Technical and economic performance of alternative feeds in dairy and pig production

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ABSTRACT

A major cost component in livestock production is feed, which suggests improved feed efficiency as a promising strategy to improve both competitiveness and environmental sustainability. This study has investigated the technical and economic efficiency of using two alternatives to the standard feeds in livestock production in Norway. Data was generated from two controlled feeding experiments involving dairy cows and finishing pigs. In the dairy cow experiment, grass silage optimal in protein content was compared to silage lower in protein content in rations to moderately yielding cows. In the pig experiment, imported soybean meal was compared to rapeseed meal in diets to finishing pigs. From Data Envelopment Analysis, we did not find significant within group as well as between group differences in technical efficiency of animals under different feeding strategies. Under the assumptions of the study, however, a feeding regime based on low protein silage was found to be cheaper (–9% to –10%) for moderately yielding dairy cows, suggesting that Norwegian milk production could be based on the low protein silage fed ad libitum. On the other hand, despite reducing feed costs, a feeding regime based on rapeseed meal was less profitable, although statistically insignificant, than soybean meal for finishing pig production. Therefore, the nutritional value must improve and/or the price of rapeseed meal drop before it becomes an economically acceptable replacement to soybean meal.

1. Introduction

Feed efficiency[1] is crucial from a farm economy perspective as feed is a major input in livestock production (Hemme et al., 2014; Hoste 2017; Niemi et al., 2010) and improved feed efficiency is accompanied by higher farm profit (Colman et al., 2011). On the other hand, apart from its negative economic effects, low feed efficiency has greater consequences. Coupled with excessive level of protein in modern feeds, low feed efficiency results in excretion of nitrogen to the environment, which contributes to environmental pollution from dairy (Kebreab et al., 2001; Tamminga 1992) and pig production systems (Jongbloed 2008; Whittemore et al., 2001).

The environmental implications become even more pronounced when one considers the high feed mileage of many protein ingredients used in Europe. For example, more than 90% of the protein ingredients used in the production of concentrates for livestock feed in Norway are imported (Landbruksdirektoratet 2018). Such reliance on imported protein to feed livestock is said to be inconsistent with sustainability objectives (Tallentire et al., 2018). As a result, an objective of Norwegian agricultural policy is increased food production based on Norwegian feed resources (Næringskomitéen 2017). In addition, much of the imported protein is sourced from soybeans, which apart from high feed mileage, may carry a high carbon footprint due to emissions related to land use change, such as deforestation in South-America (van Zanten

et al. 2018). Thus, reducing soybean-based dietary crude protein (CP) content in the feed is one of the potent strategies to improve environmental efficiency, by mitigating nitrogen and carbon emissions (Dijkstra et al., 2013; Godden et al., 2001).

Consequently, more efficient use of existing feed resources combined with the development of new local feed resources can alleviate the present reliance on imported feed ingredients and the environmental footprint of the domestic livestock sector. In a Norwegian research project (FeedMileage), the nutritional adequacy of alternative locally produced feed resources was examined through feeding experiments. These experiments compared 1) soybean meal (SBM) to rapeseed meal (RSM) in diets of finishing pigs (Skugor et al., 2019), and 2) grass-clover silage low in crude protein (LCPS) to silage optimal in crude protein (OCPS) in diets of lactating dairy cows supplemented with concentrates (Kidane et al., 2018). The premise for these experiments was the observation that reduced dietary CP levels in dairy cows can increase the reliance on local feed resources, reduce environmental impacts and decrease costs of producing silage (ibid.). In addition, rapeseed meal is a by-product from oil and biofuel production that can be used as a high-quality and cheap source of protein to replace soybean meal in diets for pigs. Higher levels of dietary rapeseed meal, however, result in increased fibre content and in certain anti-nutritional factors that can compromise feed efficiency (Mejicanos et al., 2016; Torres-Pitarch et al., 2014).

Using data from the two experiments, this study aims to assess the technical and economic efficiency of using alternative feed resources in livestock production. The technical assessment relates to how efficiently the feed inputs are utilized by the animals to produce outputs. The economic assessment relates to investigating how the farm economy is affected by choices regarding feeding strategies. For the economic assessment dairy farms are assumed to be cost minimizers given the marketing quota scheme for milk. Therefore, we compute technical, allocative, and cost efficiency scores for each animal in the two feed groups. On the other hand, pig farms were assumed to be profit maximizers. Hence, we computed technical and profit efficiency scores for each animal in the two feed groups.

