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# Gains and structural effects of exploiting scale-economies in Norwegian dairy production

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## Abstract

In this paper, we present calculations of the economic gains in terms of reduced costs by exploiting scale-economies in dairy production in Norway, and the effect this would have had on the number of farms. We also explore whether or not optimal scale and unexploited scale-economies change over time due to scale-augmenting technical change.

The analysis is based on homothetic cost functions estimated by means of data for individual dairy farms for the period 1972–1996. For 1972, we find that, by full exploitation of scale-economies, the costs could have been reduced by almost 40%, while the number of farms would have been reduced by more than 85%. The number of small farms has been substantially reduced in the period considered. This fact, combined with small scale-augmenting technical change, implies that the gains and structural effects of exploiting scale-economies have decreased over time. In 1996, costs could have been reduced by close to 30% by full exploitation of scale-economies, while the number of farms would have been reduced by slightly more than 70%. Thus, both gains and structural effects are substantially less than in 1972. Nevertheless, the calculated gains for 1996 make almost 5 billion NOK. This corresponds almost exactly to the total public support to the dairy farms in 1996.

The unexploited scale-economies are largely due to the agricultural policy. Thus, a substantial share of the same can be considered as part of the ‘price’ the Norwegian society has to pay for this policy. In addition, there are likely to be large hidden costs of this policy due in particular to the quota system and other direct production regulations. They imply that technical innovations and other efficiency-improving investments requiring increased production to be profitable are not carried out. This is the more likely explanation for the extremely poor efficiency development in Norwegian dairy production in the period studied. © 2001 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

Previous studies suggest that there are substantial economies of scale in Norwegian dairy production (Aarseth and Elstrand, 1991; Hatling and Lylum,

1993; Giæver et al., 1995; Flaten and Giæver, 1998). An explanation for these findings is likely to be the Norwegian agricultural policy, which has a comprehensive system of economic support and regulations.

This policy allows profitable production even for very small units in spite of disadvantages of a small scale of operation. Thus, the owners have an economic incentive to use the land themselves instead of renting it out to others. Moreover, the legal

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framework for renting of land is poorly developed. The system for trade of land is quite restrictive, and since 1983, there has been a system of production quotas that regulates the volume of production of each dairy farm. Until 1997, i.e. after the period considered by us, the quotas were non-tradable. Thus, there are legal and institutional restrictions on the exploitation of scale-economies in Norwegian dairy production.

As suggested by studies from countries with widely different topography and agricultural policy, there are also more general explanations for unexploited scale-economies in dairy production, cf. for instance Matulich (1978), Mochini (1988, 1990), and Bailey et al. (1997) for the US, and Dawson and Hubbard (1987), Mukhtar and Dawson (1990), Burton et al. (1993) and Hubbard (1993) for Great Britain. Analyses of scale-economies of other industries also suggest that a large majority of the firms for some reason are of sub-optimal size (Christensen and Greene (1976) for US electricity production, Ringstad (1974, 1979) for Norwegian manufacturing and Ringstad and Løyland (1998) for Norwegian day care centers).

Christensen and Greene (1976) and Ringstad and Løyland (1999) strongly suggest that technical change tends to increase scale-economies over time, i.e. that there is scale-augmenting technical change; cf. also Levin (1977) and Kerkvliet et al. (1998). As far as we know, no study has been carried out on this issue for Norwegian dairy production. One piece of evidence, however, which suggests scale-augmenting technical change in this branch of agriculture, is the fact that more recent studies like those of Hatling and Lylum (1993) and Giæver et al. (1995) provide larger estimates on the degree of economies of scale than older ones like that of Ringstad (1967). Corresponding evidence for the US is found by comparing the results of the studies referred to above with those of older studies, surveyed by Hallam (1993).

The following issues will be explored in this paper:

- Do economies of scale exist in Norwegian dairy production, and if so,
- is there an optimal scale of operation?
- Does optimal scale change over time, i.e. is there scale-augmenting technical change?
- What are the potential economic gains, and the effects on the number of farms of exploiting any scale-economies?

These issues will be explored by means of cost functions. The first issue could be analyzed by assuming a Cobb–Douglas specification of the underlying production function. This specification makes it difficult to estimate the gains and structural effects of exploiting scale-economies, however, since it implies a constant scale-elasticity. If this elasticity is below unity, there are diseconomies of scale, while there are infinite scale-economies if the scale-elasticity is above unity.

Instead, we use production function specifications which allow for positive but limited economies of scale. Homothetic functions with a scale-elasticity decreasing with production from values above unity to values below unity have this property. They imply a cost-optimal scale of operation where the scale-elasticity is exactly unity since this corresponds to the minimum of the average cost function.

The gains of exploiting the scale-economies of a farm of sub-optimal size can be calculated as the difference between the estimated costs of this farm and what it costs to produce the same amount by a farm of optimal size. By ‘transferring’ the production of all sub-optimal farms to optimal ones in this way, we obtain estimates of the total gains of exploiting the scale-economies of dairy production in Norway, and the effects this would have had on the number of farms (Ringstad, 1979; Ringstad and Løyland, 1999).

In Section 2, we present some main elements of the public support system for Norwegian dairy production. The details of the theoretical framework for the exploration of the main issues are discussed in Section 3, while the data and the variable definitions used are presented in Section 4. In Section 5, we discuss the estimated cost functions results, and in Section 6, we present some calculations of the economic gains and the effects on the number of farms of exploiting scale-economies. Section 7 includes a discussion of potential sources of errors and Section 8 contains a brief summary of the main findings of this study.

## 2. Main elements of the support system of Norwegian dairy production

There are three basic objectives of the Norwegian agricultural policy:<sup>1</sup>

<sup>1</sup> Cf. Brunstad et al. (1995) for more details.

1. Food security.
2. Prevention of depopulation in remote areas.
3. Environmental aspects: preservation of agricultural landscape and reduced risk related to the diffusion of human and livestock diseases.

The means used to obtain these objectives consist of a comprehensive system of support, regulation and protection of agricultural production. Related systems are used in most other developed countries, but the total support for Norwegian agriculture is much larger than for most of them. In 1995, it made up about 74% of the total value of production as compared to 41% for the OECD average (OECD, 1996).

The support of dairy production mainly derives from producer price support, acreage subsidies,

livestock subsidies, and support to cover the costs of stand-in workers during vacations etc. The producer price support consists of four elements: a monopoly price element, obtained by means of a legal dairy monopoly owned by the farmers, an ordinary production subsidy, an operating subsidy to production of up to 30 tonnes, and a production subsidy differentiated by region. 'Basic price' in Table 1 is the sum of the monopoly price and the ordinary production subsidy. The regional subsidy is differentiated between 11 different regions. It also includes transport subsidies.

