they do provide a much more detailed and richer source of information about the process of technology adoption that MDS.

It is clear that from very early on, the majority of the creameries measured the fat or cream content of the milk at random. A letter of September 1890 from a large dairy farmer to the board of a newly started cooperative is illustrative:

“By checking the fat content of my milk and by comparing it to that of other cooperative members I have become aware of the fact that the fat content of the milk supplied from many of the members is so low that it can only be explained by adulteration or by other kind of inadmissible conduct. I assume that the esteemed board will act vigorously upon this information now that I have called its attention to it so that it will not be necessary for me to carry the matter any further.” Minutes from Stokkemarke Andelsmejeri, Lolland Falster, 17. September 1890

This information about cream or fat content of the raw milk was, at least initially, used as a deterrent against adulteration of the milk by suppliers or in a much simpler method of quality related pay, namely a penalty for very thin milk. A typical entry from Englund creamery of September 1887 tells of a decision to buy a control apparatus “for the time being to control for adulteration.” As we have demonstrated elsewhere, Henriksen and Hviid (2004), the majority of cases where fraud was detected relied on formal testing. Of the 275 cases of adulteration recorded in the minute books, the source of information is known in 205 cases. Formal testing using the machines described above accounted for two-thirds, with the share increasing to 90 per cent if we focus on the pre-1903 cases. Thus tests played a significant role well before the full implementation of quality pay. In our sample, 25 of the creameries did for a period reduce the payment for milk where the cream fat content fell below some limit, typically 3.5 per cent or 4 per cent.

Over time the use of the test results grew ever more sophisticated. In table 5 we summarise the date of adoption for the 134 creameries where we have precise data.
Table 5. Date of adoption. Number of creameries.

<table>
<thead>
<tr>
<th>Year</th>
<th>Seeland</th>
<th>Lolland-Falster</th>
<th>Funen</th>
<th>East Jutland</th>
<th>West Jutland</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1890</td>
<td>13</td>
<td>0</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>1891-1895</td>
<td>6</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>1896-1900</td>
<td>4</td>
<td>0</td>
<td>6</td>
<td>11</td>
<td>8</td>
<td>29</td>
</tr>
<tr>
<td>1901-1905</td>
<td>11</td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>After 1906</td>
<td>8</td>
<td>4</td>
<td>3</td>
<td>10</td>
<td>4</td>
<td>29</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>7</td>
<td>25</td>
<td>37</td>
<td>23</td>
<td>134</td>
</tr>
</tbody>
</table>

Source: Minute books

The data in the table suggests a rather slower and more gradual pattern of adoption than in tables 4 and 5, with an initial surge, a drop-off in the period 1891-1895 and then a steady rate of adoption. We also find that 62 per cent adopted by 1902, a number more in line with the more extensive 1909 statistic than MDS, adding to the impression that MDS is biased towards the more "aware" creameries.

Because the method of paying for the milk is typically written into the statutes of the cooperative creamery, and hence difficult to alter, one might expect that many of the creameries founded after 1886 would use payment for quality from the start. It is therefore interesting to look at the gap between year of formation of the cooperative and the year of adoption of quality pay. Table 6 summarise the information.

Table 6. Start-up and adoption. Number of creameries.

<table>
<thead>
<tr>
<th>Year</th>
<th>At formation</th>
<th>1-5 years</th>
<th>6-10 years</th>
<th>More than 10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formed before 1887</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>Formed 1887-1890</td>
<td>15</td>
<td>11</td>
<td>4</td>
<td>42</td>
<td>72</td>
</tr>
<tr>
<td>Formed 1891-1900</td>
<td>15</td>
<td>8</td>
<td>3</td>
<td>15</td>
<td>41</td>
</tr>
<tr>
<td>Formed after 1901</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
<td>30</td>
<td>7</td>
<td>69</td>
<td>141</td>
</tr>
</tbody>
</table>

Source: Minute books

While immediate adoption was not really feasible for those formed before 1887, for the rest is was, and we see that the majority waited quite a long time before they switched from weight to quality. As the statutes were routinely revised after each 10-year loan period, it is particularly surprising that about half waited beyond the first 10-year cycle. The early creameries appear to be the more conservative when it comes to adoption. For example, of the 54 who were founded in or before 1890 and who adopted more than 10 years after their foundation, 28 adopted in or after 1904, when the procedure was very well established. Our data thus support the conclusion from section 3.1 that there were a significant number of enthusiasts followed by a larger number of laggards.
3.2.1  Procrastination

There may be two reasons why adoption did not take place. Either the information about the new technology diffused slowly to the creameries, or else they knew about it but there was significant resistance to adoption within the creameries. Given the high profile of the magazine *Mælkeritidende* and the extensive writing by respected experts such as Bøggild and Johansen about the subject, one would expect the latter to be the main reason. The data from the minute books can shed some light on this matter and tend to confirm the hypothesis that it was resistance rather than ignorance, which slowed down diffusion.

In many creameries it took several attempts to win over a sufficiently large majority for a new payment system. The minute books leave us with a mixed picture of who initiated the change. In 61 cases where a more modern and more rigorous procedure was suggested, the Board is mentioned as the proposer in 30 cases, agricultural consultants in 12 and a circulation of written material in two. In 17 cases did this kind of proposal come from individual members or groups of members. Only in two cases do we find that the Board suggested a slackening of the procedure in the form of return to an older method. The importance of the Board as initiator is not surprising when one considers that it typically contained a disproportionate number of the best and hence most respected local farmers and small holders.