Previous feed efficiency indicator studies tend to report averages across all units within a group in a study, ignoring the potentially wide-ranging outcomes across different units (Iribarren et al., 2011). In addition, common feed efficiency indicators such as output per feed unit consider only the feed inputs and hence provide an inaccurate measurement of productivity performance. Furthermore, since they are void of price considerations, they are also unreliable guides to optimal economic feeding decisions (Barnard and Nix 1979, p. 199). This study uses an alternative multiple-input, multiple-output efficiency measurement approach known as Data Envelopment Analysis (DEA). Farrell (1957) proposed the approach first. However, Charnes et al. (1978) provided the mathematical framework for the method. Since then widespread application took place and it continues to be one of the main approaches in performance assessment. DEA calculates single aggregated indices of efficiency for each unit (e.g. a farm or an individual animal) by considering all inputs and outputs of the production system, thus providing a broad view of the efficiency problem (Soteriades et al., 2015). To our knowledge, this is one of the first studies to use DEA to demonstrate and compare the technical and economic effects of various feeding regimes based on livestock production experiments.

2. Method

Data envelopment analysis is a linear programming technique that can be used to build a piece-wise production frontier against which the relative performance or efficiency of production units is assessed. In other words, the different production units are benchmarked in terms of how efficient they are in converting inputs into outputs by using the least resources or producing maximum output. Compared to its statistical alternative, i.e. the stochastic frontier analysis (SFA), it has some advantages such as requiring no prior assumption about the functional form underlying the input-output relationship. Furthermore, DEA is more suitable for experimental situations,

as in this study, since data points are usually few in such cases. Further details about the DEA method can be found in Färe et al. (1985; 1994), Thanassoulis (2001) and Wen (2015). DEA has some weaknesses too, such as failure to incorporate statistical noise and attributing all deviations from the estimated frontier to inefficiency (Thanassoulis et al., 2008) and slow convergence (Simar and Wilson 2008). Apart from extensive work to introduce statistical inference through bootstrapping techniques (Simar and Wilson 2008), alternative specifications that bridge the gap between the parametric SFA and nonparametric DEA approaches have been proposed (e.g. Kuosmanen and Kortelainen 2012).

To build the DEA model for a livestock production process, let $\boldsymbol{x} = (x_1, x_2, ..., x_i)$ be a vector of i inputs and $\boldsymbol{y} = (y_1, y_2, ..., y_j)$ be a vector of j outputs of n animals, where $n = 1, ..., N$. In this multi input - multi output setting, technical efficiency (TE) of each animal can be defined as a ratio of virtual output to virtual input. For example, for $n = 1$

$$\theta_1 = \frac{\sum_j u_{j1} y_{j1}}{\sum_i v_{i1} x_{i1}} \tag{1}$$

where θ_1 is the technical efficiency score while u and v are weights for each output and input, respectively. This indicator is a generalization of the widely used efficiency indicator in the one input-one output case, which is output per unit of an input. The interpretation of θ is therefore identical to feed conversion efficiency (FCE), except that θ can handle multi-input, multi-output cases. The key problem with computing θ is constructing the input and output weights. The utility of data envelopment analysis begins by solving this problem and computing technical efficiency scores for each animal. For this purpose, Charnes et al. (1978; 1981) proposed linear programming formulations known as CCR models assuming a technology that exhibits constant returns to scale. A production technology exhibits constant returns to scale if an equiproportional change in the quantity of all inputs leads to a change in output by the same proportion. There is, however, no compelling reason to believe a producer is operating with such a technology. Therefore, we used a modified form of the CCR model proposed by Banker et al. (1984) that allows variable returns to scale. This model is known as the BCC model in the literature. The input-oriented BCC model is given as follows (Banker et al., 1984):

$$\min_{\theta, \lambda} \theta \tag{2}$$

Subject to

$$\sum_n x_{in} \lambda_n \leq \theta x_{i0}; \ \ i = 1, ..., i$$

$$\sum_n y_{jn} \lambda_n \geq y_{j0}; \ \ j = 1, ..., j$$

$$\sum_n \lambda_n = 1; \ \ n = 1, ..., n$$

$$\lambda_n \geq 0$$

The optimal solution vector for the above problem will contain the technical efficiency scores $0 < \theta^* \leq 1$. The formulation in (2) is known as the envelopment form. The term "envelopment" arises because any admissible set of λ's determines the lower limit for inputs and upper limit for outputs (Bowlin 1998).[2] Given the flexibility in the form of variable returns to scale, one can measure both the technical and scale

