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Milk quota and the development of Irish dairy productivity: a Malmquist index using a stochastic frontier approach

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Several studies of the Irish dairy productivity and efficiency have been carried out in recent history, but none have been able to use Irish farm level data going back before milk quota's implementation. This study uses recently digitized data going back as far as 1979 to examine trends in an index of Total Factor Productivity (TFP) constructed from the parameters of Greene's 'true random effects' specification of the stochastic frontier. There is some evidence that the implementation of milk quota was associated with a general decrease in TFP, and the series also moves in line with changes in the policy which liberalised quota trade. Technical efficiency and scale efficiency are dominated by movements of the frontier as represented by the technical change component of the index.

Keywords

TFP; Total Factor Productivity; Malmquist; Stochastic Frontier; Milk Quota; Dairy; Efficiency

JEL codes: C5, O13 , Q12

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1. Introduction

The dairy sector across Europe is on the precipice of a post-quota era. A major production constraint will be lifted with milk quota's abolition in 2015; hence there is much interest in the policy from both an academic and from an industrial perspective. It is a good time to stand back from this policy—which has been an institution of European agriculture for 30 years—to assess its long term effects on production capacity. To this end, the present study examines trends in an index of Total Factor Productivity (TFP) constructed from a microeconometric model.

Several studies of the Irish dairy productivity and efficiency have been carried out in recent history. Matthews (2000), Boyle (2004), and Donnelan et al. (2009) invoke aggregate level approaches, whilst Newman and Matthews (2006, 2007), O'Neill and Matthews (2001), and O'Neill et al. (2002) use micro level data. However, none have been able to use Irish farm level data going back before milk quota's implementation because these data have only recently been made available in digital format.

The need to understand the impact of milk quota is felt most accutely in Ireland. Bovine production systems dominate here, and dairy in particular has enjoyed a long ascendancy in terms of relative importance. Specialist dairy farms were the most profitable in Ireland on a per hectare basis in 2012; the mean family farm income per hectare on dairy farms was €887 as compared to the corresponding figure of €541 for all farms. Dairy farms typically derive a larger share of their profits from market income than do other types of farms, and a larger proportion of dairy farms are therefore classed as 'economically viable' than is the case for other systems of farming. Dairy farms are tightly linked with the beef industry, both because many dairy farms have a substantial beef enterprise on them, and because roughly 80 per cent of dairy calves are sold into the beef sector every year, thus providing a key input for that system. The dairy industry is an important source of jobs in the rural economy by employing tens of thousands both in primary production and in the processing sector. Finally, Ireland is self sufficient in dairy production several times over, and this makes it a larger player in the global milk trade than its small size would otherwise imply.

Much of the research attempting to forecast the EU response to quota abolition predicts a large expansion of Irish production (Binfield et al, 2008; Bouamra-mechemeche and Jongeneel, 2008; and Lips and Rieder, 2005). This result is of obvious relevance to other dairy exporting Member States, and indeed global particpants in the milk trade. This expansion is already underway in milk quota's final year; average gross new investment per dairy farm stood at €19,558 in 2012, and this was more than double the figure for all farms at €8,173 (Teagasc, 2012). At the time of writing, dairy output was progressing at a rate which is 6.9 percent over Ireland's final quota allocation, implying a substantial superlevy in the policy's departing year.

It would appear then that Ireland is well—situated to take advantage of a post-quota era in milk production. Donnellan et al. found that Irish dairying enjoys a highly degree of competitiveness owing to its low cost production system. This cost advantage is mainly driven by a comparative advantage in inexpensive grass inputs.

However, there are concerns over how the years of production constraints may have affected Ireland's competitiveness. The Donnellan et al. study itself notes that Ireland's cost advantage is significantly eroded if proper economic value is attributed to unpaid (mainly family) labour input. Irish production is also typified by sub-optimal scale and a low level of capital intensity which further damages international rankings. The Donnellan et al. paper also notes that competitor countries which have freer quota trading systems tend also to do better in those aspects, although causality is not established.

Hennessy et al. (2009) construct a linear programming model which quantifies the inefficiencies associated with the 'ring-fenced' design of Irish quota trade, itself only in operation since 2007/2008. Mathematical programming excercises of this sort were also employed in Kirke and Moss (1987), and later Colman (2000) regarding dairy production in Northern Ireland specifically in the former, and the United Kingdom more broadly in the latter. Colman et al. (2001) also give a good demonstration of an econometric approach using the specification of ad hoc cost functions. They use these estimates to simulate various changes to quota implementation, and to draw conclusions in relation to structural change and efficiency. All of these studies conclude that milk quota is associated with decreased efficiency, or that the distribution of quota is far from optimal with respect to an efficient allocation.

Meanwhile, Newman and Matthews (2006, 2007) provides a model paper for this analysis with those also authors also choosing stochastic frontiers methods to construct Total Factor Productivity indices whilst specifically analysing Irish dairy farm data. They find higher rates of TFP growth amongst specialist dairy farms, but also some evidence of a slowing down of this growth.

Matthews also completed an earlier stochastic frontier study with O'Neill (2001) in which technical efficiency was measured, but no overall TFP index was calculated in that work. They too found that technical efficiency tended to be higher on dairy farms, but the analysis was flawed in that it assumed a common frontier for all systems of farming in Ireland, i.e. that a common technology was available to all farms.

This analysis aims to expand on the literature around milk quota and in the realm of productivity analysis more generally by employing a panel of specialist dairy farms which includes observations for five years before 1984. Hence it is now possible to observe the development of TFP and its components as the implementation of milk quota first took place in Ireland. This will give a sense of the impact of the policy on the productive capacity of the dairy sector.

The paper is organised as follows. Section 2 gives the evolution of the policy and explores the economic theory which pertains to it, concluding with statements of the main research questions addressed. Section 3 sets forth the particular methodology employed in this research. Section 4 describes the data set used. Section 5 reports the results, and Section 6 draws conclusions from those results.