Changes to the statutes typically required more than simple majority, such as 2/3, 3/4 or 4/5 majority or 3/5 of all members and often had to be agreed at two consecutive general meetings. All the methods described in section 2 basically redistributed each members claim around the average so that in any given period, about half the milk would be paid less according to quality than according to quantity. Moreover, with little knowledge about what made a good milch cow, a switch to payment for quality implied future uncertainty about income. This all make introduction of a new payment system based on (7) or (8) hard to achieve.

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17 As observed by Mokyr “… technological progress is hardly ever Pareto superior, that is an improvement for everyone affected: there are losers in the process, and while the gainers could compensate them, it is only rarely that they do.” (1990, p. 153).

18 This includes adoption of payment for quality as well as best practice in paying for quality, see section 4.

19 In addition, there is no doubt that board membership was biased against small holders. Bjørn (1982, p. 85 and 100-106) finds that in the formative period of the late 1880’s 75 per cent of all chairmen of the Board represented large landholdings and, in particular, middle-sized farms. We cannot match this information with the social recruitment of all members for the same year but in 1903 more than 32 per cent of all members possessed small holdings below 5 Hectare (Statistiske Meddelelser 4.22.5 p. 15). The problem raised brings to mind the discussion in Banerjee, Besley and Guinnane (1994, p. 498) of the agency problem facing a credit
Below in Table 7 we offer information about how long it took from the first mention to approval and also on the number of meetings at which the issue was raised before success.

<table>
<thead>
<tr>
<th>Number of creameries</th>
<th>Number of creameries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediately or within first year</td>
<td>83</td>
</tr>
<tr>
<td>1-5 years</td>
<td>31</td>
</tr>
<tr>
<td>two meetings before adoption</td>
<td>15</td>
</tr>
<tr>
<td>three or more before adoption</td>
<td>16</td>
</tr>
<tr>
<td>more than 6 years</td>
<td>20</td>
</tr>
<tr>
<td>two meetings before adoption</td>
<td>6</td>
</tr>
<tr>
<td>three or more before adoption</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>134</td>
</tr>
</tbody>
</table>

Source: Minute books

While many adopt the first time the issue is mentioned in the minutes, there are still 40 who do not adopt within two years of the first suggestion in a (general) meeting and of these, 29 required three or more meetings to secure adoption.

This slow process of adoption is illustrated in Table 8 by events in the cooperative creamery Haugerup, Sorø County. Changing the statutes of Haugerup required a yes vote from 3/5 of the members. In 1904 it had 162 members, of whom 99 had less than four cows. A total of 98 yes votes were thus needed.

<table>
<thead>
<tr>
<th>Date</th>
<th>Meeting</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.6.1903</td>
<td>GM</td>
<td>Appoint committee to report on quality pay</td>
</tr>
<tr>
<td>7.12.1903</td>
<td>GM</td>
<td>Proposal from Committee rejected: 49 for, 53 against</td>
</tr>
<tr>
<td>15.6.1904</td>
<td>GM</td>
<td>Proposal rejected: only 49 for</td>
</tr>
<tr>
<td>3.12.1904</td>
<td>GM</td>
<td>Proposal rejected: only 50 for</td>
</tr>
<tr>
<td>29.5.1905</td>
<td>Board</td>
<td>Invite creamery consultant to present case for quality pay</td>
</tr>
<tr>
<td>June 1905</td>
<td>GM</td>
<td>Proposal rejected: only 61 for</td>
</tr>
<tr>
<td>2.12.1905</td>
<td>GM</td>
<td>Propose that Board propose quality pay next GM</td>
</tr>
<tr>
<td>13.6.1906</td>
<td>GM</td>
<td>Proposal rejected: only 82 for</td>
</tr>
<tr>
<td>27.11.1909</td>
<td>GM</td>
<td>Unanimous decision to adopt Faktor 2 from 1.2.1910</td>
</tr>
</tbody>
</table>

Source: The minute books from Haugerup

It takes 6 years and 8 months from the first proposal at a general meeting until final acceptance. This process is started at a point in time where the vast majority of creameries had already adopted payment for quality and when Haugerup finally adopt, they adopt a methodology, which is at least 10 years out of date. Note also that until the final meeting less than 50% vote yes (in 1907, there are 166 members), so enthusiasm by the rank and file for cooperative, given that some members, the net lenders, have an outside option, namely that of lending to non
change is very limited, although it must have been the case that the board of the cooperative was positive as the proposal was put to the general meeting again and again. Interestingly a favoured and usually successful trick by boards trying to secure change from a reluctant general meeting, to invite a famous creamery consultant to speak to the general meeting, did not work.

Just because a cooperative had adopted a new method of payment, the decision was no irreversible. We find that ten creameries changed their mind, trying out quality pay only to abandon it for a while. From the MDS we similarly find some creameries introduce quality pay one year and reverse this the next. Contemporary comments do suggest that the early methods were not always completely reliable, which possibly explains this behaviour. An interesting example is the cooperative creamery Bredstrup, which first adopts quality pay and then reverses its decision. They carry out a fairly scientific series of tests of samples of the same milk and find that the measured fat content of the same milk vary by anything from 0.1 to 0.5 percentage points, which as the average was about 4.5 per cent is considerable. On the basis of these tests, which indicated that the method was simply too unreliable to be useful, the general meeting on 30 of August 1888, decided to reverse an earlier decision to pay according to quality and revert to paying according to weight. The cooperative Ellinge-Ejer provides one of the longest sagas in terms of adoption. The main events are contained in table 9 below.

Table 9. Events in Ellinge-Ejer Andelsmejeri.