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[2] Some of the efficient units identified by DEA programs may be "weakly efficient", suggesting that there are non-zero slacks (Wen 2015). This problem can be dealt with approaches such as the two-stage approaches suggested by Ali and Seiford (1993) or the multi-stage approach suggested by Coelli (1998). On the other hand, Coelli et al. (2005) argue that slacks are consequences of the piece-wise linear approximation and finite samples. Therefore, one can proceed without overstating the importance of slacks in efficiency analysis. See Coelli (2005) for more details

efficiency (i.e. how close an animal is operating to its optimal scale of production) in the BCC model.

We are however interested beyond the technical performance of each animal or efficiency in feed utilization. If price data is available and one is willing to make a behavioral assumption about the economic objective of production, one can also construct indicators of economic performance. For example, assume the farmer is seeking to maximize profit per animal. This is a proper assumption for finisher pig production in Norway since the industry does not face quantity restriction in both the input and output side.

Let $p = (p_1, p_2, ..., p_j)$ be a vector of output prices and $w = (w_1, w_2, ..., w_i)$ be a vector of input prices. Then indicators of economic performance such as profit efficiency (*PE*), or how close each animal is to optimal profit, can be obtained by solving two linear programming problems (Coelli et al., 2005): one for measuring the technical performance and another for measuring the economic performance. The former is identical to the linear programming problem in (2) and the latter can be specified as follows in an *envelopment form*:

$$\pi^* = \max_{y,x,\lambda} \pi = \sum_n p_j y_{j0} - \sum_n w_i x_{i0} \qquad (3)$$

Subject to

$$\sum_n x_{in} \lambda_n \leq x_{i0}; \quad i = 1, ..., i$$

$$\sum_n y_{jn} \lambda_n \geq y_{j0}; \quad j = 1, ..., j$$

$$\sum_n \lambda_n = 1; \quad n = 1, ..., n$$

$$\lambda_n \geq 0$$

where π refers to observed profit per animal and π^* refers to optimal profit per animal. Once the optimal input and output combinations are discovered, we can compute the optimal profit using the objective function of the linear programming problem in (3). Then profit efficiency (*PE*) of the animal, can be computed as a ratio of the observed profit (π) to the optimal profit (π^*). Note however that the profit efficiency indicator is not bounded between zero and unity since profits can be negative (Coelli et al., 2005).

In some cases, producers may face restrictions on the input (e.g. input usage restrictions) or output side (e.g. marketing quota). For example, the Norwegian dairy sector operates under a milk quota regime and hence cost minimization is a proper assumption for specialized dairy farms. In such cases, economic performance can be assessed by replacing the objective function in (3) by:

$$C^* = \min_{x,\lambda} C = \sum_i w_i x_{i0} \qquad (4)$$

where *C* is observed cost per animal and *C** is optimal cost per animal. Once the optimal solution is obtained, we can compute two indicators of economic performance. First, a measure of cost efficiency (*CE*), or how close each animal is to optimal cost of production, can be obtained by taking the ratio of optimal cost (*C**) to observed cost (*C*). As a result, $0 \leq CE \leq 1$, where a $CE = 1$ implies cost efficiency and $CE < 1$ implies cost inefficiency. For example, $CE = 0.88$ can be interpreted as a potential to decrease costs by 12%. Second, an indicator of allocative efficiency (*AE*), measuring the extent to which the feed budget is allocated efficiently among inputs, can be obtained. Since $CE = TE \times AE$, we can recover the allocative efficiency scores easily using $AE = \frac{CE}{TE}$ and $0 \leq AE \leq 1$. Low allocative efficiency implies the feed budget can be reduced without output loss by re-allocating more of the feed budget towards cheaper feed inputs and away from expensive feed inputs.

The Benchmarking package (Bogetoft and Otto 2018) written for the R platform was used for solving the linear programming problems above.

3. Data

The data for this study came from two feeding experiments involving dairy cows and growing-finishing pigs. Both experiments were conducted at the Center for Animal Research, Norwegian University of Life Sciences, Aas, Norway, under the FeedMileage project.