The system of production quotas for each farm introduced in 1983 was combined with a two-price system. The producer price support applies to the production quota only. The basic price for any

Table 1  
The support system of Norwegian dairy production (in 1996-prices)<sup>a</sup>

Year	Basic price	Operating subsidy	Regional subsidy	Acreage subsidy	Livestock subsidy	Stand-in worker subsidy <sup>b</sup>	Basic price+ total support	Total support <sup>c</sup>
1972	4.68	0.00	0.42	0.00	0.00	0.00	5.10	747
1973	4.51	0.00	0.43	0.00	0.00	0.00	4.94	756
1974	4.67	0.01	0.43	0.00	0.00	0.00	5.12	787
1975	4.91	0.13	0.47	0.00	0.44	0.00	5.95	1861
1976	5.05	0.40	0.55	0.00	0.45	0.12	6.56	2767
1977	5.10	0.56	0.55	0.00	0.48	0.16	6.84	3188
1978	5.08	0.67	0.54	0.00	0.53	0.26	7.08	3620
1979	4.90	0.67	0.52	0.00	0.58	0.26	6.94	3731
1980	4.69	0.70	0.48	0.00	0.56	0.23	6.66	3761
1981	4.40	0.78	0.46	0.00	0.70	0.24	6.58	4166
1982	4.11	0.82	0.45	0.26	0.70	0.34	6.67	5049
1983	3.79	0.87	0.43	0.27	0.66	0.37	6.39	5052
1984	3.77	0.93	0.44	0.26	0.65	0.35	6.41	5112
1985	3.91	1.03	0.45	0.26	0.63	0.33	6.61	5129
1986	4.12	1.10	0.47	0.26	0.47	0.30	6.72	4938
1987	3.94	1.12	0.47	0.29	0.46	0.29	6.57	5077
1988	3.92	1.17	0.47	0.31	0.56	0.32	6.74	5272
1989	3.99	1.14	0.50	0.34	0.51	0.33	6.81	5382
1990	4.00	1.11	0.49	0.36	0.51	0.33	6.79	5338
1991	3.93	1.11	0.40	0.46	0.62	0.32	6.84	5417
1992	3.98	1.07	0.32	0.53	0.65	0.34	6.89	5394
1993	3.61	1.04	0.30	0.54	0.64	0.33	6.45	5265
1994	3.56	0.98	0.28	0.54	0.63	0.35	6.34	5000
1995	3.36	0.88	0.26	0.66	0.53	0.33	6.02	4712
1996	3.35	0.85	0.25	0.77	0.46	0.33	6.00	4627

<sup>a</sup> Source: Norwegian Agricultural Economics Research Institute (NAERI) and Statistics Norway. Basic price and the various subsidies are in NOK per kilo. Total support in the final column is in million NOK.

<sup>b</sup> Support to cover the costs of labor hired during vacations etc. for the farmers.

<sup>c</sup> Does not include the monopoly- or the ordinary production subsidies elements of basic price. In 1996, the ordinary production subsidies were about 350 million NOK.

production above the quota is much lower, and there are no operating or regional subsidies.<sup>2</sup>

The various types of support to total dairy production in Norway in the period covered by our analysis are presented in Table 1. Note that the various subsidies per kilo, and thus, also the sum of basic price and total support, are averages, and vary widely between farms, in particular, by size and region. Acreage subsidies, livestock subsidies and stand-in worker subsidies are for agricultural production in general. Those for dairy production have been estimated, using the share of dairy products (with jointly produced beef) in total agricultural production value as weight for the former, and its share of total livestock production for the other two.

Due to incomplete information, the ordinary production subsidies are not included in total support. In 1996, they made about 350 million NOK, which implies a total support to the dairy farms this year of almost 5 billion NOK.

There are some other types of support as well, such as investment subsidies, and publicly financed crop insurance arrangements. These subsidies are of minor importance, as compared to those included in Table 1.

### 3. The theoretical framework

#### 3.1. The specification of scale-properties of the production function

Our theoretical point of departure is a single output production function:

$$Y = f(X) \quad (1)$$

where  $Y$  is output and  $X$  a vector of inputs.

The scale-elasticity is defined as

$$\varepsilon(X) = \sum_i \left( \frac{\partial Y}{\partial X_i} \right) \left( \frac{X_i}{Y} \right), \quad (2)$$

i.e. the percentage change in  $Y$  by a 1% increase in all inputs.

<sup>2</sup> In 1983–1984, the above-quota price was 1 NOK per liter (=0.97 NOK per kilo), in 1985–1987, 0.6 NOK per liter, in 1988–1991, 0.3 NOK per liter and in 1992–1996, 0.15 NOK per liter, all in nominal prices. Taking the increased price level in this period into account, there has obviously been a steep decrease in the above-quota price since this system was introduced.

Homothetic production functions are characterized by a scale-elasticity depending on production only, and not on the input-mix, with a constant elasticity as a special case.<sup>3</sup> A sub-class of homothetic production functions has a scale-elasticity decreasing monotonically with production, from values above unity to values below unity, which implies a U-shaped average cost function with a minimum where the scale-elasticity is exactly unity.

Focusing on scale-properties, as we do in this study, homothetic production functions offer attractive specifications. In contrast to more flexible functional forms, like translog-functions, fewer parameters have to be estimated, and they offer unique estimates of optimal scale as the level of production where the average cost function has its minimum. In this way, we are likely to obtain about the same results as we would have done by estimating a fully specified translog-function and calculating the average cost function and optimal scale for the sample means of the factor-prices.

In this study, we will use two homothetic production function specifications of this kind, introduced by Nerlove (1963) and Zellner and Revankar (1969), respectively, both of which have the Cobb–Douglas production function as a special case.<sup>4</sup> We also use a combined version, introduced by Ringstad (1974), that makes it possible to test whether or not one specification is better than the other one. Moreover, the two specifications selected allow us to test if the average cost function actually is U-shaped, with a Cobb–Douglas specification as the null-hypothesis.

The cost function corresponding to a Cobb–Douglas specification is (in logarithms, and ignoring the intercept term)

$$\ln C = \alpha \ln Y + \phi'Z, \quad (3)$$

where  $C$  stands for costs and  $Z$  is a vector of other variables like factor-prices and characteristics of the production activities. Production is assumed to be exogenously given, which is quite reasonable since the production of each farm has been regulated by quotas during most of the period studied.

<sup>3</sup> Cf. Førsund (1975) for a survey of homothetic production functions.

<sup>4</sup> The analysis could easily be made slightly more general by not assuming an elasticity of substitution equal to unity implied by our specification; cf. Ringstad (1979).

In this case, the scale-elasticity is

$$\varepsilon = \frac{1}{\alpha}. \quad (4)$$

The cost function corresponding to the Nerlove specification is

$$\ln C = \alpha \ln Y + \beta (\ln Y)^2 + \varphi' Z, \quad (5)$$

with the scale-elasticity

$$\varepsilon(Y) = \frac{1}{\alpha + 2\beta \ln Y}. \quad (6)$$

Correspondingly, the Zellner–Revankar specification implies the cost function

$$\ln C = \alpha \ln Y + \gamma Y + \varphi' Z, \quad (7)$$

with the scale-elasticity

$$\varepsilon(Y) = \frac{1}{\alpha + \gamma Y}. \quad (8)$$

By combining the two specifications, we get

$$\ln C = \alpha \ln Y + \beta (\ln Y)^2 + \gamma Y + \varphi' Z, \quad (9)$$

which implies

$$\varepsilon(Y) = \frac{1}{\alpha + 2\beta \ln Y + \gamma Y}. \quad (10)$$

All cost functions are estimated by means of ordinary least squares. By assuming normally and independently distributed error terms, the specification of scale-properties could be tested by a two-level test procedure; cf. Fig. 1. At Level 1, both the Nerlove specification ( $\gamma=0$ ) and the Zellner–Revankar specification ( $\beta=0$ ) serve as null-hypotheses with the combined specification in (9) as the alternative hypothesis in both tests. If both null-hypotheses are rejected, our results suggest that they are both too simple to represent the scale-properties properly. If one null-hypothesis is rejected, but not the other, our results suggest that the non-rejected hypothesis could be a proper specification. In this case, the winning specification could be tested at Level 2 with the Cobb–Douglas specification ( $\beta=\gamma=0$ ) as the null-hypothesis. If the null-hypothesis is rejected, the alternative hypothesis is the final winner. If not, the Cobb–Douglas specification wins.