<table>
<thead>
<tr>
<th>Date</th>
<th>Meeting</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.7.90</td>
<td>Extra GM</td>
<td>Faktor 2 approved: 22 for - 7 against</td>
</tr>
<tr>
<td>2.8.90</td>
<td>Extra GM</td>
<td>2nd round, approved: 21 for - 7 against</td>
</tr>
<tr>
<td>29.9.91</td>
<td>GM</td>
<td>Return to quantity approved</td>
</tr>
<tr>
<td>10.10.91</td>
<td>Extra GM</td>
<td>2nd round, approved</td>
</tr>
<tr>
<td>21.5.92</td>
<td>GM</td>
<td>Faktor 2 (7%) approved: 26 for - 14 against</td>
</tr>
<tr>
<td>10.7.93</td>
<td>GM</td>
<td>Return to quantity approved</td>
</tr>
<tr>
<td>18.7.93</td>
<td>GM</td>
<td>2nd reading: approved</td>
</tr>
<tr>
<td>4.1.97</td>
<td>Extra GM</td>
<td>Faktor 2 (7%) approved: 31 for - 22 against</td>
</tr>
<tr>
<td>16.10.97</td>
<td>GM</td>
<td>Faktor 2: 17 votes - quantity 24 votes; latter approved for 98</td>
</tr>
<tr>
<td>14.10.98</td>
<td>GM</td>
<td>Faktor 2: 26 votes - quantity 22 votes; former approved</td>
</tr>
<tr>
<td>30.12.99</td>
<td>GM</td>
<td>Faktor 2: 47 votes - quantity 20 votes; former approved</td>
</tr>
</tbody>
</table>

Source: The minute books from Ellinge-Ejer members.

Suppliers would only subject themselves to use the results of the tests if they had confidence in them. Testing the milk almost always involved the manager who possessed the technical skill to do so. In the cooperatives at a very early stage, the dairymen was joined and supported by one or more members when carrying out control tests. This suggests that the manager's authority alone was not considered strong enough for him to be an impartial outside controller. If that was not the case for cooperatives, where the manager was less of a residual claimant, the problems must have been more substantial in the private creameries.
As already mentioned a decision needed to be approved at two consecutive general meetings. Over a nine year period, they reverse their decision four times and there are a further three unsuccessful attempts to do so. Given their rules about consecutive general meetings, this is even more remarkable, since those in favour of status quo could have turned up to the second meeting, even if they were blind sided for the first.

3.3 Curbing adulteration

We saw in section 3.2 that there were many potential benefits from paying according to quality of the milk, one of which was curbing adulteration. Monitoring the quality of milk through taking random samples in the creamery, followed up by visits to the farm whenever the test showed a low fat percent, was introduced very early on.\textsuperscript{21} In many creameries the main aim was to detect or deter cheating and also to provide the members with information about the quality of their herds. It is clear from the minute books that the introduction and use of the means of testing for either cream or fat content in many cases occurred long before payment for quality was introduced.

From the discussion around tables 2 and 3, it appears that the immediate effect on the overall efficiency of the creamery of introducing quality pay for milk was modest. Unless adoption is self-selection by those creameries, which had a problem with adulteration which they could not be solve efficiently by other means, the case for adulteration as an important driver is severely weakened. The data from the minute books, which also contain information about adulteration, allows us to test this indirectly, as creameries who had not previously paid according to quality and who experienced a case of cheating, should adopt fairly swiftly thereafter. Some but not all cooperatives switch to paying to quality pay after a case of adulteration.

An interesting picture emerges when we look at the 20 creameries where five or more cases of adulteration was recorded. These account for 139 of the 275 cases observed in the 214 minute books read. These creameries are typically late adopters both in time and relative to when they were formed. Two have an early fling with quality payment, of which only one continued for any length of time, but do not really adopt until well after 1900. Two other creameries adopt before the turn of the century, the remaining 16 adopted after 1900. Not only are they late adopters, the adoption does not appear to be triggered by an adulteration

\textsuperscript{21} Because of the costs, testing rarely took place more than once or twice a week at irregular days.
case. Only two adopt within 10 years of their first case, and one of these is after 9 years. We find that 89% of the adultery cases in these twenty creameries arise while they are not paying according to quality and most had all their cases before adoption. For only one of these creameries, Holme, is behaviour consistent with adoption being triggered by a case of adulteration. This does not support the thesis that payment for quality is strongly related to curbing adulteration and hence the driving force behind adoption. Instead, as demonstrated in Henriksen and Hviid (2004), the cooperatives used other ways of dealing with adulteration such as enforcing the statutes on fraud rigorously.\textsuperscript{22}

4 Best practices in paying for quality.

Recall from table 9 that Haugerup adopted an outdated method. They were not alone in this. The 1914 statistical analysis revealed that a large proportion of those paying according to quality were not using current best practices. In this section we will focus on the five true "payment for quality" systems which were used during our period up to 1915. Their main features are summarised in table 10 below. Faktor 2 ceases to be best practise with the arrival of the more precise measuring apparatus, Laktoskopet. However, the important point is that for the first three methods, there is for each apparatus a single right method of calculating $\lambda_i$ that is the butter to milk ratio of supplier i. This method was for each manifested in a table which was purchased separately and which was used by the dairyman to translate the observed cream percent or fat per cent into a measure of quality.

\begin{table}[h]
\centering
\caption{Payment systems.}
\begin{tabular}{|l|l|l|l|l|}
\hline
Name & Mechanical device & Estimation method to get $\lambda_i$ & Calibration constant & Best practice (roughly) \\
\hline
Faktor 2 & Fjord's apparatus & Fjord’s method: $\tilde{\lambda}_i = \lambda + (\delta_i - \Delta) \cdot K$ & K = 2.4 & 1886-1898 \\
Gerber & Gerber's apparatus & Fjord’s method: $\tilde{\lambda}_i = \lambda + (\phi_i - \Phi) \cdot K$ & K = 4.6 & 1898-1905 \\
Faktor 3 & Laktoskopet & Fjord’s method: $\tilde{\lambda}_i = \lambda + (\delta_i - \Delta) \cdot K$ & K = 3.2 & 1898-1905 \\
Cream Units & Fjord's or Laktoskopet & Berg's method $\tilde{\lambda}_i = \lambda \cdot (\delta_i / \Delta)$ & & 1905 - \\
Fat Units & Gerber's & Berg's method $\tilde{\lambda}_i = \lambda \cdot (\phi_i / \Phi)$ & & 1905 - \\
\hline
\end{tabular}
\end{table}