3.1. Quantity data

The data for dairy cows originated from 48 individually fed early- to mid-lactation Norwegian Red (NRF) cows with details described in Kidane et al. (2018). In brief, the cows were randomly allocated to two dietary treatments after balancing for initial milk yield, stage of lactation, body weight and parity. The cows were then fed grass-clover silages either low in crude protein (late cut silage; LCPS; 112 g CP per kg dry matter (DM)) or optimal in crude protein (mixture of 4 different silages; OCPS; 142 g CP per kg DM) ad libitum for a period of 54 days. Furthermore, the cows were supplemented with a fixed level of commercial concentrate feed (FORMEL Favør 90, Felleskjøpet Agri, 160 g CP per kg DM). The amount of concentrate feed for each individual cow was estimated to meet the requirements for the expected milk yield and nutrient balance according to the Nordic Feed Evaluation System (Norfor) feeding standards (Volden 2011). However, to challenge the 24 LCPS cows, the concentrate proportion of the diet was estimated by the NorFor system assuming the OCPS was the only available silage. The NorFor system would have required a concentrate feed with better quality than we used here if it were to optimize diets with the LCPS silage as a basal feed. Data available included daily forage and concentrate dry matter intake, milk yield (energy corrected milk (ECM)), milk component (fat, protein, lactose) yield, body weight, and body condition score at individual cow level.

The feed input vector for the DEA analysis for dairy production included intake of silage (kg DM in the experimental period) and concentrates (kg DM in the experimental period). The output vector included milk yield (kg ECM in the experimental period) and gain in live weight (kg) during the experimental period. Summary statistics for the data used in DEA model for dairy production are presented in Table 1 per diet.

The data for growing-finishing pigs were generated from an 88 day long feeding experiment where 84 individually fed purebred Norwegian Landrace pigs from 16 litters were used (Skugor et al., 2019). The experiment was conducted as a randomized complete block design where pigs were blocked by litter and sex and grouped by initial weight to one of the two dietary treatments with 42 replicates per treatment. Average initial live weight was 24.9 kg and average final live weight was 109.7 kg. The dietary treatments consisted of a commercial control diet based on barley, wheat, oat and soybean meal (SBM), and an experimental diet based on barley, wheat, oat and 20% inclusion of commercial expeller pressed rapeseed meal (RSM). Diets were formulated to meet or exceed the requirements for indispensable amino acids and all other nutrients (National Research Council 2012). Diets were formulated to be isonitrogenous and isoenergetic and to contain equal levels of methionine + cysteine, and threonine. The fiber content of the diets was different: the soybean meal diet (144 g per kg of neutral detergent fiber and 43 g per kg of acid detergent fiber) and the rapeseed meal diet (159 g per kg of neutral detergent fiber and 61 g per kg of acid detergent fiber). Composition and analysis of the diets are shown in Appendix A. Pigs were individually fed twice per day according to a restricted Norwegian feeding scale (Øverland et al., 1997). Feed consumption and live weight of pigs were recorded weekly to determine average daily feed intake (ADFI) and average daily gain (ADG). At slaughter, carcass weight and percent lean were measured (GP7Q pistol, Hennessy System Ltd, Auckland, New Zealand), and the value of the carcasses was evaluated based on carcass weight and percent lean according to the commercial method used at Norwegian abattoirs (Norwegian Meat Research Centre, Oslo, Norway). In summary, the

Table 1
Summary statistics of the input and output vectors in the DEA model for dairy production per feeding strategy for a feeding period of 54 days ($N = 48$).

Diet	Variable	Mean	SD	25th Percen.	50th Percen.	75th Percen.
	Inputs (feed intake)					
	Silage (kg DM)	671.1	104.5	591.8	672.3	735.1
	Concentrates (kg DM)	339.2	133.7	253.7	330.2	455.0
LCPS	Outputs					
	Milk (ECM, kg)	1339	276.3	1175	1391	1480
	Live weight gain (kg)	32.4	23.2	14.0	28.5	45.5
	Inputs (feed intake)					
	Silage (kg DM)	654.1	126.0	558.1	643.1	700.3
OCPS	Concentrates (kg DM)	341.4	109.8	264.3	346.0	439.1
	Outputs					
	Milk (ECM, kg)	1359	228.0	1219	1336	1554
	Live weight gain (kg)	29.4	17.1	20.5	28.5	42.5

LCPS = low crude protein silage; OCPS = optimal crude protein silage; SD = standard deviation; DM = dry matter; ECM = energy corrected milk, Percen. = Percentile.

available data from the pig experiment included individual information about the total amount of feed consumed, the total weight gained during the experimental period, pig-specific carcass price indicating quality differences, as well as the feed price.