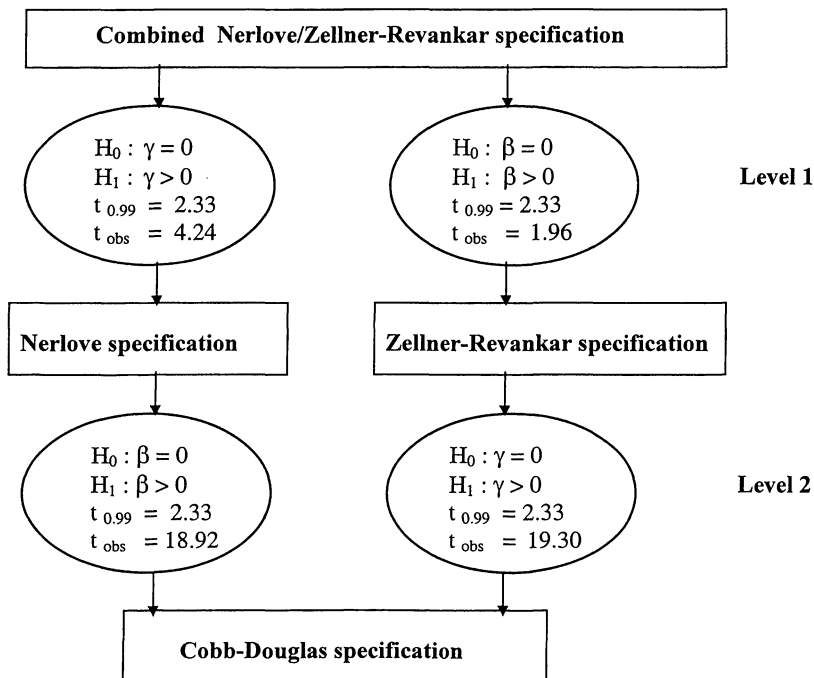


Fig. 1. Test of the form of the production function for dairy production.

### 3.2. The specification of technical change

The main focus concerning technical change is on its possible interaction with economies of scale, in particular, optimal scale of operation. To explore this issue, we introduce a trend and an interaction term between trend and production in the cost function. Thus, in the more general case in (9), we have

$$\ln C = \alpha \ln Y + \beta (\ln Y)^2 + \gamma Y + \eta t + \mu t \ln Y + \varphi' Z, \quad (11)$$

where  $t$  is measured in years.

The trend-modified version of (10) becomes

$$\varepsilon(Y, t) = \frac{1}{\alpha + 2\beta \ln Y + \gamma Y + \mu t}. \quad (12)$$

Scale-augmenting technical change as suggested by Christensen and Greene (1976), Levin (1977), Kerkvliet et al. (1998) and Ringstad and Løyland (1999) implies that  $\mu < 0$ , which is easily tested by an ordinary  $t$ -test. We note that the constraints  $\beta = \gamma = 0$ ,  $\gamma = 0$ , and  $\beta = 0$  in the expression in (12) provide ‘technical change-extended’ versions of (4), (6), and (8), respectively.

### 3.3. Calculation of gains and structural effects of exploiting scale-economies

Since optimal scale implies  $\varepsilon(Y) = 1$ , we obtain optimal scale from the Nerlove specification (ignoring technical change) as

$$Y_N^{\text{opt}} = \exp \left[ \frac{1 - \alpha}{2\beta} \right]. \quad (13)$$

For the Zellner–Revankar specification, we obtain correspondingly

$$Y_{Z-R}^{\text{opt}} = \frac{1 - \alpha}{\gamma} \quad (14)$$

while we cannot get any explicit solution for optimal scale from the combined specification. It could be found in various other ways, however, for instance by numerical calculation from

$$\alpha + 2\beta \ln Y + \gamma Y = 1. \quad (15)$$

If  $\mu \neq 0$ , we can calculate optimal scale for year  $t$  by substituting  $\alpha + \mu t$  for  $\alpha$ . Thus, for the Nerlove specification, we have

$$Y_N^{\text{opt}} = \exp \left[ \frac{1 - \alpha - \mu t}{2\beta} \right] \quad (16)$$

and correspondingly for the Zellner–Revankar and the combined Nerlove/Zellner–Revankar specification.

Using the same method as in Ringstad (1979), and Ringstad and Løyland (1999), we obtain an estimate of the gains of exploiting scale-economies in dairy production by substituting farms with optimal size for the sub-optimal ones for the same total quantity of milk produced. Thus, we first calculate the number of farms of optimal size needed to produce the same amount of milk as the sub-optimal farms in year  $t$ , i.e.

$$n_t^{\text{opt}} = \frac{\sum_i Y_{it}^{\text{opt}}}{Y_t^{\text{opt}}}. \quad (17)$$

We then obtain an estimate on the relative gain of exploiting scale-economies for Norwegian dairy production in year  $t$  as

$$\frac{\sum_i C_{it}^{\text{opt}} - n_t^{\text{opt}} C_t^{\text{opt}}}{\sum_i C_{it}}. \quad (18)$$

There is an argument for a corresponding ‘transformation’ of the super-optimal units, but we have not performed it. Anyway, it turns out to make very little difference in our case due in part to few farms of super-optimal size, and partly due to small differences in unit costs between optimal and super-optimal farms.

## 4. Data and variable definitions

### 4.1. The data

The data used in the estimation of cost function are mainly based on the ‘Account Results in Agriculture and Forestry’ (ARAF) for 1972–1996, collected by the Norwegian Agricultural Economics Research Institute (NAERI). They consist of information about size of holdings, land use, crop yields, livestock production, various inputs, producer prices, agricultural assets, investments, depreciation, sales, grants etc. for about 1000 farms each year. About 200 of them have taken

part in the survey during the whole period. In addition, we use price data published by Statistics Norway for four types of inputs, specified later.

The total sample consists of about 25 000 observations. Our analyses are limited to farms with milk as the main product. They also have some beef production, but mostly as a joint product to milk. Thus, our sample is smaller — an unbalanced panel data set of 11 069 observations.<sup>5</sup>

To calculate the gains and structural effects of exploiting scale-economies, we also use information about the farms of an ‘estimated’ population of dairy farms corresponding roughly to the sample. Thus, our population does not include all milk producers. Information for 1994 suggests that close to 90% are, however, included.

The population data provide information about acreage and number of cows, but no information about production. Thus, production is calculated ad hoc by means of a ‘production function’ estimated by ordinary least squares on the sample data, where production data are available. This function is specified as follows:

$$\begin{aligned} \ln Y = & \theta + \varphi_1 \ln AC + \varphi_2 \ln CO \\ & + \varphi_3 t + \omega_1 [\ln AC]^2 + \omega_2 [\ln CO]^2 + \omega_3 t^2 \\ & + \omega_4 [\ln AC][\ln CO] + \omega_5 [\ln AC]t \\ & + \omega_6 [\ln CO]t + u, \end{aligned} \quad (19)$$

where AC is acreage (in hectares), CO the number of cows and  $t$  a trend,  $t = 0, 1, \dots, 24$  for the years 1972–1996.

We have data for each year in the period 1972–1996, except 1979, 1989 and 1991. The annual populations are obtained by means of annual surveys carried out by Statistics Norway. For the years 1972–1978, the surveys covered 10% of the farms with 0.5–9.99 ha (1 ha=10 000 m<sup>2</sup>=2.47 acres), 20% of those between 10 and 49.99 ha, and all of those with 50 ha or more. The population is estimated by letting each farm in the survey sample with 0.5–9.99 ha represent 10 farms, and each of the farms of the middle-sized group represent five farms. By adding the biggest units, we obtain an ‘estimated’ population of dairy farms for each year in this period. After 1979, the surveys consist of

10% of the farms with 0.5–9.99 ha, 20% of those with 10–19.99 ha, 33% of those with 20–49.99 ha and all of those with 50 ha or more, and the annual populations are ‘estimated’ correspondingly.<sup>6</sup>

In Table 2, we present the size-distribution of the farms in the population and the ARAF-sample for 1972 and 1996. In Table 3, a corresponding size-distribution by the number of cows is presented.<sup>7</sup> We note that the size-distribution has changed substantially, with less of small farms and many more large ones in 1996. In 1972, almost 75% had less than 10 ha, while about 5% had 20 ha or more. In 1996, about 20% had less than 10 ha and almost 28% had 20 ha or more. Table 3 shows a corresponding picture.