\textsuperscript{22}Of the 275 cases of fraud recorded in 70 cases the sanction was either exclusion from the creamery or a fine together with damage of a ruinous size or both. We also find that the recorded frequency of adultery declined substantially over time.
4.1 Implementing Faktor 2

While not strictly speaking necessary, it was common to specify a maximum cream percentage when using Faktor 2. The reason for this was that very high readings could occur either as a result of fraud or because the cow was milked over too long a period.\textsuperscript{23} Through his research, Fjord demonstrated that cream percentages above 8 per cent were very rare, as was indeed readings over 7\%. While he did not prescribe 8 per cent as the "right" maximum, he did, in an article in \textit{Mælkevidende} 1890 and elsewhere, recommend 7 per cent or 8 per cent. Two years after such a clear and authoritative statement about the maximum percentage from the acknowledged expert, Johansen (1893) found that of the 63 creameries using Faktor 2, only 43 per cent (27 creameries) is following this advice. Given their general willingness to listen to the experts, especially Fjord and Bøggild, (see Nielsen, 2003) this provides the first surprise when it comes to implementation.

4.2 Later choices

Although one might expect that usage becomes more appropriate over time with learning, matters do not improve later when the other three dominant methods, Faktor 3, Cream Units and Fat Units, are available. During the second half of the 1890s, Laktoskopet was gradually replacing Fjords apparatus. For example, of the 66 creameries surveyed by Johansen (1900), 22 used Fjords, 33 used Laktoskopet and 2 Gerber's apparatus. This should have been accompanied by a shift from Faktor 2 to Faktor 3 or Cream Units.

MDS include information about the payment method from 1907-08. KfM contains information for a larger and likely more representative sample for 1908, 1910 and 1914. These are collected in table 11 below:

<table>
<thead>
<tr>
<th>Year</th>
<th>Faktor 2</th>
<th>Faktor 3</th>
<th>Cream unit</th>
<th>Fat Unit</th>
<th>Weight or No information</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDS 1907</td>
<td>66.8</td>
<td>6.5</td>
<td>16.6</td>
<td>0.0</td>
<td>10.1</td>
<td>555</td>
</tr>
<tr>
<td>MDS 1908</td>
<td>61.5</td>
<td>5.9</td>
<td>21.0</td>
<td>2.5</td>
<td>9.1</td>
<td>628</td>
</tr>
<tr>
<td>MDS 1909</td>
<td>56.6</td>
<td>5.1</td>
<td>30.4</td>
<td>2.2</td>
<td>5.7</td>
<td>631</td>
</tr>
<tr>
<td>MDS 1910</td>
<td>54.5</td>
<td>5.1</td>
<td>32.2</td>
<td>2.2</td>
<td>6.0</td>
<td>683</td>
</tr>
<tr>
<td>MDS 1911</td>
<td>51.1</td>
<td>5.5</td>
<td>36.0</td>
<td>2.8</td>
<td>4.7</td>
<td>709</td>
</tr>
<tr>
<td>MDS 1912</td>
<td>44.5</td>
<td>5.3</td>
<td>42.8</td>
<td>2.5</td>
<td>5.0</td>
<td>722</td>
</tr>
<tr>
<td>KfM 1908</td>
<td>66.1</td>
<td>6.5</td>
<td>13.8</td>
<td>1.8</td>
<td>11.8</td>
<td>992</td>
</tr>
<tr>
<td>KfM 1910</td>
<td>60.2</td>
<td>5.8</td>
<td>20.8</td>
<td>2.2</td>
<td>10.9</td>
<td>993</td>
</tr>
<tr>
<td>KfM 1914</td>
<td>43.8</td>
<td>4.6</td>
<td>40.5</td>
<td>3.5</td>
<td>7.7</td>
<td>1028</td>
</tr>
</tbody>
</table>

Sources: \textit{Mejeri-Driftsstatisken} (MDS) and \textit{Kontoret for Mejeristatistik} (KfM)

23 While guarding against some forms of fraud, this clearly also weakens the incentives to produce fatty milk.
While the majority of the creameries had replaced Fjords apparatus by 1907, about two thirds of the creameries still used a method linked to that apparatus and this fraction had only fallen to about half five years later. Thus Faktor 2 shows a surprising persistence despite being inappropriate with the contemporary measuring devices, something, which by 1914 had been the case for more than fifteen years. Even by 1914, Cream Units had not overtaken Faktor 2 as the most popular method of paying for quality. The much more complete sample by KfM, suggest that this understates the persistence in the use of an outdated method. Interestingly, a lot of the growth in Cream Units and the accompanying decline in Faktor 2 are driven by the increase in the sample size. Thus those who start supplying information later are using more sophisticated methods.

The tendency not to utilise the most up to date practices found in the official statistics is echoed in the minute books. Table 12 below provide information on when a switch from Faktor 2 to cream units or other more modern methods took place.

<table>
<thead>
<tr>
<th>Period</th>
<th>Switch from F2 to modern method</th>
<th>F2 at end of minute book</th>
<th>Adoption of modern method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1905</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1905-1909</td>
<td>17</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>1910-1914</td>
<td>23</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>1915 or after</td>
<td>2</td>
<td>64</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>79</td>
<td>58</td>
</tr>
</tbody>
</table>

Source: Minute books.