The feed input vector used in the DEA analysis for the finisher pig production included only average daily feed intake (ADFI, kg). The output vector included average daily weight gain (ADG, kg) only. Summary statistics for the variables used in the DEA model for finisher pig production is provided in Table 2 per diet.

3.2. Price data

Price data is required for economic performance assessments. With respect to concentrate price for dairy cows, multiple procurements were made from early January to Mid-March 2015 with an average price of NOK 3.4 per kg feed (€ 1 ≈ NOK 9.00 in 2015). Assuming a DM content of 87%, the price of concentrate used for the analysis was NOK 3.9 per kg DM.

On the other hand, there are no widely quoted market prices for silage. Therefore, the grass-clover silages were valued according to their cost of production. Forage quality parameters of both types of silage used in the dairy cow experiment were close to the phenological stages, digestibility and the CP content of the yields of grass-clover for silage from field experiments in the years 2003–2008 of typical 2-cut and 3-cut systems at Løken Research Station located in a mountainous dairy region of Eastern Norway (Flaten et al., 2015). Therefore, we considered it to be appropriate to use the costings per kg DM for the 2-cut and 3-cut systems in this crop experiment to estimate the costs of feeding cows with LCPS and OCPS silages, respectively. Data on forage yields, composition of the silages and the calculations of the costs of the baled grass silage are presented in Flaten et al. (2020). Input prices in 2014 were used. Based on these calculations, the cost of optimal crude

protein silage was 2.29 NOK per kg DM compared to 1.84 NOK per kg DM for low crude protein silage. The higher cost per kg DM of the higher quality optimal crude protein silage was due to lower dry matter yields, increased cutting costs, and more frequent sward renewal.

Given the carcass quality variation, indicated by carcass price differences (see Table 3), the pigs' production performance cannot be compared directly based on observed output levels. The first step was, therefore, to express observed carcass output in terms of some quality standard. In order to do this, it was assumed that carcass of the same quality results in the same price. To achieve this, sex-specific average carcass prices were calculated for each experiment group. These prices represent the price of the average quality carcass from a specific sex pig fed in either of the alternatives. Then the observed carcass prices were expressed relative to these prices. The quality corrected output quantities were then obtained by multiplying the observed output quantities with the relative prices.

The product of the two variables then shows the amount of average quality output that each pig in each feeding group produced during the experimental period. After such a correction, the output from all pigs can be assumed homogeneous and hence the production performance of the pigs can be compared. Since feed prices were identical for pigs in each experiment group (RSM-diet: 3.59 NOK per kg and for SBM-diet: 3.75 NOK per kg), it was assumed that there were no feed quality differences within groups.

Using the input, output, and price data described above DEA models were estimated. In the dairy cow case, separate frontiers were fitted for cows under each diet while in the finisher-pig case sex and diet specific frontiers were fitted.

4. Results and discussion

Below is a summary and discussion of the main results obtained from the data envelopment analysis models based on data from the two experiments.

Table 2
Summary statistics of the input (ADFI) and output (ADG) vectors in the DEA model for growing-finishing pig production per sex and feeding strategy for a feeding period of 88 days ($N = 84$). .

	SBM-diet				RSM-diet			
	Gilts		Barrows		Gilts		Barrows	
	ADFI	ADG	ADFI	ADG	ADFI	ADG	ADFI	ADG
Mean	1.97	0.79	2.03	0.86	1.89	0.75	1.98	0.82
SD	0.07	0.06	0.11	0.08	0.13	0.08	0.07	0.06
25th Percentile	1.93	0.74	2.02	0.83	1.84	0.69	1.95	0.77
50th Percentile	1.99	0.78	2.03	0.89	1.91	0.73	1.98	0.84
75th Percentile	2.02	0.83	2.09	0.91	2.00	0.81	2.03	0.86

SBM = soybean meal; RSM = rape seed meal; SD = standard deviation; ADFI = average daily feed intake (kg feed/day); ADG = average daily weight gain (kg/day).

Table 3
Carcass price (in NOK/kg CW) of growing-finishing pigs by sex and feeding strategy for a feeding period of 88 days ($N = 84$).

Sex	Feeding strategy			
	SBM-diet		RSM-diet	
	Mean	SD	Mean	SD
Gilts	26.90	0.56	26.96	0.38
Barrows	26.24	0.55	26.22	0.59

NOK = Norwegian krones; CW = carcass weight; SBM = soybean meal; RSM = rape seed meal; SD = standard deviation.