The sample we use is quite small as compared to the population. Note, however, that we use the data for all years in the cost-function estimation. Since the population is decreasing over time while the sample is increasing slightly, the sample-share of the population increases from less than 0.7% in 1972 to about 2% in 1996.

We also note that small farms are heavily under-represented in our sample in 1972, while the biggest farms are correspondingly over-represented. Due to the substantial reduction in the number of small farms in the population, the size-distribution of our sample corresponds fairly well to the population in 1996. There are a few other problems of representativeness when using this sample for our purpose. We return to these issues when presenting the results obtained.

#### 4.2. Variable definitions

The production variable,  $Y$ , is an aggregate of milk and beef. Both components are measured in kilo units. Milk consists mainly of milk for sale. Thus, own use of milk is not included since it is mostly used as input in beef production which is measured as the weight added to the livestock during the year minus the weight of any lost livestock. It is calculated in milk

<sup>5</sup> On the average, the share of milk in total production value is about 76%. Almost all of the rest is joint product-beef.

<sup>6</sup> Some small corrections are made in this ‘estimation’ due, among other things, to differences in the response percentages for the various size-groups.

<sup>7</sup> The number of cows is actually what we, analogous to man-years, could denote ‘cow-years’, i.e. the number of ‘cows’ is obtained by weighting each by the share of the year it is in production.



Table 2

Size-distribution, by acreage, of dairy farms in Norway

Size-group (ha)	1972				1996			
	All farms		Sample		All farms		Sample	
	No. of farms	Percent of total	No. of farms	Percent of total	No. of farms	Percent of total	No. of farms	Percent of total
0.5–4.99	18183	33.9	11	3.0	468	2.1	2	0.5
5–9.99	21885	40.8	122	33.8	4006	18.2	43	9.8
10–19.99	10809	20.2	189	52.4	11459	52.0	249	56.4
20–49.99	2594	4.8	39	10.8	5927	26.9	146	33.1
50+	156	0.3	0	0	184	0.8	1	0.2
Total	53627	100	361	100	22044	100	441	100

equivalents by multiplying the beef production by the average relative meat/milk-price for each year. Thus, our production measure is milk production in kilo units plus beef production in milk equivalents.

Variable costs ( $C_V$ ) consist of the costs of four categories of inputs:

1. Labor input.
2. Fertilizers and lime.
3. Concentrated feed.
4. Other inputs, mainly seeds, veterinary costs and medicines.

The main part of labor input consists of the work of owners and family members. The corresponding labor costs are calculated as the average wage rate (with social costs included) for hired labor in forestry and agriculture, multiplied by the number of hours worked by owners and family members according to the NAERI data. Adding these costs to the costs of hired labor (with social costs included), we get total labor costs.

Total costs ( $C_T$ ) consist of variable costs plus capital costs, where capital costs are the sum of interest costs on the total capital stock, depreciation costs, maintenance costs, and costs of hiring machines and land. For maintenance and hiring costs, we have detailed and reliable information. In the ARAF sample, depreciation costs are calculated as a percentage of historical costs, with a different percentage for different capital assets. At one extreme, we have land, where it is 0, and on the other, we have machines with 10%, i.e. a linear depreciation over 10 years.

There are several sources of errors in this capital measure. The more important one is due to the fact that the economic life for most assets is much longer than the depreciation period. This implies too large capital costs for farms with more recent investments and too small capital costs for those with mainly old assets. Another corresponding error is caused by appreciation of the capital value to market value by change of ownership.

Table 3

Size-distribution, by number of cows, of dairy farms in Norway

Size-group in no. of cows	1972				1996			
	All farms		Sample		All farms		Sample	
	No. of farms	Percent of total	No. of farms	Percent of total	No. of farms	Percent of total	No. of farms	Percent of total
0–4.99	21102	39.3	16	4.4	629	2.9	4	0.9
5–9.99	20392	38.1	129	35.7	6061	27.5	101	22.9
10–19.99	10129	18.9	172	47.7	12526	56.8	300	68.0
20–49.99	1959	3.6	44	12.2	2776	12.6	36	8.2
50+	45	0.1	0	0	52	0.2	0	0
Total	53627	100	361	100	22044	100	441	100

Table 4  
Sample statistics for the main variables<sup>a</sup>

Variable		Mean	S.D.	Minimum	Maximum
Production in kilo units of milk+beef in milk equivalents	$\ln Y$	11.43673 (92664)	0.49270	8.14650	12.82102
	$Y$	103402	46921	3451	369912
Variable costs in NOK, in 1996-prices	$\ln C_V$	13.22087 (551761)	0.33023	11.48570	14.31219
	$C_V$	581345	186700	97314	1643260
Total costs=variable costs+capital costs, in NOK, in 1996-prices	$\ln C_T$	13.41626 (670823)	0.36335	11.48407	14.64352
	$C_T$	713671	245158	97156	2288750

<sup>a</sup> Geometric means in parentheses.

In Table 4, we present sample statistics for the production and costs variables used in the calculations. Costs are inflated by the consumer price index and are calculated in 1996-prices. In addition, we use price indices for the four categories of variable inputs explained above. They are obtained from the Statistical Yearbooks of Norway (1973–1997).

## 5. The cost function results

All relationships estimated are cost functions. Thus, variable costs and total costs, measured as explained in the previous section, are the dependent variables in all calculations presented in this section. All relationships also contain production as an independent variable. In addition, only input prices are included. The results concerning the main issues (cf. Section 1) may be sensitive to how the input prices are treated. Since they vary along the time-dimension only, the results concerning the degree and nature of technical change are likely to be particularly sensitive. We have no proper price for capital. Thus, this issue is explored for variable costs only.

To explore the robustness of the results of the way input prices are treated, five sets of calculations are carried out:

1. No input prices are included.
2. Input prices are included with no restrictions on input elasticities. This implies that the scale-elasticity is, however, over-identified.
3. Input prices are included, but a restriction is added to provide a unique estimate on the scale-elasticity.
4. The parameters of input prices are estimated by factor-shares. This method also provides a unique estimate on the scale-elasticity.

5. To allow for non-neutral technical change, the parameters of input prices are estimated by factor-shares for each year. While this allows for systematic (as well as unsystematic) changes in the factor-elasticities over time, their variation with scale of operation is either time-independent or varies in the same way as the scale-elasticity; cf. (12), and corresponding expressions when  $\beta=\gamma=0$ ,  $\gamma=0$  and  $\beta=0$ , respectively.

Each of the five sets of results consists of 12 estimated relations. In addition, we have one set of results with total costs as dependent variable. Since we do not have any proper price of capital in our data, no factor-prices are included in this set.

These results allow us to carry out the test procedures given in Fig. 1, as well as tests of hypotheses concerning the degree and nature of technical change. In Table 5, we present the results for variable and total costs with no factor-prices included. And in Table 6, the main findings from these calculations, as well as those for variable costs with factor-prices included, are presented.<sup>8</sup> They can be summarized in the following way. The results for the Cobb–Douglas specification confirm the results of previous studies about increasing returns to scale in Norwegian dairy production. According to the Cobb–Douglas results, the scale-elasticity is increasing over time, supporting the hypothesis of scale-augmenting technical change.

The test procedure of functional form explained in Section 3 provides a unique outcome for all sets of results, with the Zellner–Revankar specification as the winner. An illustration of this test procedure is pre-

<sup>8</sup> However, the latter sets of cost-function results are not reported here. They are available on request.