2. Context, theory and research questions

To state that the dairy sector is less reliant on direct payments than other farm systems is not to say that it is fully liberalised. Most Irish dairy farms have a substantial beef enterprise, so dairy farms may draw supports related to that commodity in the same manner as more specialised beef producers. Furthermore, several market based supports are still enshrined in the CAP. Indeed, it was the market distortions initiated in Reg. 804/68 (SP OJ 1968 (1)) which provided the need for some form of policy-based production control.

The first attempt at curtailing production was a co-responsibility levy in Reg. 1079/77 (OJ 131 26-5-77) in 1977, but this was of only minor effect (Fennel, 1987). This was followed on by various guarantee limits in 1981, but it would take the introduction of quotas in 1984 with Reg. 856/84 (OJ L90, 1-4-84) before any real levelling-out of production could be said to have taken place in Ireland.

Since the introduction of milk quota there have been various adjustments to the policy. Several EU wide reductions to Member State’s national allocations took place in the 1980’s. Quota was at first ‘attached to the land’, but this was relaxed as part of reforms to the CAP in 1993, and the different Member States have since allowed various amounts of freedom in quota markets. There have also been a number of increases to national quota allocations in the 1990’s, around the Agenda 2000 reforms, and most recently five straight years of one or two per cent increases starting in 2009.

In Ireland, quota redistribution was handled administratively until 2007/08 when a 'ring-fenced' market mechanism was put into place. Prior to this, redistribution was carried out on the basis of various restructuring schemes at prices set by the State, and with the link to the land largely maintained. Even since the establishment of a market mechanism, 30 per cent of traded quota had to be made available for 'priority pools' at the statutory price, with access to this pool being reserved for classes of producers which were designated in the Irish legislation. The priority pools tended to make quota more difficult for larger, more commercial operations to obtain quota, and this may have adversely affected sectoral productivity and efficiency.

Other policies of consequence in the timeline include a Milk Outgoers scheme in 1986 Reg 1336/86 (OJ L119, 8-5-86) which incentivised permanent cessation of dairy production amongst marginal producers, and several changes to intervention buying-in of butter and skimmed milk powders in Reg. 773/87, 774/87, 777/87 (OJ L78, 20-3-87) in 1987. Another noteworthy change was the exclusion of salted butter from any intervention buying, which is moderately consequential in Ireland and the United Kingdom (UK) as most butter produced in this region is of the salted variety.

Theory predicts several ways in which quota may have affected technical efficiency:

a. **Through farm entry and exit**—Giving farms a legal right to produce on the basis of historical production prevents the imposition of market discipline, i.e. lowest cost (hence most profitable) producers cannot expand their market share at the expense of higher cost producers whom either choose not to sell, or else cannot sell because of restrictions on quota trade.

b. **Sub-optimal scale**—artificially restricting output has the effect of cementing less than optimal scale of production. An example of such efficiency losses would be the under-utilisation of tractors and other farm equipment. This particular effect may have been pronounced in Ireland, as quota administrative policy has actively sought to preserve the number of farms in production rather than the efficiency of that production.

c. **Uncertainty in production**—farmers must make decisions regarding the buying of inputs and the setting of a target for output each year. Unlike most other industries, farm production is a biological process which has a high dependency on suitable weather conditions, so accurately predicting annual output with high precision presents quite a challenge. This is made all the more complicated by the existence of superlevies which will consume all profits from over-quota production without compensation for the inputs which were embodied therein. As a result, many farms do not fill all of their quota in any given year, and there will be some waste associated with this phenomenon. Some farms also take the gamble that the national quota will not be filled. In this case, unused quota is allocated to the over-quota production, thereby avoiding superlevies. This scenario rewards speculators, but these may or may not be the most efficient producers.

d. **Disincentive to investment**—related to sub-optimal scale and increased uncertainty, another way inefficiency may enter the system is through dissuading farmers from maintaining an adequate level of investment. Sluggish investment both prevents the implementation of more efficient technologies, such as automated daiiry parlours, and also results in the degradation of existing capital which requires a base level of maintenance.

Given the theoretical effects stated above, it is proposed that any TFP index which includes data from before and after the implementation of the milk quota in 1984 should register a disimprovment around this time. Furthermore, as quota became more freely traded, and in-line with previous research on the topic, it is expected that TFP should improve, reflecting greater efficiency in the system. The components of TFP should point to the drivers of change in productivity. There is an *a priori* expectation that scale efficiency and technical efficiency will be negatively affected. However, previous research shows that technical change tends to drive TFP both in Ireland, and in Europe more generally, so this will likely still be the most influential component. Furthermore, technical change is conceptualised as movements in the entire frontier over time. As quota was applicable to all producers, it is expected that technical change will register an adverse effect from the policy's implementation.

3. Methodology

The methodology followed in this analysis is very close to that in Newman and Mattews (2006). A stochastic frontier model is specified, the parameters of which are then used to construct a Generalised Malmquist index of Total Factor Productivity (TFP). The index is then decomposed into three constituent parts á la Orea (2002), i.e. technical change, technical efficiency change, and scale effects.