The final column shows when new methods were adopted, either through a switch from Faktor 2, or because it was the first adoption of quality pay. When the Minute Books end, we have information about the methods used by 137 creameries and of these 58 per cent is using Faktor 2. Thus we see a very strong tendency to hold on to what you have got and know works despite clear benefits from the switch for those with better quality milk.

Thus while the shift from payment according to weight to payment for quality was slow following early enthusiasm, switching to, or keeping up with, the current best practice is even slower. Even by 1920, 16 per cent nationally (in some local areas up to 33 per cent) use the out-dated computation method, Faktor 2. Moreover, and this could account for the slow process, the methods are often used inappropriately. We first saw this with the maximum percentage for Faktor 2 in table 5, and then in the use of Faktor 2 rather than 3 when they switch from Fjords apparatus to Laktoskopet. One can possibly understand the reluctance to switch from Faktor 2 to one of the other methods given how time consuming altering the
statutes could be as evidenced by tables 8 and 9. This does not explain why so many when starting afresh, chose the wrong method to calculate the quality of the raw milk.

In the literature on diffusion there is a tendency to assume that if new technology is adopted, it is implemented correctly and to its best effect. The results in this section challenge this assumption, although in section 7 below offers one explanation for the observed behaviour. Further reflections on new technology and in particular computer software suggest that the current, historical, example is not unique. Each of the calculation methods described in this paper was available to the user in the form of a table, with a software manual being a modern analogy. What we observe is the equivalent of either upgrading the software but using the old manual, or buying new software but using a manual for a competing software programme.

5 The incentive of the median voter

We have seen that the transition to the new technology was by no means smooth. The picture emerging from all the data sources is, however, very similar. Apart from a non-trivial group of enthusiasts, adoption is slow, stuttering and often appears less than competent. How can we explain this slow adoption of a system which appears to be both fairer and have much better incentive properties?

Although some testing of the milk was widespread from fairly early on in the period under consideration, giving individual farmers some information about both the absolute and relative quality of their own herd, there was no clear understanding of what caused some cows to produce higher quality milk. For example in the quote from the Patriotic Society of Funen above, we see that they thought that feeding had an effect, which is in fact not the case. The experience of British and American dairy farming only slowly found its way into Danish agricultural journals. Two scientific articles from 1893 in the leading general agricultural journal *Ugeskrift for Landmand* focus on the subject. Faber (pp. 77-79) reports on a milch cow competition held by the British Dairy Farmers’ Association, which showed that the ability to give fat milk belonged to certain breeds and to certain individuals. Branth (pp. 117-118) who had already pointed this out in the same journal in 1891 calls for the establishment of a Danish strain of ‘butter-cows’. However, bringing together of a herd of cows with a high butter fat content in their milk was for obvious reasons a time consuming and costly process and as he observed: “There is no doubt that the individual farmer can

24 For exceptions to this, see, for example, Silverberg et al. (1988) and Battista and Stoneman (2003).
accomplish little”. Not until 1895 did Danish farmers begin a systematic registering of the fat per cent from the individual animals and thereby to lay the foundation for conscientious breeding on fat per cent. But that was only the modest beginning. During most of the time we are considering here the majority did not know the milk quality of their individual animals (although they knew the test results) and hence they may not have understood that they were able to affect the pay they would get from their milk. As the benefit of payment for quality depended on the relative quality of your herd both now and in the future, adopting such a system of payment might appear similar to entering a lottery, but one where you know your short-run chance of winning or losing.

That paying for the milk according to quality can introduce large variations in pay per pound of raw milk is easily demonstrated. To do so and also to facilitate comparison between the various methods, a numerical example is provided below.25

<table>
<thead>
<tr>
<th>Raw milk (Pounds)</th>
<th>% cream (Per cent)</th>
<th>By Weight (Kroner)</th>
<th>By Faktor 2 (Kroner)</th>
<th>By Faktor 3 (Kroner)</th>
<th>By Cream units (Kroner)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1688</td>
<td>4.0</td>
<td>57.15</td>
<td>53.44</td>
<td>51.59</td>
<td>50.81</td>
</tr>
<tr>
<td>1272</td>
<td>4.2</td>
<td>43.07</td>
<td>41.39</td>
<td>40.55</td>
<td>40.20</td>
</tr>
<tr>
<td>6045</td>
<td>4.4</td>
<td>204.68</td>
<td>202.03</td>
<td>200.70</td>
<td>200.14</td>
</tr>
<tr>
<td>3060</td>
<td>4.8</td>
<td>103.61</td>
<td>107.65</td>
<td>109.67</td>
<td>110.52</td>
</tr>
<tr>
<td>642</td>
<td>5.2</td>
<td>21.74</td>
<td>23.72</td>
<td>24.70</td>
<td>25.12</td>
</tr>
<tr>
<td>346</td>
<td>5.4</td>
<td>11.72</td>
<td>13.09</td>
<td>13.77</td>
<td>14.06</td>
</tr>
<tr>
<td>98</td>
<td>6.0</td>
<td>3.32</td>
<td>3.97</td>
<td>4.29</td>
<td>4.42</td>
</tr>
</tbody>
</table>

Source: Landbrugets Ordbog.

It assumes that 506 pounds of butter was produced and that the price per pound of butter was 0.88 Kroner. The average cream percentage is 4.5 per cent, so the first three suppliers have milk with below average cream percentage.