Table 5

Cost-function results for Norwegian dairy production<sup>a</sup>

	Intercept	ln Y	$(\ln Y - \overline{\ln Y})^2$	Y/100 000	t	t ln Y	R <sup>2</sup>
<i>Variable costs</i>							
1	6.3861 (0.0330)	0.5976 (0.0029)					0.7950
2	6.1760 (0.0360)	0.6150 (0.0031)	0.0486 (0.0034)				0.7986
3	6.4219 (0.0328)	0.5914 (0.0029)			0.0028 (0.0002)		0.7985
4	5.9066 (0.0583)	0.6368 (0.0051)			0.0526 (0.0047)	−0.0047 (0.0004)	0.8005
5	6.1918 (0.0356)	0.6100 (0.0031)	0.0542 (0.0034)		0.0032 (0.0002)		0.8029
6	5.4206 (0.0629)	0.6776 (0.0055)	0.0658 (0.0035)		0.0729 (0.0047)	−0.0061 (0.0004)	0.8067
7	7.5724 (0.0762)	0.4822 (0.0083)		0.1291 (0.0087)			0.7990
8	7.7775 (0.0862)	0.4591 (0.0083)		0.1469 (0.0087)	0.0033 (0.0002)		0.8036
9 <sup>b</sup>	7.2962 (0.0921)	0.4997 (0.0087)		0.1681 (0.0087)	0.0686 (0.0047)	−0.0057 (0.0004)	0.8070
10	7.5564 (0.3026)	0.4837 (0.0287)	0.0006 (0.0110)	0.1277 (0.0278)			0.7989
11	8.0007 (0.3003)	0.4380 (0.0285)	−0.0084 (0.0109)	0.1673 (0.0276)	0.0033 (0.0002)		0.8036
12	6.7138 (0.3112)	0.5548 (0.0295)	0.0215 (0.0110)	0.1169 (0.0276)	0.0704 (0.0048)	−0.0059 (0.0004)	0.8070
<i>Total costs</i>							
1	5.9855 (0.0380)	0.6497 (0.0033)					0.7762
2	5.8621 (0.0416)	0.6599 (0.0036)	0.0285 (0.0039)				0.7772
3	6.1387 (0.0332)	0.6233 (0.0029)			0.0121 (0.0002)		0.8296
4	5.7292 (0.0591)	0.6594 (0.0052)			0.0516 (0.0047)	−0.0035 (0.0004)	0.8307
5	5.9239 (0.0361)	0.6406 (0.0031)	0.0506 (0.0035)		0.0124 (0.0002)		0.8328
6	5.2844 (0.0639)	0.6967 (0.0056)	0.0602 (0.0035)		0.0702 (0.0048)	−0.0051 (0.0004)	0.8350
7	6.5988 (0.0999)	0.5901 (0.0096)		0.0668 (0.0101)			0.7770
8	7.3831 (0.0874)	0.5018 (0.0084)		0.1349 (0.0088)	0.0125 (0.0002)		0.8331
9 <sup>b</sup>	6.9879 (0.0936)	0.5351 (0.0089)		0.1523 (0.0089)	0.0662 (0.0047)	−0.0047 (0.0004)	0.8350
10	5.6691 (0.3505)	0.6783 (0.0333)	0.0352 (0.0127)	−0.0178 (0.0322)			0.7772
11	7.3645 (0.3046)	0.5036 (0.0289)	0.0007 (0.0110)	0.1332 (0.0280)	0.0125 (0.0002)		0.8331
12	6.2951 (0.3166)	0.6007 (0.0230)	0.0256 (0.0112)	0.0914 (0.0280)	0.0683 (0.0048)	−0.0049 (0.0004)	0.8351

<sup>a</sup> Standard deviation in parentheses.<sup>b</sup> The relation selected by the test procedure outlined in Fig. 1.

sented in Fig. 1, based on the results for variable costs in Table 5, and relations (6), (9), and (12). The results imply that the Zellner–Revankar specification is not rejected for the combined Nerlove/Zellner–Revankar specification at the 1% level, while the Nerlove specification is. At the second level, the Cobb–Douglas specification is rejected for both the Nerlove and the Zellner–Revankar specifications. Thus, the Zellner–Revankar specification wins, and so it does for all other cases explored as well.

Using variable costs, technical change seems to be positive (implying reduced average costs over time) for medium-sized and big farms only. Using total costs, technical change is actually negative (implying larger average costs over time) for all size-groups; cf. Fig. 2. The exclusion of factor-prices could be an explanation for these rather strange results. However, when including factor-prices, technical progress is negative for all units according to the variable costs results also.

This suggests, if anything, that the results reported above *under-rate* the degree of reduced efficiency in Norwegian dairy production in the period studied.

Since the interaction term between production and the trend variable has a significantly negative coefficient, optimal scale increases significantly over time. This is the more direct test of scale-augmenting technical change. We note from Table 6 and Fig. 2 that it is, however, quite small. The optimal scale is 10–27% larger in 1996 than in 1972 according to the results reported in Table 6.

All of our main results are surprisingly robust towards the way input prices are treated. This is the case both for the level of the scale-elasticity according to the Cobb–Douglas relation, the change over time in the level of the scale-elasticity, the outcome of the test of the form of the production function, and the degree of scale-augmenting technical change. Not even allowing time-dependent factor-share-estimates

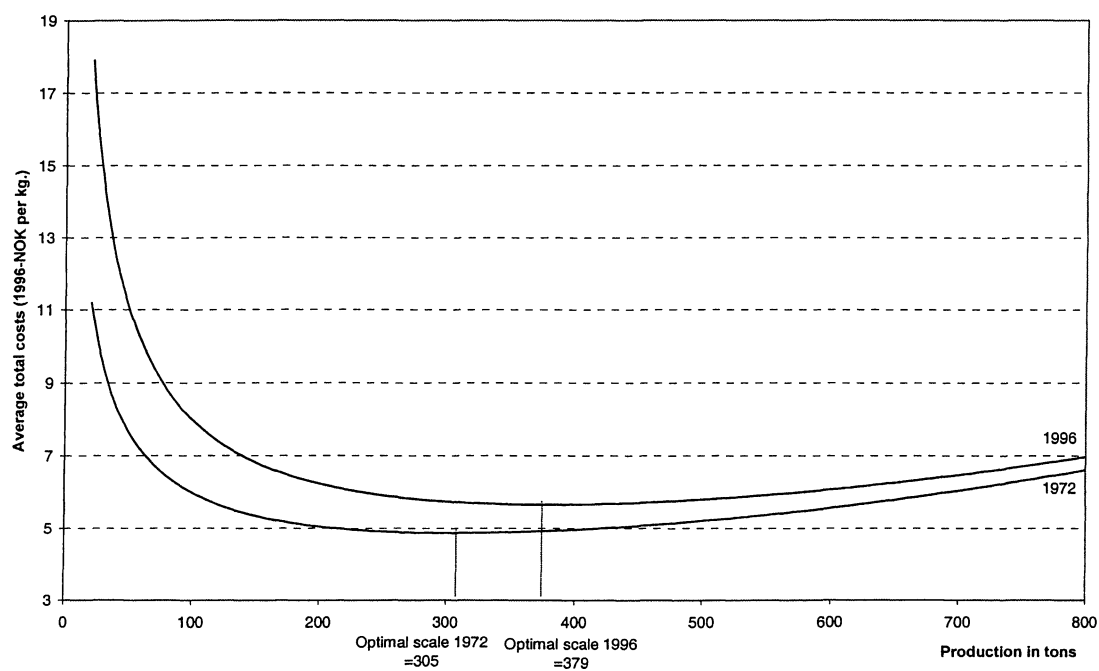
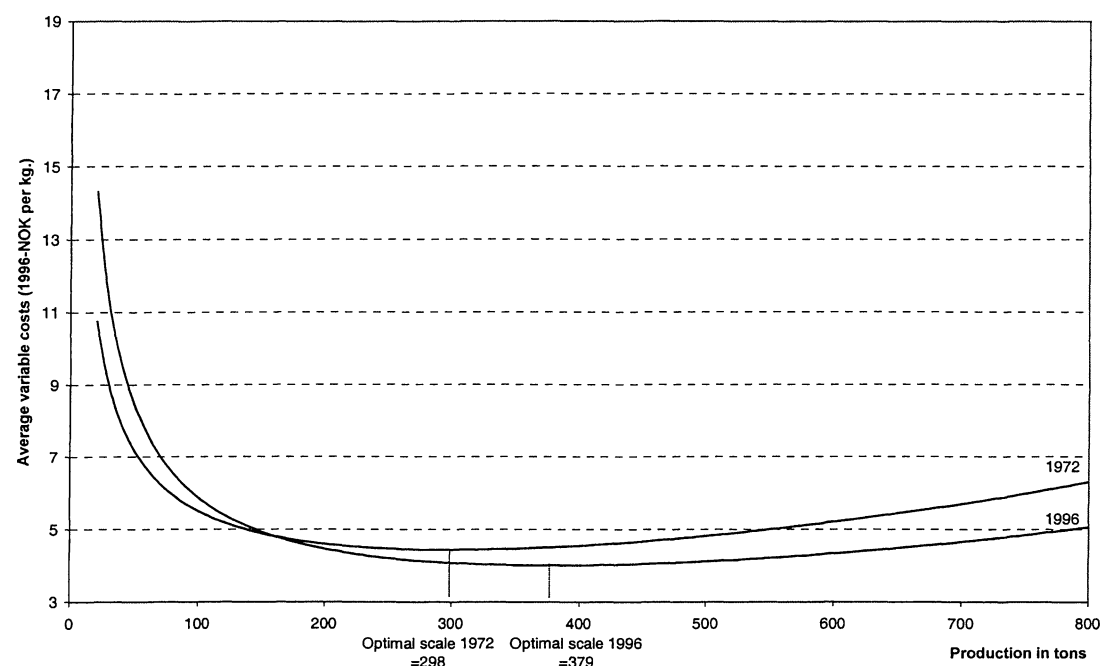