Newman and Matthews specified a distance function in their work, but this analysis uses a production function approach instead. The main benefit of the former is that it accomodates multi-output production systems. This is a desirable property in a whole-farm model, given that Irish dairy farms are—without exception—multiple output production systems. However, the focus of this work is on the dairy enterprise as distinct from the other business activities which are undertaken on these farms, so there is less need to accommodate non-milk sources of revenue which are minimal by comparison. Moreover, the difference may be purely semantic, as a single-output, output-orientated distance function has an econometric specification which is equivalent to a standard production function (Coelli et al., 2005; p. 331), i.e. this may be viewed as a special case of the more general specification used by Newman and Matthews. The final simplified equation for the index given in their paper is reproduced for the reader's benefit below. The supporting equations are omitted in the interest of brevity.

$$\ln G_{oi} = \ln M_{oi} \frac{1}{2}\left[\sum_{k=1}^{K}\left(-\sum_{k=1}^{K}\frac{\partial \ln D_{oi}^{t+1}}{\partial \ln x_{ki}} - 1\right)\epsilon_{ki}^{t+1} + \left(-\sum_{k=1}^{K}\frac{\partial D_{io}^{t}}{\partial \ln x_{ki}} - 1\right)\epsilon_{ki}^{t}\right] ln\left(\frac{x_{ki}^{t+1}}{x_{ki}^{t}}\right).$$

where G_{oi} is the Generalised Malmquist index, M_{oi} is the standard Malmquist index, the D_{oi} terms are values of a distance function which are equivalent to the inverse of technical efficiency supplied by the model with $TE = \exp(-u)$,and ϵ_{ki} are (in this case) input elasticities.

Particular attention is paid to the issue of farm heterogeneity via the use of Greene's (2005) 'true' random effects model. This is a panel model, and it is also estimated through Maximum Likelihood, but it is qualitatively different in that it allows for the inefficiency term's time path to vary over individual farms.

$$\ln y_{it} = (\alpha + w_i) + \mathbf{B}'\ln \boldsymbol{x_{it}} + v_{it} - u_{it}$$

$$v \sim N[0, \sigma^2]$$

$$u \sim |N[0, \sigma^2]|$$

$$w \sim with\ 0\ mean\ and\ finite\ variance$$

The equation above defines Greene's 'true random effects' specification of the stochastic frontier which supply the parameters for the TFP index and its components. The model is a special case of a random parameters type of model, where the only parameter which is treated as random is w_i, i.e. part of the component constant term. The model is estimated using the translog functional form, so $\mathbf{B}'\ln \boldsymbol{x_{it}}$ should be understood to contain all the primary and quadratic terms necessary for the specification.

There are several advantages to this type of approach. Firstly, the use of the stochastic frontier framework incorporates a random element in the description of the efficient frontier, thus removing it from the measure of inefficiency being estimated. This is a major reason SFA has found favour in agricultural applications, as this sector is exposed to wider range of random shocks than most (e.g. poor weather), but it does require assumptions regarding the functional form of the frontier and the distribution of the inefficiency term. Data Envelopment Analysis (DEA) provides an alternative approach which has no such requirements, but this comes at the cost of using a purely deterministic model, although more recent iterations of these models do attempt to incorporate randomness in some fashion.

Another benefit of the approach is that it is possible to calculate farm level measures of technical efficiency. Furthermore, all of these methods all have established statistical properties; hence, it is possible to carry out hypothesis tests on several quantities of interest. This cannot be done with DEA.

The choice to model the production relationship, rather than a cost, revenue, or profit function relieves the need to make behavioural assumptions concerning the objective function, i.e. profit maximising, or equivalently cost minimising behaviour. This is particularly useful in the context of Irish agriculture where such assumptions are seemingly contradicted by the data, although this is less of a concern for Irish specialist dairy farm data which less frequently frustrate standard theory. However, this comes at the cost of sacrificing the ability to quantify economic concepts of efficiency; the model can only inform the reader about technical aspects of production.

4. Data

The National Farm Survey (NFS) provides an unbalanced panel of specialist dairy farms with observations recorded from as long ago as 1979 and as recently as 2012. The survey is conducted on a voluntary basis annually by Teagasc, the Food and Agriculture Authority of Ireland. It is a high quality micro level dataset, with measures of economic, sociographic, and technical variables all of which are collected by professional farm recorders, often with the aid of farm accounting documents provided during the interview. The NFS is also the national liason for the Farm Accountancy Data Network (FADN).

The sample includes data from 1,844 farms which participated at any point during 1979-2012, yielding a total of 9434 observations. Though the panel spans 34 years, most respondents contribute for a far shorter period than this with average duration at 5.1 years, and the interquartile range of participation being 2 to 7 years.

The variables of interest in this analysis consist of the portion of farm gross output directly attributable to the dairy enterprise as the dependent variable, and five regressors which capture the various types of inputs of this business activity. These are the 12 month average number of dairy cows, variable costs, capital expenditure, labour input in standard man days, and dairy forage area in hectares.

The inclusion of monetized variables is both a concession due to a lack of quanity variables in the cases of certain inputs, and also an allowance for some aggregation of otherwise unreconcilable measures, eg. a tractor and a farm building. A similar argument could be made for different classes of outputs, eg. a cull cow and a litre of milk cannot be meaningfully combined except in monetary terms. The need for some variable aggregation stems from the nature of the translog production function used to estimate the model, as it specifies several interactions and squared terms for each input in the primary model. As Newman and Matthews (2006, pg. 196) point out, the aggregation process also alleviates problems concerning the translog functional form's inability to manage zero valued observations of modelled variables.

Variable costs include concentrate feeds, costs associated with pasture production (mainly fertilisers) and expenditure on lime. Capital expenditure consists of upkeep of land, machinery, and buildings, all of which are not specific to the dairy enterprise, but have been allocated proportionate to the ratio of dairy gross ouputs to total farm gross output per farm per year.These measures, being nominal, have all been deflated using appropriate commondity specific price indices obtained from the Central Statistics Office (CSO), hence allowing them to be used as an aggregated volume measure. The same procedure has been carried out for the other monetized variable in the model, i.e. dairy gross output, which is the dependent variable.

Finally, it is important to note a few substantial differences in the NFS methodology just at the point of the introduction of milk quota in 1984. The NFS follows a random stratified sample design to ensure the national representativeness of the data within size and production system 'cells'. Prior to 1984, the sample was expanded or contracted as necessary to ensure it's representativeness within the overall farming population, but since 1984 the sample number is essentially fixed prior to collection, and a system of weights is employed to achieve representivity. This leads to a situation whereby the sample has a noticably different distribution across categories of farm size prior to, and after the change in methodolgy.