Table 4

Technical, allocative, and cost efficiency indicators of experimental dairy cows for a feeding period of 54 days ($N = 48$).

Statistics	LCPS			OCPS		
	Technical Efficiency	Allocative Efficiency	Cost Efficiency	Technical Efficiency	Allocative Efficiency	Cost Efficiency
Mean	0.94	0.95	0.89	0.93	0.98	0.91
SD	0.07	0.06	0.07	0.10	0.02	0.11
Min.	0.78	0.82	0.76	0.70	0.93	0.70
Max.	1.00	1.00	1.00	1.00	1.00	1.00

LCPS = low crude protein silage; OCPS = optimal crude protein silage; SD = standard deviation.

4.1. Experiment with dairy cows

The result in Table 4 shows that there was no big difference between the cows under the two feeding strategies in terms of their technical efficiency. On average the technical efficiency scores in the two groups were about 94% and the within-group variation was small. Therefore, under our test conditions, the type of silage did not seem to make a big difference with respect to the dairy cows' technical ability to transform feed inputs to outputs.

On the other hand, allocative efficiency was higher in the OCPS group (98%) than in the LCPS group (95%). We tested if these differences were statistically significant using the nonparametric Kolmogorov-Smirnov test for equality of distributions, as suggested by Banker (1993) for cases when no a priori assumption is made about the distribution of efficiency scores. The test weakly rejected the null hypothesis that the cost efficiency distributions were equal ($P < 0.1$).

These findings imply that the feed input mix in the OCPS group was closer to the allocatively optimum combination given the feed prices than in the LCPS group. Due to this, the cost efficiency within the OCPS group was higher than within the LCPS. This difference, however, should not be interpreted as if the per unit cost of producing milk using the OCPS strategy is lower than using the LCPS strategy due to the silage price difference between the two groups. Instead, since the abovementioned difference was primarily driven by differences in allocative efficiency, it should be understood as a difference in the possibility of reducing production cost further by using less of the expensive and/or more of the cheaper input. Therefore, the fact that the cost efficiency score of the OCPS group was higher implies that there are more limited possibilities of cost reduction through feed substitution than in the LCPS group.

To compare the two diets more explicitly in terms of a monetary indicator, namely the cost of production, the optimal production cost of a fixed output vector was computed. Two such output vectors were used, *viz* the mean output vector of the OCPS group (output vector A: Milk = 1358 ECM kg, weight gain = 29.4 kg) and mean output vector of the LCPS group (output vector B: Milk = 1339 ECM kg, weight gain = 32.4 kg). Using the technologies constructed above, the optimal inputs of feed required to produce each of the two vectors were computed and then valued at the above-stated prices. See Table 5 for details.

In all cases, we found that production cost was 9–10% higher when the fixed output vectors were produced by OCPS fed cows than the LCPS fed cows. Our results of the lowest cost for the LCPS strategy are comparable with results from modelling studies of Norwegian and Dutch dairy farming systems (Flaten et al., 2015; Van Middelaar et al. 2014).

The 30% higher dry matter grass yields associated with the LCPS (2-cut) compared to OCPS (3-cut) (Flaten et al., 2020) can contribute to increased self-sufficiency in forages for ruminant livestock production. In addition, the LCPS strategy would further lower the amount of nitrogen consumed by dairy cows, which resulted in lower N-excretion (Kidane et al., 2018). However, some studies have found lower

Table 5

Optimal production cost of reference output vectors in NOK per cow (feeding period of 54 days).

Output vector	Diet	Cost
A (Milk = 1358 ECM kg; weight gain = 29.4 kg)	OCPS	2414
	LCPS	2180
B (Milk = 1339 ECM kg; weight gain = 32.4 kg)	OCPS	2411
	LCPS	2171

LCPS = low crude protein silage; OCPS = optimal crude protein silage.

greenhouse gas emissions by harvesting at a young stage of maturity to produce high-quality grass silage (Warner et al., 2016; Åby et al., 2019). More studies are needed to explore the synergies and trade-offs related to environmental effects of grass silage production and diets to dairy cows.

4.2. Experiment with pigs

The data envelopment analysis models for finisher pigs were constructed separately for each sex and experiment group. In other words, it was assumed the production technology varies according to the aforementioned factors.