Fig. 2. Average cost functions for dairy production.

Table 6  
The form of the production function and the degree of scale-augmenting technical change for Norwegian dairy production

Year	Variable costs										Total costs	
	No factor-prices included		Factor-prices included but no restrictions on elasticities		Factor-prices included and restrictions on elasticities		Factor-share-estimates on factor-elasticities		Year-specific factor-share-estimates on factor-elasticities		No factor-prices included	
	1972	1996	1972	1996	1972	1996	1972	1996	1972	1996	1972	1996
Scale-elasticity (Cobb–Douglas with trend)	1.69		1.72		1.72		1.71		1.71		1.54	
Change overtime in Cobb–Douglas scale-elasticity	1.57	1.80	1.68	1.80	1.70	1.78	1.70	1.78	1.70	1.78	1.52	1.74
Outcome of test of functional form	Zellner–Revankar		Zellner–Revankar		Zellner–Revankar		Zellner–Revankar		Zellner–Revankar		Zellner–Revankar	
Cost-optimal scale (ton)	298	379	334	379	346	383	345	380	345	382	305	379

of factor-elasticities seems to matter much. This is particularly surprising since there are substantial and systematic movements of the factor-shares over time, suggesting strong non-neutral technical change.

## 6. Estimated gains and structural effects of exploiting scale-economies

By using the procedure explained at the end of Section 3 on the production data, we get an estimate on the potential gains of exploiting scale-economies in Norwegian dairy production. As explained in Section 4, we then have to use calculated production. This is done by means of the ‘production function’ in (19) estimated on the basis of the sample data:

$$\begin{aligned} \ln Y = & 8.3897 + 0.3071 \ln AC \\ & (0.0390) \quad (0.0326) \\ & + 0.8506 \ln CO + 0.0241t + 0.0349[\ln AC]^2 \\ & (0.0271) \quad (0.0016) \quad (0.0122) \\ & + 0.1159[\ln CO]^2 - 0.0006t^2 \\ & (0.0072) \quad (0.00003) \\ & - 0.1572[\ln AC][\ln CO] + 0.0044t[\ln AC] \\ & (0.0181) \quad (0.0008) \\ & - 0.0052t[\ln CO] \quad R^2 = 0.8991. \quad (20) \\ & (0.0008) \end{aligned}$$

Gains and structural effects are also calculated on the basis of observed production in the *sample*, and production in the *sample* computed by means of (20). This can serve as a basis for evaluating our ad hoc estimated production procedure for the *population*.

In Table 7, some basic statistics for the three sets of production data, as well as optimal scale are presented

for selected years. We note from Table 7 that the largest farms in the population are many times larger than the largest farms in the sample. Thus, even if the large farms are over-represented in our sample during most of the period considered (cf. Table 2), the really large ones are not.

We also note that estimated production data in the sample seem to correspond fairly well to observed production. This suggests that the estimated production procedure used by us is fairly reliable. The differences between the two sample sets on one hand and the set of estimated production for the population on the other are likely to reflect the differences pointed out in Section 3.

In Table 8, we present the estimated average costs for farms of optimal size and the gains of exploiting scale-economies, estimated on the basis of the three sets of production presented in Table 7. In Table 9, we correspondingly have the estimated effect on the number of farms. Tables 8 and 9 tell us several interesting stories.

In 1996, full exploitation of scale-economies would reduce total costs by 27%, or in absolute numbers, slightly less than 5 billion NOK. This corresponds almost exactly to the total public support of dairy farms in 1996; cf. the end of Section 2.

The effect this would have had on the number of farms is, however, dramatic: a reduction of about 73%, or in absolute numbers, from about 22 000 to less than 6000.

In the period considered, there have been comprehensive changes in the farm structure. As demonstrated in Tables 2 and 3, almost 60% of the farms, mostly small ones, disappeared between 1972 and

Table 7  
Production and optimal scale (ton) for selected years

Year	Observed production in the sample			Estimated production in the sample			Estimated production in the population			Optimal scale	
	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Variable costs results	Total costs results
1972	8	79	370	12	79	353	4	43	1251	298	305
1980	12	109	320	18	106	337	4	79	1820	325	330
1985	12	105	259	14	107	277	6	91	1669	342	345
1990	20	105	245	18	107	271	6	93	1054	359	361
1996	17	106	332	24	106	294	7	102	1360	379	379
Trend in per cent <sup>a</sup>	4.5 (1.1)	0.8 (0.2)	−0.2 (0.3)	4.3 (1.1)	0.8 (0.2)	−0.6 (0.3)	2.6 (0.3)	3.1 (0.3)	−1.5 (0.5)	1.0 (0.01)	0.9 (0.01)

<sup>a</sup> Standard deviation in parenthesis.

Table 8

Estimated minimum average costs and gains by exploiting scale-economies for selected years<sup>a</sup>

Year	Estimated minimum average costs		Estimated gains in terms of percentage reduction in costs					
			Observed production in the sample		Estimated production in the sample		Estimated production in the population	
	Variable costs	Total costs	Variable costs	Total costs	Variable costs	Total costs	Variable costs	Total costs
1972	4.44	4.86	24	23	25	24	39	37
1980	4.31	5.13	20	19	21	20	29	27
1985	4.22	5.29	24	23	24	22	28	26
1990	4.13	5.46	27	25	26	24	30	27
1996	4.01	5.65	29	27	30	27	30	27
Trend <sup>b</sup>	−0.43 (0.004)	0.63 (0.003)	0.32 (0.05)	0.25 (0.04)	0.32 (0.04)	0.25 (0.04)	−0.22 (0.08)	−0.24 (0.08)

<sup>a</sup> Average costs are in NOK per kilo, in 1996-prices, the trend (calculated on the basis of data for all years) is in percent for average costs and in percentage points for estimated gains.