Furthermore, the entire panel of farms was resampled in this same year. Thus the panel nature of the data cannot be fully exploited for 1984. This should not adversely affect the TFP index because it is constructed from sample averages (which will still be representative) and because measures will be taken to account for differences in sample design in the model.

5. Results

The parameters for the frontier model are reported below in Table 2. Herd size and direct costs (mainly feed and fertilisers) are the dominant inputs, and four of the five primary terms are statistically significant at the 99 percent level. Not shown are the time dummy variables included in the model. All of these were significant at the 99 percent level as well, barring 4 individual years for which were not statistically significant at all.

Table 3 reports (weighted) mean input elasticities and technical efficiency scores for a selection of individual years. The function was generally increasing in inputs, as theory dictates, but slightly increasing returns to scale were present for most of the panel, and the first five years show negative signs on the labour inputs, but after this point all input elasticities were positive. The estimated returns to scale associated with this production function were 1.073 in 1979, but this gradually decreased to roughly constant returns to scale by the final years.

The overall level of TE is generally high, and increasing over time. This is a positive sign for the development of the sector, but it also in part due to the increasing homogeneity of the group of farms classified as specialist dairy producers. The 'true random effects' specification also has the effect increasing TE, as the random farm effect (meant to capture farm heterogeneity) absorbs some of the variation in output that would otherwise be attributed to inefficiency.

Figure **1** plots the cumulative index and its components. After an initial rise in 1980 to 1983, TFP falls quite substantially with further drops observed until the late 1980's when the series stabilises. However, it must be emphasized that the discontinuity in the series observed in 1984 will also be due to the methodological changes in the sample's design, so the authors make no assertion as to the magnitude of the effect in 1984. Instead, we focus on growth rates before and after the discontinuity, which should give a clearer effect and are of more interest.

One important aspect which the figure reveals is that change in TFP growth is primarily driven by movements in the productive frontier which is represented by the technical change component. This is in agreement with other studies examining both Ireland specifically and for Western Europe generally for this time period.

Surprisingly, the scale change component is never adversely affected at all in the entire period of the sample. This may be a failure of the model to adequately measure the effects of milk quota on the counterfactual scale which would have existed had the policy never existed. It may also be the case that some of the effect on scale is actually being captured by movements in the frontier itself, i.e. the technical change component of the model. Another explanation may lie in the fact that the quota limits themselves were based on historical production which was already high. The first few years do exhibit a flat trend in the scale change series; consistent scale growth is only evident from the early 1990's, and this coincides with the beginnings of quota trade liberalisation. A slight increase in the scale change series is also visible from 2007 onwards, which is when a market mechanism for quota was implemented, and which also coincides with annual incremental increases in the national quota allocation from the EU.

Table 4 summarises the linear growth rates visible from the figure above. The overall growth rate was weakly positive, indicative of the fact that the series did not return to the 1979 level until the mid-1990's. The technical change component was the largest component, and it accounted for over half of total growth in the series. Scale change was the next most influential, and it was positive as well. As was apparent from the figure above, technical efficiency change was negligible.

Technical efficiency change is remarkably static throughout the panel. The largest change is an increase of 0.05 percent in the growth rate for this component of TFP. This occurred in the five years period after milk quota was introduced, but this period also saw an EU wide Milk Outgoers scheme which incentivised permanent cessation of dairy production amongst marginal producers. This may be tentative evidence of a positive effect from that policy. If less efficient farms exited milk production at this time, then that would explain why average technical efficiency improved, both because the remaining farms were objectively more efficient, and because the group of remaining farms would have been more homogenous. However, changes in this component are minimal.

A general tendency for stronger and positive growth rates was observed as the panel advances through the various reforms of the CAP and milk quota policy. In the pre-quota period the series is at its strongest growth rate, but this is almost entirely due to technical change. As the series progress through the various eras of the policy, overall growth weakens dramatically, then recovers to mild rates, and scale change become increasingly important. However, these growth rates (below 1 perc cent per annum) are low by international standards, and they indicate a technically constrained system.

6. Conclusion

The results presented in this paper harmonise well with the theory associated with milk quota's implementation as put forth in Hennessy and Srestha (2007), ie. that milk quota has been associated with a loss of efficiency, but that this has become less egregious as the policy has allowed for more liberalised trading of quota, thus giving more efficient producers the ability to expand their market share.

In relation to the hypotheses set out in Section 2, this analysis finds some evidence that the implementation of milk quota was associated with a general decrease in TFP, and in particular productivity growth rates seem to have suffered as the policy was first implemented. Furthermore, productivity does improve over time, and inflection points in the series appear with changes in the policy which theory points to as significant.

Technical efficiency is negatively affected in the early years of milk quota, but improves around the time of the Milk Outgoers scheme. This is followed by a flat trend, indicative of a certain degree of stagnation. However, it must be said that levels of TE are quite high throughout the sample, so this may just be the effect of being near 'the ceiling'.

An unexpected result is given by the fact that scale efficiency is at no point in a state of regress. The scale series remained essentially flat until the early 1990's. The series started showing consistent improvement from then. That time period saw a freeing up of quota trade and increases in the national allocation of milk quota. A stronger improvement is recorded since the establishment of a quota market mechanism, although this also coincided with annual increases quota, which will make discerning the relative importance of the market mechanism difficult.

The results suggest that movements of the frontier have been far more influential than the average distance from it. Dairy farms are, and have been, highly technically efficient throughout the sample, when full account is given for the technology that has hitherto been available in Ireland. Whether or not the nature of that technological relationship is fundamentally changed by the abolition of milk quota is an open question.