Based on the estimated technologies, Table 6 shows that the average technical efficiency scores of finisher pigs under the two feeding strategies were very similar. The Kolmogorov-Smirnov test could not reject the null hypothesis that the technical efficiency scores of both gilts and barrows under the two diets were equal ($P > 0.1$). In addition, there was little variation around the average in all cases. This indicates that the ability of the average finisher pig to transform feed into growth is largely unaffected by the shift from SBM-diet to RSM-diet. Therefore, economic effects from the use of the RSM-diet, if any, are likely to arise from changes in total feed intake and the consequent total growth attained during the feeding period.

To highlight feed intake and weight gain during the experimental period under different diets, as well as to compute profit efficiency scores, optimal values of these variables under the two diets were computed for gilts and barrows. Table 7 summarizes these results.

Given the input and output prices, the economically optimal average daily feed intake and average daily growth per day for gilts fed

Table 6

Average technical efficiency scores of growing-finishing pigs by sex and diet for feeding period of 88 days ($N = 84$).

Statistics	SBM-diet		RSM-diet	
	Gilts	Barrows	Gilts	Barrows
Mean	0.95	0.94	0.95	0.95
SD	0.03	0.05	0.04	0.03
Min.	0.91	0.82	0.86	0.89
Max.	1.00	1.00	1.00	1.00

SBM = soybean meal; RSM = rape seed meal; SD = standard deviation.

Table 7
Optimal daily feed intake, weight gain, gross margin, and profit efficiency of growing-finishing pigs by sex and diet for a feeding period of 88 days ($N = 84$).

Sex	Diet	Feed intake (kg/day)	Weight gain (kg/day)	Gross margin (NOK/day)	Profit efficiency (%)
Gilts	SBM	2.07	0.92	16.93	81.0
	RSM	2.05	0.90	16.76	80.0
Barrows	SBM	2.03	0.96	17.57	85.3
	RSM	1.97	0.94	17.49	82.5

SBM = soybean meal; RSM = rape seed meal.

the SBM-diet were 2.07 kg per day and 0.92 kg per day, respectively. This resulted in an optimal gross margin of NOK 16.93 per day. Expressed relative to the observed gross margin from each gilt, the optimal gross margin implied an average profit efficiency of 81% in this group.

Compared to the result under the SBM-diet, the optimal daily feed intake and daily weight gain of the gilts declined slightly under the RSM-diet. In particular, the economically optimal average daily feed intake and average daily growth were 2.05 kg per day and 0.90 kg per day, respectively. The corresponding optimal gross margin was NOK 16.76 per day, indicating that the negative effect on profits from the decline in output outweighed the positive effect from the decline in feed intake. Consequently, the profit efficiency of gilts under the RSM-diet was 80%.

The same kinds of effects on feed intake, weight gain, and profit efficiency were observed for barrows. Under the SBM-diet, the economically optimal average daily feed intake and average daily growth of barrows were 2.03 kg per day and 0.96 kg per day, respectively, with a corresponding optimal gross margin of NOK 17.57 per day. This implies a profit efficiency of 85.3%.

On the other hand, barrows on the RSM-diet had an economically optimal average daily feed intake and average daily growth of 1.97 kg and 0.94 kg per day, respectively, with corresponding optimal gross margin of NOK 17.49 per day. The implied profit efficiency of barrows under the RSM-diet was 82.5%.

The profit efficiency score distributions under the two diets both for gilts and barrows were not significantly different ($P > 0.1$; Kolmogorov-Smirnov test). However, the lack of statistical significance does not mean that the choice of diet is unimportant in an economic sense. This is especially the case when one considers that the feed experiment resulted in a NOK 0.17 per day greater gross margin for gilts under the SBM-diet than the RSM-diet (Table 7). This adds up to NOK 15 per finisher pig, or substantial NOK 14,960 per 1000 pigs. The difference for the barrows were NOK 7040 per 1000 pigs.

The promising result of finishing pigs performing in comparable technically efficiency under RSM-diet as when under the SBM-diet has relevance in terms of food security in the sense that there are alternatives to rely on if imported feed protein supplies are not available. One should, however, note the negative impacts on farm profits and limited availability of domestically sourced rapeseed meal. Oilseed crops can mainly be cultivated in some areas in the south-eastern part of Norway. The estimated maximum arable land of the area is around 26,000 hectares annually, which is less than 3 percent of the total farmland in Norway (Granlund et al., 2010). Currently, rapeseed is grown on around 4000 hectares in Norway (Statistics Norway 2019).