The example demonstrates several things. Firstly, as all payment-for-quality systems redistribute around the mean, there are winners and losers.26 Secondly, while four of the suppliers gain from paying according to quality, the three who would lose supply more than 2/3 of the total amount of milk. Thus whether or not payment for quality would be introduced in the example above, could depend not only on how large a majority would be required, but also on issues such as whether the vote was one-member-one vote or one-cow-one vote.

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25 This is taken from Landbrugets Ordbog [the farming dictionary], 1912, Gyldendalske Boghandel, Nordisk Forlag, København.
Thirdly, paying according to cream units penalise "thin" milk more than Faktor 2 while Faktor 3 is close to Cream Units. Thus Faktor 2 is more conservative in its redistributive effects.

Non-adoption could clearly have been caused by the costs of adoption being too high relative to the benefits. There is an important literature on technological change, which argues convincingly that the progress in the adoption of a new technology can be accurately explained by calculating costs and short run economic benefits.\(^\text{27}\) While the benefits in our case are most likely to be achieved in the long-run, it is relevant to consider the costs of adoption, which at a first glance seem modest. The majority of creameries already possessed a control apparatus in order to test for adulteration, so the adoption of quality pay at most involved upgrading to a larger one. Typical sums mentioned are 100-130 Danish Kroner if the old apparatus was returned to the dealer or 225 Kroner for a new device (in 1890). Probably the monitoring costs were the most important. The additional costs to the creamery of extended control, were typically 100 Kroner to the person carrying it out. In addition we must add the costs of members attending the control, an indirect measure of which is the size of the fine for non-attendance, typically 2 Kroner a day. All these costs are modest compared with the annual wage of a fully employed rural labourer in 1897 of 534 Kroner and of a dairy manager of above 2000 Kroner.

For cooperatives, if the aim was either to increase the overall efficiency by improving the herd or to curb adulteration, one would expect that it would be relatively easy to attract the necessary majority to enable a change from quantity to quality. Below we focus on the potentially more contentious issue of the redistributive effects of a new payment system. We will initially assume that all members are risk-neutral, which will make acceptance more likely. Most of the cooperatives made their decisions based on one-member-one-vote, but typically required more than simple majority for any changes to the statutes. We will focus on the case where the decision is by simple majority so that we need to look at the incentives of the median voter. Again this will bias the decision towards acceptance.

\(^\text{26}\) According to Bøggild (1916, p. 243) some farmers with herds of 10-15 cows saw their pay per year change by 100 - 200 Kroner. Given that the pay per cow was typically not much more than 200 Kroner, this translates into 5 to 10%. For those with small herds, he records cases where differences could be as high as 70 Kroner per cow.\(^\text{27}\) In a pioneering article David (1966) examined the adoption of mechanical reaping machines in the Midwest during the 1850s in the light of the development in relative factor prices and rising grain prices. Whatley (1987) explained how an institution, the Southern agrarian contracts hindered the attempts to mechanize cotton picking for quite a long time. Other examples within this tradition are Whatley (1991), Clarke (1994) and White (2000).
Rewrite the expressions for the payment systems in (5), (7) and (A8), setting the suppliers’ share of surplus, \( \alpha = 1 \), the cost of the creamery, \( C = 0 \), and letting \( F_j \) be the relevant multiplier in (6).

\[
W_w = s_i \cdot B \cdot P_B \quad (8)
\]

\[
W_{ Bj} = \frac{F_j}{\lambda} \left( \delta_i - \sum_{j=1}^{n} s_j \cdot \delta_j \right) \cdot s_i \cdot B \cdot P_B + s_i \cdot B \cdot P_B \quad (9)
\]

\[
W_C = \left( \frac{\delta_i - \sum_{j=1}^{n} s_j \cdot \delta_j}{\sum_{j=1}^{n} s_j \cdot \delta_j} \right) \cdot s_i \cdot B \cdot P_B + s_i \cdot B \cdot P_B \quad (10)
\]

where as above, \( s_i \) is the share of supplier \( i \), \( B \) the amount of butter produced, \( P_B \) the price of butter, \( \lambda \) the average butter per milk ratio and \( \delta_i \) the cream percentage of supplier \( i \).

Comparing (8) - (10), it is clear that member \( i \) will benefit from payment according to quality if:

\[
\left( \delta_i - \sum_{j=1}^{n} s_j \cdot \delta_j \right) > 0 \quad (11)
\]

The second term is the weighted average of the cream percentages, where the weights are the shares of the total amount of milk supplied. It is obvious that

**Proposition:** If the distribution of \( \delta_i \) is symmetric and members are risk neutral, the median votes is indifferent between the two payment systems, prefer quantity pay or quality pay depending on whether \( \delta_i \) and \( s_i \) are uncorrelated, positively correlated or negatively correlated.

**Proof:** Given symmetry, the median voter has the mean value of \( \delta_i \). For \( \left( \delta_i - \sum_{i=1}^{n} s_i \cdot \delta_i \right) > 0 \), for the median voter, \( \delta_i \) and \( s_i \) must be negatively correlated. QED

The intuition for the result is that if the members with large herds also have the higher quality milk, then with a quality payment system a large part of the profits go to the top end of the distribution, leaving less for the median voter. It is sometimes argued that members with fewer cows milked more carefully, as it was the owner rather than a milking maid who did the milking. This would give us the negative correlation between size and quality. The testable implication is that cooperatives with more members that have small herds are more likely to switch to quality pay. Looking at the 1903-04 MDS, which contains information on whether or not the creamerries entered have adopted quality pay as well as information on the number of members and the number of members with large and small herds we find no
correlation between size or size distribution and the probability to adopt. Attempting to
explain the probability to adopt on the 1902-03 data was similarly unsuccessful, with neither
the amount of milk supplied, the number of members or the number of cows being significant
explanatory factors. There may be a very simple reason for this. Above we assumed risk-
neutrality. We would intuitively expect the farmers with the small herds to be relatively risk
averse and this makes them less likely to vote for quality pay.