The dominance of the technical change component and the stable TEC component imply that sector wide developments have been more influential on TFP than have individual farm decisions. Changes to milk quotas are the most salient examples of such a factor. With the abolition of quotas this year, one may expect both that TC will increase in a positive direction, and also that TEC may fall as individual farms find innovative ways to expand their production, thus separating themselves from the rest. In such a scenario, policies which encourage widespread adoption of innovative technologies, and extension programmes which aid farms in selecting appropriate modes of expansion will be well placed.

Given the increasing importance of scale efficiency presented here, policies which promote the upscaling of production will positively affect productivity. At this point, achieving efficient scale is as important as improving the available technology.

A final note concerns the limitations of this analysis. Production of any sort often entails negative externalities, and this is also true in dairy systems. Negative effects on the environment, animal welfare, and rural development all fit into this category. While this analysis supports the hypothesis that milk quotas adversely affected sectoral productivity it may also have avoided several of these externalities, and that was not explicitly accounted for in this work. Consideration of such issues must temper the discussion of how best to develop the dairy sector in the future.

Tables and Figures

Table 1 Summary statistics

	Specialist dairy farms (n = 9434)			
	Mean	Standard Deviation	Minimum	Maximum
Size (Ha)	39	24	4	394
Dairy gross ouput (€, base = 2000)	55,946	48,447	139	747,429
Herd size (dairy cows)	41	27	9	441
Direct costs (€, base = 2000)	15,426	13,824	119	289,719
Capital (€, base = 2000)	46,567	47,561	143	603,024

Table 2 Frontier primary and quadratic parameters

Herd (head)	0.70	***	(0.007)
DC (real €)	0.20	***	(0.003)
Capital (real €)	0.05	***	(0.002)
Labour (days)	0.04	***	(0.005)
Forage (ha)	0.03	*	(0.005)
$Herd^2$	-0.08	***	(0.02)
Herd: DC	-0.10	***	(0.02)
Herd:Captial	0.03	*	(0.009)
Herd:Labour	0.10		(0.02)
Herd:Forage	0.03	***	(0.02)
$DC:^2$	0.03	***	(0.005)
DC:Capital	-0.01	**	(0.005)
DC:Labour	0.01	***	(0.01)
DC:Forage	0.02	***	(0.01)
$Capital^2$	0.00		(0.002)
Capital:Labour	0.00	***	(0.006)
Capital:Forage	-0.01	***	(0.006)
$Labour^2$	-0.03	***	(0.006)
Labour:Forage	-0.03	*	(0.02)
$Forage^2$	-0.01	***	(0.009)

* , ** , *** = 90, 95, and 99% confidence

Herd = 12 mo. average no. dairy cows,
DC = Direct Costs, i.e. variable costs which are directly attributable to the dairy enterprise on the farm,
Capital = investment in buildings and machinery,
Labour = standard man days,
Forage = farm forage area allocated to dairy herd

Table 3 Technical efficiency (TE) output elasticities,

and returns to scale (RTS)

		Output elasticities					
	TE	Herd	DC	Capital	Labour	Forage	RTS
1979	0.91	0.86	0.17	0.05	-0.01	0.01	1.07
1980	0.91	0.85	0.17	0.05	-0.01	0.01	1.07
1981	0.91	0.88	0.18	0.04	-0.03	0.01	1.08
1982	0.92	0.84	0.18	0.05	-0.01	0.02	1.07
1983	0.91	0.83	0.18	0.04	-0.01	0.02	1.06
1984	0.91	0.78	0.19	0.05	0.01	0.03	1.06
1985	0.91	0.79	0.18	0.05	0.01	0.03	1.06
1986	0.90	0.80	0.19	0.05	0.00	0.03	1.07
1987	0.91	0.79	0.19	0.05	0.00	0.03	1.06
1988	0.92	0.79	0.20	0.05	0.00	0.03	1.07
1989	0.91	0.78	0.20	0.04	0.01	0.03	1.06
1990	0.92	0.77	0.20	0.05	0.01	0.03	1.06
1991	0.92	0.77	0.19	0.05	0.02	0.03	1.06
1992	0.92	0.77	0.20	0.05	0.01	0.03	1.06
1993	0.92	0.75	0.20	0.04	0.02	0.04	1.05
1994	0.91	0.75	0.21	0.04	0.02	0.04	1.05
1995	0.92	0.74	0.21	0.04	0.02	0.04	1.05
1996	0.91	0.74	0.20	0.05	0.02	0.04	1.05
1997	0.91	0.74	0.19	0.05	0.03	0.04	1.04
1998	0.91	0.73	0.20	0.04	0.03	0.04	1.04
1999	0.91	0.72	0.21	0.04	0.03	0.04	1.04
2000	0.91	0.72	0.20	0.04	0.03	0.04	1.04
2001	0.92	0.71	0.20	0.04	0.04	0.04	1.03
2002	0.91	0.70	0.21	0.04	0.04	0.04	1.03
2003	0.91	0.71	0.20	0.04	0.04	0.04	1.03
2004	0.91	0.70	0.20	0.05	0.04	0.04	1.03
2005	0.91	0.70	0.20	0.05	0.04	0.04	1.02
2006	0.91	0.70	0.21	0.04	0.04	0.03	1.02
2007	0.91	0.71	0.21	0.04	0.04	0.03	1.02
2008	0.91	0.71	0.19	0.05	0.05	0.03	1.02
2009	0.90	0.69	0.19	0.05	0.05	0.04	1.02
2010	0.91	0.69	0.20	0.05	0.05	0.04	1.02
2011	0.92	0.67	0.19	0.05	0.06	0.04	1.00
2012	0.91	0.65	0.20	0.05	0.06	0.04	1.00

TE = technical efficiency

RTS = returns to scale

Figure 1 Cumulative TFP index (base = 1979)