Despite the inferior economic outcomes, one can argue substitution of SBM with RSM can have implications for the environmental footprint of finishing pig production, given the reduction in feed mileage and

deforestation associated with soybean cultivation. However, when addressing the direct environmental impacts, a Dutch study have found that replacing SBM with RSM in finishing pig diets hardly changed greenhouse gas emissions and energy use while land use decreased (van Zanten et al. 2018). In fact, when the indirect environmental consequences also were considered, the same study found that replacing SBM with RSM resulted in increased greenhouse gas emissions, use of energy, and land. More studies are therefore needed to evaluate the environmental impacts under Norwegian conditions, for example by use of life-cycle assessment.

5. Conclusions

Low self-sufficiency in protein supply for livestock production may be a risk to food security in Norway, associated with factors such as trade distortions, extreme weather, and global price volatility. The development of alternatives, preferably based on local feed resources, is therefore likely to promote self-sufficiency in feed. This study evaluated the technical and economic implications of two alternative feeds in dairy and finishing pig production. In doing so, the study has employed data envelopment analysis.

Results from the dairy experiment showed that cheaper low protein silage could be fed to dairy cows without losses in milk production. Beyond the obvious cost savings, this result is indicative of lower N-excretion to the environment and higher dry matter grass yields arising from harvesting silage at later stages of maturity. On the other side, greenhouse gas emission intensities from milk production may rise at later maturity stages, pointing to trade-offs between multiple economic and environmental concerns.

Results from the finishing pig experiment showed that the ability of pigs to transform feed into body growth was not affected by the replacement of SBM with RSM. However, the optimal feed intakes under an RSM-diet were lower than under an SBM-diet. Consequently, the optimal daily weight gain was higher under the SBM-diet. This implies that the lower feed costs from the RSM-diet are accompanied by lower revenues due to the negative effects on the growth rate. The computed values suggested the negative effects on revenue outweighed the lower feed costs from the RSM-diet. As a result, the optimal profit under RSM-diet was lower than under SBM-diet. This implies that the adoption of RSM can have negative consequence on the farm economy. Further research on improving the nutritional value and palatability of RSM can be crucial for efforts to promote it as an economically viable option to SBM. One can argue the lower profits under RSM are prices society must pay for lower environmental impacts of using local over imported feed resources. However, previous studies in other countries did not provide credence to such claims and further research is needed to ascertain the environmental impacts under Norwegian conditions.

Declaration of Competing Interest

None.

Appendix A. Composition and analysis of diets used in the pig experiment

Table A.1.

Table A.1
Ingredients and chemical composition (g/kg, unless otherwise stated) of diets based on soybean meal (SBM) and rapeseed meal (RSM).

Ingredient	Diet SBM	RSM
Barley	380.2	340.4
Wheat	240.0	233.4
Oats	140.0	140.0
Soybean meal (SBM) (45% CP)	150.0	0.0
Rapeseed meal (RSM)	0.0	200.0
Rendered fat (tallow)	50.4	50.0
Limestone	11.3	8.0
Monocalcium phosphate	16.4	16.4
Salt	4.0	4.0
L-lysine · HCl (98%)	2.9	3.8
Threonine	1.5	1.5
DL-methionine	0.9	0.0
Tryptophan	0.1	0.2
Micromineral/vitamin premix[a]	2.2	2.2
Calculated contents, g/kg		
Net energy, MJ/kg	9.3	9.2
SID[b] lysine	8.2	8.2
SID methionine + cysteine	4.9	5.0
SID threonine	5.4	5.4
SID tryptophan	1.6	1.6
Calcium	8.7	8.5
ATTD[c] phosphorus	3.9	4.3

[a] Provided the following amounts per kilogram of feed: 105 mg of Zn (ZnO); 75 mg of Fe (FeSO$_4$. H$_2$0); 60 mg of Mn (MnO); 15 mg of Cu (CuSO$_4$ x 5H$_2$O); 0.75 mg of I (Ca(IO$_3$)$_2$; 0.3 mg of Se (Na$_2$SeO$_3$); 9000 IU of vitamin A; 1125 IU of cholecalciferol; 112.5 mg of dl-α-tocopheryl acetate; 2.25 mg of menadione; 5.625 mg of riboflavin, 18.73 mg of D-pantothenic acid; 22.5 mg of cyanocobalamine; 22.5 mg of niacin; 0.225 mg of biotin; 1.69 mg of folic acid; 364 mg of choline; 100 mg of yttrium oxide as an inert marker.
[b] Standardized ileal digestible. [c] Apparent total tract digestible.

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