<sup>b</sup> Standard deviation in parenthesis.

Table 9

Percentage reduction in number of farms by exploiting scale-economies

Year	Observed production in the sample		Estimated production in the sample		Estimated production in the population	
	Variable costs results	Total costs results	Variable costs results	Total costs results	Variable costs results	Total costs results
1972	73	74	73	74	86	86
1980	66	70	67	68	76	76
1985	69	70	69	69	74	74
1990	71	71	70	70	74	74
1996	72	72	72	72	73	73
Trend in per cent <sup>a</sup>	0.08 (0.05)	0.05 (0.05)	0.08 (0.05)	0.04 (0.04)	−0.44 (0.06)	−0.46 (0.06)

<sup>a</sup> Standard deviation in parenthesis.

1996, while the average size more than doubled. Since scale-augmenting technical change was weak, this implies that unexploited scale-economies, as well as the structural effects of exploiting them, were substantially reduced in this period. According to our calculations, the unexploited gains measured by the potential reduction in costs are lower by about 10% in 1996 as compared to 1972, while the calculated reduction in the number of farms exploiting this potential is lower by about 13% at the end of the period.

## 7. Discussion

There are several potential sources of errors in our calculations. Let us first point out that, in one important respect, they could be misleading. The most obvious way to exploit scale-economies is to merge or

otherwise transform small farms into units with optimal size. In particular, due to topographical reasons, this is, however, not possible in all cases. Some of the small units will survive anyway, but a substantial fraction of the same are more likely to leave dairy production, or go out of agricultural production entirely. Thus, the structural changes of the period studied (cf. Tables 2 and 3) are likely to continue into the future.

Let us also point out in this context that the estimated average costs function is rather flat for most of the scale of variation of production (cf. Fig. 2). Thus, it is possible to exploit most of the scale-economies by transforming the very small farms to larger ones, but far from as large as those of optimal size. This is also demonstrated by the calculations presented in Table 10 which tells us for instance that, if farms with less than 25 cows were merged or otherwise transformed into farms of that size, most of the scale-economies would be exploited. We note that this size is slightly more

Table 10

Gains and structural changes in 1996 by transferring the production of small dairy farms to larger ones

Production of small farms 'transferred' to farms with:		Reduction in costs (%)		Reduction in costs (billion NOK)	Reduction in number of dairy farms (%)
Production (ton)	Number of cows <sup>a</sup>	Costs of the production 'transferred' from small farms	Costs of total dairy production		
120	15	17	10	1.8	25
200	25	23	21	3.7	50
280	35	27	26	4.6	63
379 <sup>b</sup>	47.4	28	27	4.9	73

<sup>a</sup> Number of cows is calculated from production by assuming a production of 8000 kilo of milk and beef (in milk equivalents) which is close to the average in the sample.

<sup>b</sup> Optimal size in 1996.

than half the optimal size. Exploiting the remaining scale-economies would imply small gains in relation to the structural changes required.

Second, our results can be affected by usage of calculated instead of observed production. We note that the two sample sets of production data provide quite different results from those obtained on the basis of the population data. They suggest both that gains and effects are *increasing* over time in contrast to the population data results. This is likely to be quite misleading, however, and has to do with the non-representative nature of the sample concerning the 'dynamics' of the population in the period studied. The sample does not reflect properly the structural changes taking place in dairy production during this period; cf. Tables 2 and 3. From Tables 2 and 3, we can also see that the size-distributions of the population and the sample correspond fairly well at the end of the period. Thus, as is shown in Tables 8 and 9, the three sets of production data used provide almost exactly the same results for 1996.

Apart from the problem of representation pointed out, there are surprisingly small differences in the calculated gains and structural effects from the three sets of production data. Thus, it seems there are no big and systematic errors in the results referred to above due to the way the calculations are carried out.

Moreover, in an analysis of grain production related closely to the present one, production data are available both for the sample and the population. Using an ad hoc procedure of the same kind as the one applied above, we obtain almost exactly the same results about gains and effects of exploiting scale-economies

on the basis of estimated production as on the basis of observed production.<sup>9</sup> This too indicates that our ad hoc procedure is fairly good for our purpose.

Third, the method used is vulnerable to non-homogeneous production. In many industries, small units specialize in small-market/high-price products, while the big ones specialize in mass production. This would lead to positive biases in the estimates of both gains and structural effects of exploiting scale-economies. In manufacturing for instance, this argument could apply, since even within the groups of the more detailed classification, widely different products could be found.<sup>10</sup> In dairy production, this argument cannot, however, be very serious since the output is rather homogenous. Milk is the main product, while most of the beef is a joint product to milk. Actually, a main reason why we selected this branch of agriculture for our exploration was exactly to minimize this source of error.

Fourth, it has been argued that there could be a systematic positive error in the ARAF data on input of labor, overstating the number of hours of work of owners and family members. Even if this could be true, we have found no convincing evidence from Norwegian sources of a substantive error of this kind.

An analysis by Niemi (1983), however, suggests that, for Finland, the actual work done by owners and

<sup>9</sup> Cf. Ringstad and Løyland (1999), Tables 8 and 9.

<sup>10</sup> Cf. Ringstad (1979) where the results, using the same method as in the present one, suggest that the costs of Norwegian mining and manufacturing could be reduced by about 7%, with a reduction of number of firms of about 70%; cf. Table 2.



family members in agriculture is about 20% less than the work reported in investigations corresponding to those carried out by NAERI for Norway. We do not know if this applies to our data. If it does, calculations carried out, but not reported here, suggest that we have on the average overstated the gains of exploiting scale-economies by about 4 percentage points, and the structural effects by about 2 percentage points.

Fifth, in our calculations, the opportunity cost of labor is the value of the work done by owners and family members in alternative employment outside the farm. Thus, we ignore the fact that the reservation wage for many farmers is likely to be less (cf. Gaasland and Nersten, 1993). This should be taken into account in the interpretation of the results.

Sixth, it has been frequently argued that the ARAF farms are not representative due to a self-selection effect: those willing to take part in a comprehensive reporting of their required activities are likely to be better farmers than the average. In this study, we do not have the information needed to be able say anything about the possible impact this has on our results. It has been explored for specialized grain production, however, and the results suggested that this self-selection problem does not matter much.<sup>11</sup>

Finally, analyses carried out previously suggest that there are substantial regional differences in costs in Norwegian dairy production; cf. for instance Giæver et al. (1995). This could have affected our calculations. This is the case, if for instance efficiency is generally better in regions with larger farms than in other regions.

By introducing binary variables for region in our cost functions, regional cost differences are confirmed.<sup>12</sup> They have almost no impact on the calculated gains and structural effects of exploiting scale-economies, however. Taking regional differences in costs into account, both are slightly larger, but the difference is on the average less than 1 percentage points. Thus, if anything, these calculations

suggest that we have under-rated the gains and structural effects of exploiting scale-economies by the calculations reported previously.

Results obtained for specialized grain production are basically the same as those reported here.<sup>13</sup> The most important difference is that, in the tests of the functional form, the Nerlove specification wins in all cases. There is also another striking contrast between dairy and grain production, both concerning the development of efficiency and the degree of scale-augmenting technical change during the period 1972–1996. In grain production, there is a substantial improvement in efficiency during this period, at least in terms of reduced average variable costs, and the optimal scale is between two and three times larger in 1996 than in 1972.

We do not have the information available to be able to explain these differences properly. A likely explanation, however, comprises the quota system and other quantitative regulations of dairy production not found in grain production. Such regulations imply that efficiency-improving investments that require larger production to be profitable will not be carried out. The livestock subsidy could also have a negative impact on efficiency since it gives the farmers an incentive to keep more cows, with larger feeding and capital costs. Another possible explanation comprises regulations due to environmental considerations.