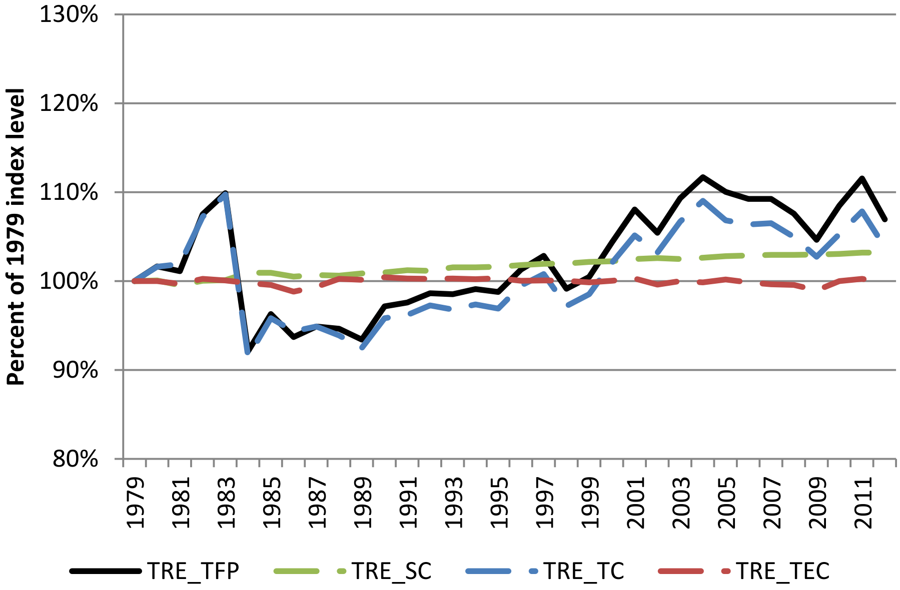

Table 4 Productivity change and decomposition on dairy farms 1979 -- 2012

	Generalized Malmquist TFP	Scale change	Technical change	Technical efficiency change
		<u>Period linear growth rates</u>		
		Entire panel		
1979 – 2012	0.20%	0.09%	0.11%	-0.01%
		Pre-quota		
1979 – 1983	1.91%	0.02%	1.87%	0.01%
		Restrictive quota		
1984 – 1989	0.23%	-0.01%	0.18%	0.06%
		Mac Sherry era		
1990 – 1994	0.39%	0.11%	0.32%	-0.04%
1995 – 1999	0.34%	0.10%	0.33%	-0.09%
		Agenda 2000 and quota trade		
2000 – 2008	0.34%	0.08%	0.32%	-0.05%
2008 – 2012	0.54%	0.06%	0.26%	0.22%

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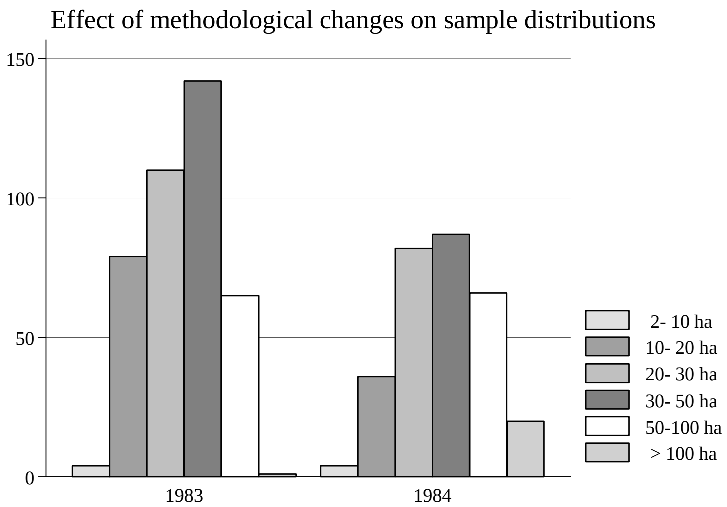
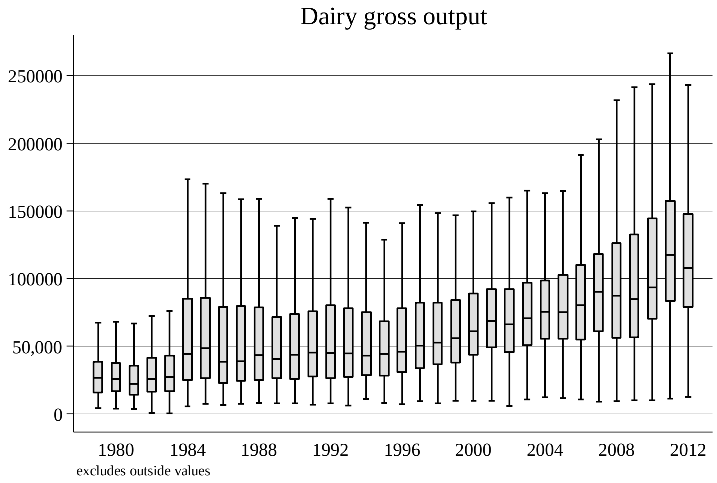
Appendix

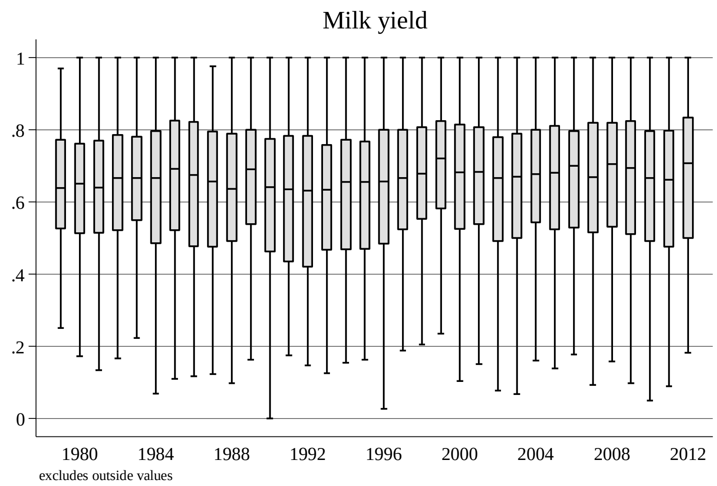
The year 1984 brought with it not only a major new policy in the form of milk quota, but also a substantial methodological change in the collection of farm data by the NFS. In the years prior, the national representativeness of the sample was accomplished by continuing the selection of farms until the sample resembled a scaled version of the farming population in terms of the desired criterion (of which size and system were a part). From 1984 onwards, the sampling procedure was brought in line with the EU methodology which underpins the Farm Accountancy Data Network's data, and in a similar way the national representativeness of the sample is now accomplished through a weighting scheme.