We saw earlier that in implementing Faktor 2, many cooperative creameries made
what looked like a mistake in that they chose to truncate the distribution of \( \delta_i \) at a too low
value. We may be able to offer a perfectly rational reason for this. The effect of truncating \( \delta_i \)
is to lower \( \sum_{j=1}^{n} s_j \cdot \delta_j \) which in turn imply that there will be more winners. Essentially
truncating the distribution from above ensures that many gain a little, while a few lose a lot.
This makes it easier to get the proposed change to the payment system accepted. In other
words the incorrectly low level at which \( \delta_i \) was truncated may have been the necessary
compromise to get the proposal accepted.

We also found another surprising mistake, namely that firms who adopted late and
who used Laktoskopet also chose to use the tables for Faktor 2. Table 13 gives us a first
indication of the consequence of this, namely that the redistribution is less extreme. Formally,
Faktor 2 give a less extreme distribution if

\[
\frac{1}{\sum_{j=1}^{n} s_j \cdot \delta_j} > \frac{F_j}{\lambda} = \frac{F_j}{\sum_{j=1}^{n} s_j \cdot \lambda_j}
\]  

(12)

As \( \delta_j \) and \( \lambda_j \) are closely correlated, establishing when (12) holds is not straightforward. The
average milk per butter ration (1/\( \lambda \)) is rarely below 28 and never below 30. Setting it equal to
the larger amount and use \( F_j = 0.006 \) for Faktor 2, we find that for (12) to hold, the cream
percentage has to be below 5.55%, which given the assumption about 1/\( \lambda \) is highly unlikely.
This may confirm that for at least some of the cooperatives, members were risk-averse. They
dragged their feet for a long time and when they did choose to change, they chose a method,
which led to less variance in their future income. If we recall the story from earlier where a
farmer over time saw both his cream percentage drop from 6% to 5% and his quantity of milk
decrease, it is hardly surprising that members were reluctant to buy into the new riskier
system. Indeed, one could interpret the old system as a means of risk sharing.

In summary, it is possible to give an explanation of both the foot dragging in terms of
adoption and the apparent failures to adopt the correct system when the change is made. If
concerns about the variability and unpredictability of future income were strong, the median voter had no interest in adopting the new method, and where they did, to adopt a method, which either made it less likely that one would be among the losers or which made the losses smaller. Given the general willingness to adopt new technology such as steam power and to listen to the experts, all of whom urged the creameries to adopt quality pay, it is reassuring that at least one potential rational explanation for their behaviour can be found.

6 Conclusion

The paper documents the slow, reluctant and at times inefficient adoption by cooperative creameries of a technology, which not only led to a fairer division of the surplus but also had better incentive properties. One might have thought that the new technology would appeal to either the social aspect of cooperatives so often claimed to be their motivation, or their wish to make money, which seems to fit the Danish model better. However, the short-run effects of the new methods were largely to reallocate a fixed amount of surplus from butter making, implying that change created both losers as well as winners. The long-run effects may be positive, but at least initially also uncertain, increasing the risk faced by each supplier. Finally, monitoring the monitor was costly. As the introduction required a change to the statutes of the cooperative, something, which typically required more than just simple majority, and as most used one-member-one-vote, the outcome of a proposal to change is not immediately obvious. When looking at the details from creameries, we saw that many struggled with the introduction through many general meetings.

Of the three broad arguments in favour of payment according to quality, fairness, positive incentives (herd improvements and new members) and negative incentives (fraud prevention), our data provide little support for the first and third and little direct information about the second. If fairness was an important motivation, then why the procrastination? Why the slow diffusion, especially when most of the creameries had the necessary measuring technology long before they introduced payment according to quality? If the aim was fraud prevention, why did only one of the 20 creameries with recurrent problems of adulteration introduce quality pay immediately after their first case? Remember that most of those waited more than 10 years. And, unless the transactions costs of the payment method is larger than the transaction costs of monitoring and enforcing the statutes, what are we to make of table 3, where those who adopt see no significant short-term impact on their efficiency. Of course there is no reason for why there should be one single reason. Motives may indeed have been
very mixed.

For a group in society who, as argued in Nielsen (2003), were generally technology friendly and savvy, there were two surprises in the data. One is that they often did not use the correct procedure given the technology they had purchased. The other is that when they did adopt, they did not adopt the current best practice. This is particularly odd since the technology was up-to-date, it was the implementation which was not. As demonstrated in Van der Vleuten (1994) the Danish creameries were very quick to introduce steam power and steam powered cream separators. Similarly, Nielsen (2003) show how quick they are to introduce other new inventions, such as better lactic bacteria. We may be able to understand the reluctance to update the methodology from, say, Faktor 2 to Cream Units, since this would require yet another change in the statues. If the introduction had been traumatic enough maybe no one wanted to open up old wounds. Section 7 offered an alternative explanation. The apparently inefficient adoption mitigated the potential losses and created relatively more winners, thus enabling the adoption in the first place.

Most of the evidence has come from cooperatives. One of the possibly surprising facts about the development of the creamery sector is that over time while cooperatives thrived, private creameries did not, see Bjørn (1977) and Henriksen (1999). Explaining this evolution is still a challenge. Looking at the introduction of payment for quality may provide us with at least a glimmer of an alternative explanation. An unnamed owner of a private creamery, writing in Mælkeritidende (1903, p. 576-580) makes the observation that it was simply not feasible for him to introduce payment for quality with his suppliers. To see the point he is making, note that only those with quality milk have something to gain from the change and only those would do so. Because a private creamery could not force those with thin milk to alter their contract, introducing quality pay was not a case of reallocating the amount due for the milk from one group to another. Furthermore, trusting a private firm with test results of quality is clearly much more problematic as the owner of a creamery would benefit directly from cheating on the measurement. This is illustrated in Drejer (1937, 77-8), see also Henriksen (1999), in the context of bacon factories in Denmark where suppliers did not trust private firms to weigh the pigs correctly. It is also found in Balbach (1998) in the context of sugar beet, where only cooperatives adopted a payment related to the sugar content.