## 8. Main conclusions

In this paper, we have explored four main issues about Norwegian dairy production:

1. Do scale-economies exist in this branch of agricultural production, and if so,
2. is there an optimal scale of operation?
3. Is there scale-augmenting technical change?
4. What are the gains of exploiting any scale-economies, and what would be the structural effects of doing so?

These issues are analyzed by means of data for dairy farms in the period 1972–1996, and even if we have a very small sample in relation to the population, the answers for all of them come out loud and clear from our calculations:

<sup>11</sup> Cf. Ringstad and Løyland (1999), Section 6.

<sup>12</sup> We use the same classification as Giæver et al. (1995) with eight regions. In the calculations, the farms of the central-eastern part of Norway form the basis group. We find that total costs are significantly larger for farms in non-central-eastern part of Norway and for those in northern Norway, while they are significantly smaller for the farms of other regions (in western Norway and middle Norway).

<sup>13</sup> Cf. Ringstad and Løyland (1999).

1. There *are* large unexploited scale-economies in Norwegian dairy production.
2. There *is* an optimal scale of operation for a given year.
3. There is *some* scale-augmenting technical change since optimal scale increases slightly but significantly over time.
4. Full exploitation of scale-economies would imply substantial cost reductions. Our calculations suggest that, in 1996, costs could have been reduced by about 27%, or slightly less than 5 billion NOK, which is almost exactly the total public support to dairy farms that year. It would imply a dramatic reduction, however, in the number of farms: about 73%.

In 1996, this would have required that the small farms were merged or otherwise transformed into farms with slightly less than 50 cows. This would have implied a reduction in the number of farms from about 22 000 to less than 6000.<sup>14</sup> However, most of the scale-economies can be exploited by transforming small farms to farms substantially below the optimal size. Thus, by transforming farms with less than 25 cows to farms of this size, about three-fourths of the gains could be exploited, with substantially less dramatic structural effects.

The calculated gains and effects of exploiting scale-economies are substantially larger at the start of the period studied than at the end. During this period, almost 60% of the dairy farms, mostly small ones, disappeared. Thus, some of the scale-economies present at the start of the period have been exploited. During the same period, there has been some scale-augmenting technical change which increases the scale-economies over time. These changes have, however, been small, both as compared to the structural changes taking place during the period, and as compared to the scale-augmenting technical change in a different part of Norwegian agriculture, grain production, during the same period (Ringstad and Løyland, 1999).

General cost-saving technology development in Norwegian dairy production is also quite poor in the period studied. This, as well as the small

scale-augmenting technical change, are likely to be due to the comprehensive quantitative regulations of dairy production, in particular, the quota system, which for instance implies that efficiency-improving investments which require larger production to be profitable are not carried out.

Thus, there seem to be substantial hidden costs of the Norwegian dairy farm policy. Actually, this could be a more serious side effect than the unexploited scale-economies as calculated by us, which are also largely due to this policy.

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### References

- Aarseth, R., Elstrand, H., 1991. Kostnader ved melkeproduksjon på Vestlandet og Østlandets flatbygder ved varierende produksjonsomfang. Master thesis, Department of Economics and Social Sciences, Agricultural University of Norway, Ås.
- Bailey, K., Hardin, D., Spain, J., Garrett, J., Hoehne, J., Randle, R., Ricketts, R., Steevens, B., Zulovich, J., 1997. An economic simulation study of large-scale dairy units in the Midwest. *J. Dairy Sci.* 80 (1), 205–214.
- Brunstad, R.J., Gaasland, I., Vaardal, E., 1995. Agriculture as a provider of public goods: a case study for Norway. *Agric. Econ.* 13, 39–49.
- Burton, M., Ozanne, P.A., Collinson, C., 1993. Long-run average cost curves in the England and Wales dairy industry — comment. *J. Agric. Econ.* 44, 502–506.
- Christensen, L.R., Greene, W.H., 1976. Economies of scale in US electric power generation. *J. Pol. Econ.* 84, 655–676.
- Dawson, P.J., Hubbart, L.J., 1987. Management and size economics in the England and Wales dairy sector. *J. Agric. Econ.* 38, 27–37.
- Flaten, O., Giæver, H., 1998. Strukturendringer i norsk mjølkeproduksjon. Report No. 18, Department of Economics and Social Sciences, Agricultural University of Norway, Ås.
- Førsund, F., 1975. The homothetic production function. *Swedish J. Econ.* 77, 234–244.
- Gaasland, I., Nersten, N.K., 1993. Jordbruksmodellen. Working Paper No. 44, SNF-Bergen.
- Giæver, H., Flaten, O., Jervell, A.M., Hegrenes, A., 1995. Kostnader og omstillingsmuligheter på norske mjølkeproduksjonsbruk. NILF-report 1995, p. 3.

<sup>14</sup> Note that only farms with milk as the main product are included in our analysis. This means that about 10% of farms producing milk are excluded.

- Hallam, A., 1993. Empirical studies of size, structure and efficiency in agriculture. In: Hallam, A. (Ed.), *Size, Structure and the Changing Face of American Agriculture*. Westview Press, Boulder, CO, pp. 204–231.
- Hatling, R., Lynum, E., 1993. En analyse av kostnadsvariasjon i norsk melkeproduksjon. Master thesis, Department of Economics and Social Sciences, Agricultural University of Norway, Ås.
- Hubbard, L.J., 1993. Long run average cost curves in the English and Wales dairy sector. *J. Agric. Econ.* 44, 144–148.
- Kerkvliet, J.R., Nebesky, W., Tremblay, C.H., Tremblay, V.J., 1998. Efficiency and technological change in the US brewing industry. *J. Product. Anal.* 10, 271–288.
- Levin, R.C., 1977. Technical change and optimal scale: some evidence and implications. *Southern Econ. J.* 44, 208–221.
- Matulich, S.C., 1978. Efficiency in large-scale farming: incentives for structural changes. *Am. J. Agric. Econ.* 60, 642–647.
- Mochini, G., 1988. The cost structure of Ontario dairy farms: a microeconomic analysis. *Can. J. Agric. Econ.* 36, 187–206.
- Mochini, G., 1990. Nonparametric and semiparametric estimation: an analysis of multiproduct returns to scale. *Am. J. Agric. Econ.* 72, 589–596.
- Mukhtar, S.M., Dawson, P.J., 1990. Herd size and unit costs of production in the England and Wales dairy sector. *J. Agric. Econ.* 41, 9–20.
- Nerlove, M., 1963. Returns to scale in electricity supply. In: Christ, C.F. (Ed.), *Measurement in Economics*. Stanford University Press, Stanford.
- Niemi, I., 1983. Systematic bias in hours worked? *Statistisk tidskrift* 4, 326–330.
- OECD, 1996. *Agricultural policies, markets and trade in OECD. Monitoring and evaluation. Main Report*, Paris.
- Ringstad, V., 1967. Econometric analyses based on a production function with neutrally variable scale-elasticity. *Swedish J. Econ.* 69, 115–133.
- Ringstad, V., 1974. Some empirical evidence of the decreasing scale-elasticity. *Econometrica* 42, 87–101.
- Ringstad, V., 1979. A method of calculating the effects and gains of utilizing scale-economies. *Econometrica* 47, 789–795.
- Ringstad, V., Løyland, K., 1998. Cost-optimal scale of child care institutions. *J. Product. Anal.* 10, 305–311.
- Ringstad, V., Løyland, K., 1999. The Gains and Structural Effects of Exploiting Scale-Economies in Specialized Grain Production in Norway. Working Paper No. 1/99, Telemark Research Institute, Bø.
- Statistics Norway (1973–1997), *Statistical Yearbook*. Oslo.
- Zellner, A., Revankar, N.S., 1969. Generalized production functions. *Rev. Econ. Stud.* 36, 241–250.