The effects of this change can be seen in the size distributions of the sample in the years surrounding the change.



This difference in the composition of the sample will sometimes affect the distributions of variables of interest, ie. means will be skewed if the variables vary appreciably and systematically across the size distribution of farms. The dairy output of the farm i.e. (the dependent variable of the production function) exhibits such sensitivity, whilst average milk yield shows virtually no response to the change in sample design.

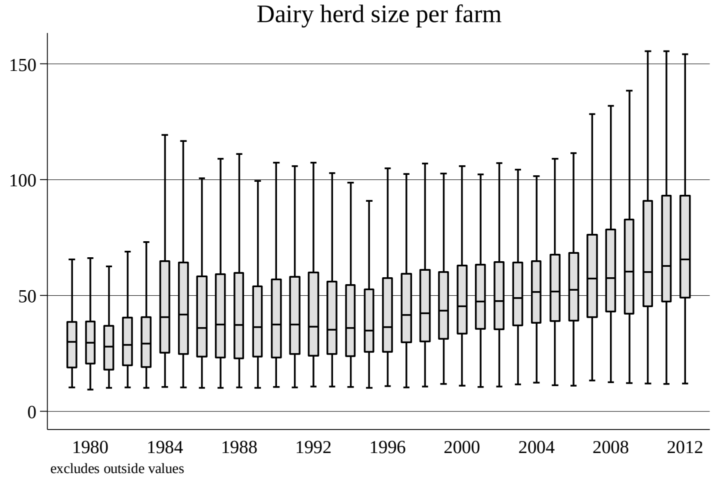




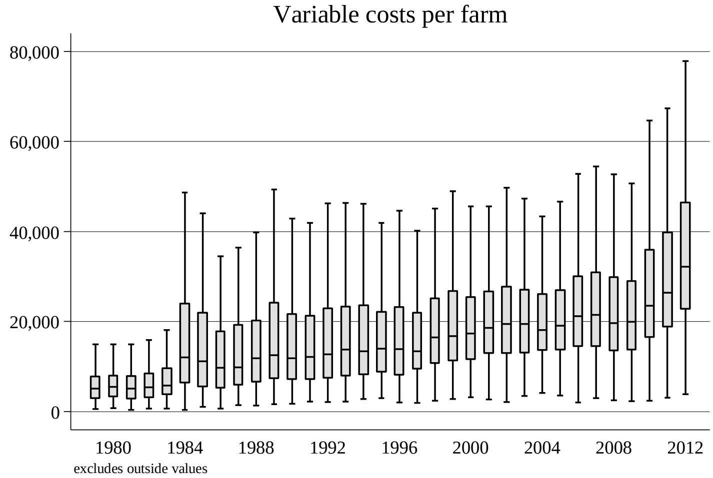
The extent to which these methodological changes matter depends on the sensitivity of the other regressors to the change in frequencies within the size strata. The figure below shows the degree of discontinuity in the data for right-hand side variables of the model. It is apparent that the different distributions do have an effect on the regressors. What effect, if any, these discontinuities in the data will have on parameter esimtates is unclear, but the “within transformation” cannot be relied on to rescue the models alone, so it was deemed a necessary precaution to include dummy variables for the classes of the size distribution to control for the possibly obscuring effects of the change in sample design and thereby avoid spurious results. Changes in definition of farm systems also occurred over time, but this was not the case for the specialist dairy system. Since this analysis is confined to a subset of the farms classified in that system, no extra measures need to be taken along this dimension of the data.

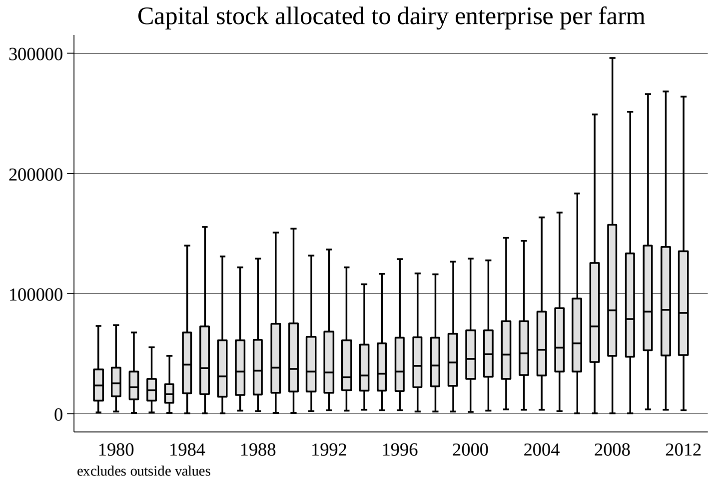
The concerns mentioned above pertain to the effect of the change in sampling methods on parameter estimates. The validity of generating descriptive statistics from the data is not in question, as the weights used to achieve representativeness in the originally published annual reports were available, and they were used to calculate any such figures.