28 There is thus a parallel with the arguments for the emergence Merchant Guild put forward by Greif et al. (1994). The owner of a private creamery might be able to pick off farmers one at the time and under-pay, but if they are organised, this is no longer the case.
The historical case documented here reminds us that just because firms adopt new technology, they may not necessarily put it to its best use. In many cases, the benefits from new technology do not come from having the state of the art version, but how the technology is being used. Thus we may undervalue new technology because the effect on productivity following adoption appears slight. The challenge is to get observations both on the adoption of the technology and on whether or not it is used as it was intended or to its potential.

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Appendix A. Derivations for section 2

(i) Comparison of (3) and (5)

Differentiating (5) w.r.t. \( m_i \) we get after rearrangement:

\[
P_B \cdot \lambda + P_B \cdot (1-s_i) \cdot s_i \cdot \lambda_i - s_i \cdot \frac{dC(m)}{dm} - (1-s_i) \cdot AC(m) > 0 \tag{A1}
\]

Comparing (4) and (A1), we see that the last two terms are identical. Thus the incentive to supply for supplier \( i \) is increased if we pay according to quality if

\[
P_B \cdot \lambda + P_B \cdot (1-s_i) \cdot s_i \cdot \lambda_i > P_B \cdot \lambda_i \tag{A2}
\]

from which it is clear that those with high quality has a disincentive to supply. Finally, differentiating (5) w.r.t. \( m_i \), keeping \( \lambda_i \cdot m_i \) constant, we get:

\[
(1-s_i) \cdot P_B \cdot \lambda - s_i \cdot \frac{dC(m)}{dm} - (1-s_i) \cdot AC(m) > 0 \tag{A3}
\]

Compared to (3), where there was no incentive for this form of adulteration, so long as the average value of the milk, \( \lambda P_B \) is greater than average costs, at least the smaller suppliers have an incentive to add water to the milk.

(ii) Illustrating the incentive effect of the typical quantity payment methods.

The amount of skimmed milk is approximately the difference between the amount of raw milk and butter. Where no cheese was produced, the amount returned was typically proportional to the amount supplied, \( s_i \cdot (m-\lambda \cdot m) = m_i \cdot (1-\lambda) \). The net surplus of the creamery can then be written as

\[
\hat{\Pi} = P_B \cdot \sum_{j=1}^{n} m_j \cdot \lambda_j + m \cdot (1-\lambda) \cdot P_s - \lambda \cdot m \cdot \bar{P}_B - C(m) \tag{A4}
\]

The return to member \( i \) can be written as

\[
\hat{w}_i = \bar{\lambda} \cdot m_i \cdot \bar{P}_B - m_i \cdot (1-\lambda) \cdot P_s + s_i \cdot \hat{\Pi} \tag{A5}
\]

which we can rewrite as

\[
\hat{w}_i = P_B \cdot m_i \cdot \sum_{j=1}^{n} s_j \cdot \lambda_j - s_i \cdot C(m) \tag{A6}
\]

which (for \( \alpha = 1 \)) is equal to (5) and therefore share the same related incentive properties. Note that if a private creamery had used a similar payment method, but the net surplus was not returned to the suppliers, each supplier would have little incentive to increase
\( \lambda_i \) (the only incentive comes from there being less skimmed milk) but a strong incentive to increase \( m_i \) (as the creamery pay more for the raw milk than they charge for the skimmed milk). The incentive problems are thus greater for a private creamery.

As costs depended on the quantity of milk processed, an alternative, and possibly more correct, to pay for costs was through a levy on the milk supplied. If instead the real butter price and the true average butter per pound of milk ratio was used together with a levy of \( \beta \) per pound of milk to cover costs, total net surplus would be:

\[
\hat{\Pi}' = P_B \cdot \sum_{i=1}^{n} \lambda_i \cdot m_i + \beta \cdot m - \lambda \cdot m \cdot P_B - C(m) \quad \text{(A7)}
\]

However, if the supplier get his share of the net surplus, the payoff for the individual member is still given by (5) and the incentive problems remain. A private creamery would still face a greater incentive problem than a cooperative, but it would be less acute than those arising from the more common payment method.

(iii) A payment system based on a conversion to cream or fat per cent

A payment system, which was independent of the measurement apparatus used was based on converting the supply of each farmer into the amount of milk with 1% cream, \( m_i \cdot \delta_i \) (or fat, \( m_i \cdot \phi_i \)) and then pay for the milk according to each supplier's share of that, \( \tilde{s}_i = m_i \cdot \delta_i / \sum_{j=1}^{n} m_j \cdot \delta_j \). Using cream percentage, the payment would then be:

\[
\tilde{w}_i = \alpha \cdot \left( \frac{m_i \cdot \delta_i \cdot P_B \cdot B - s_i \cdot C(m)}{\sum_{j=1}^{n} m_j \cdot \delta_j} \right) \quad \text{(A8)}
\]

so that for a cooperative with \( \alpha = 1 \), surplus would be zero. Note that for compatibility with the other measures, we can extract the implied estimate of \( \lambda_i \) from (A8) as

\[
\tilde{\lambda}_i = \frac{\delta_i}{\sum_{j=1}^{n} \delta_j} \cdot \lambda \quad \text{(A9)}
\]