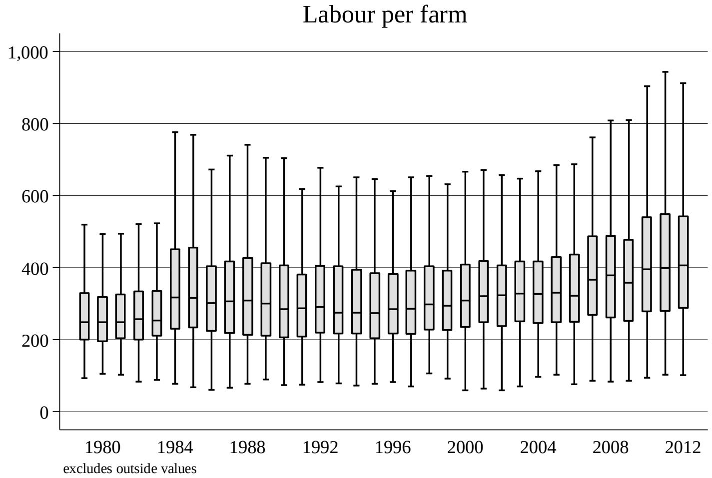
Dairy herd size per farm

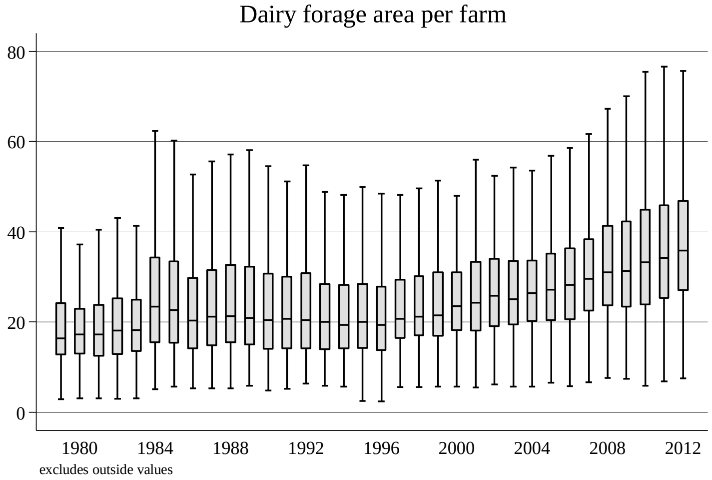


Variable costs per farm




Capital stock allocated to dairy enterprise per farm
300000
200000
100000
0
1980
1984
1988
1992
1996
2000
2004
2008
2012
excludes outside values


Labour per farm
1,000
800
600
400
200
0
1980
1984
1988
1992
1996
2000
2004
2008
2012
excludes outside values


Dairy forage area per farm
80
60
40
20
0
1980
1984
1988
1992
1996
2000
2004
2008
2012
excludes outside values

Various hypothesis test are presented in the tables below. These include specification tests for functional form and inclusion of time dummies and control variables. The hypothesis of constant returns to scale (CRS) is rejected at the 99 per cent confidence level.

Several variants of the SF model were estimated, with the TRE model being selected as the best compromise between theoretical and econometric considerations. A Hausman test supports selection of a fixed effects panel model, but the relation of this test to the SF breed of models is, as yet, unclear. Furthermore, the True Fixed Effects (TFE) model violates monotonicity and 2nd order conditions at most data points in this panel.

Specification tests of dairy enterprise production technology

H_0 Cobb-Douglas production function
H_A Translog production function
Statistic: 165.40
Critical Value: $\chi_{15,0.01} = 30.58$
Reject null at 1% significance

H_0 Translog, no technical change
H_A Translog, neutral technical change
Statistic: 1116.00
Critical Value: $\chi_{33,0.01} = 54.78$
Reject null at 1% significance

H_0 Translog, neutral technical change, no sampling controls
H_A Translog, neutral technical change, with sampling controls
Statistic: 18.35
Critical Value: $\chi_{5,0.01} = 15.09$
Reject null at 1% significance

Hausman test for RE vs. FE (estimates from OLS panel regression used)
H_0 Farm effect is uncorrelated with error term (RE is favoured)
H_A Farm effect is correlated with error term (FE is favoured)
Statistic: 685.81
p-value: $p_{57,0.05} = 0.00$
Reject null at 5% significance

Percentages of sample meeting theoretical regularity conditions

	Monotonicity	Diminishing marginal product	Monotonicity & Diminishing Marginal Product
Pitt-Lee	84	96	84
Battese – Coelli	84	96	84
True Random Effects	76	86	76
True Fixed Effects	2	0	0

Correlations amongst model estimates of inefficiency parameter

	PL	BC	TRE	TFE
PL	1.00	0.99	0.42	0.28
BC	0.99	1.00	0.43	0.28
TRE	0.42	0.43	1.00	0.90
TFE	0.28	0.28	0.90	1.00

PL – Pitt-Lee, BC – Battese-Coelli, TRE – True Random Effects, TFE – True Fixed Effects

Regularity conditions for translog production function (evaluated at sample means)

	Monotonicity	Diminishing marginal product	Quasi-concavity
Pitt-Lee	F	F	NF
Battese – Coelli	F	F	NF
True Random Effects	F	F	NF
True Fixed Effects	NF	NF	NF

F = condition fulfilled, NF = condition not fulfilled

Quasi-concavity evaluated on the basis of eigenvalues of the bordered Hessian matrix. Negative values for all eigenvalues indicate a negative semi-definite matrix, which is a necessary and sufficient condition for local concavity.

Hypothesis tests of constant returns to scale

	Wald Statistic $\chi^2_{6,0.05}$	p-value	Conclusion
Pitt-Lee	157.35	0.00	VRS
Battese – Coelli	154.67	0.00	VRS
True Random Effects	210.42	0.00	VRS
True Fixed Effects	147.03	0.00	VRS

CRS – constant returns to scale, VRS – variable returns to scale.