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Rationalising inefficiency in agricultural production

-the case of Swedish dairy production

Rationalising inefficiency in agricultural production - the case of Swedish dairy agriculture

Agrifood Economic Center working paper

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Abstract

Inefficiency in agricultural production is generally interpreted as waste in the use of production factors. We challenge this interpretation by providing an explanation for why apparent inefficiency may result from rational production decisions by farmers and demonstrating systematics in the inefficiency patterns amongst the production factors that lend support for this, i.e. the rational inefficiency hypothesis. Based on a multidirectional efficiency analysis of 421 Swedish dairy farms and statistical analyses of the inefficiency patterns, we provide support for the existence of rational inefficiency. These findings have clear implications for policy schemes aiming at pushing farms towards the efficient production frontier.

Keywords: Dairy farms, non-use values, rational inefficiency, use values, Sweden

1 Introduction

Within the agricultural economics literature, estimation of technical efficiency (TE) is a common way of evaluating the performance of farms. Achieving technically efficient farm production is also a way of contributing to the objectives of the Common Agricultural Policy (CAP) (Latruffe *et al.*, 2017), as some of its objectives relate to the prosperity of farms, with CAP measures aimed at enabling increased agricultural productivity, optimal use of agricultural production factors and ensuring the living standard of farmers (Massot, 2016). The TE approach builds on a microeconomic model of the farm business. An efficient isoquant, or production possibility frontier, is estimated empirically based on best practice revealed in the available data and then the position of each farm business relative to this isoquant or frontier is determined (e.g. Coelli *et al.*, 2005). Possible deviations from the isoquant (frontier) are considered inefficiency, indicating that smaller amounts of the production factors could be used to produce the current level of output (input orientation) or that the level of output could be increased given the current use of production factors (output orientation). Inefficiency in production thereby represents waste in either the use of production factors or the production of outputs. Applications of TE analysis have considered not only the level of inefficiency, but also the associations between TE and characteristics of farms and/or the policy environment in which farms operate. For instance, many recent papers have considered the relationships between TE and factors such as: agricultural subsidies (Latruffe and Nauges, 2013); differences in housing systems (e.g. Labajova *et al.*, 2016); management routines and practices (e.g. Labajova *et al.*, 2016; Rougoor *et al.*, 1998; Hansson, 2008); management control (e.g. Trip *et al.*, 2002; Manevska-Tasevska and Hansson, 2011); financial management (Davidova and Latruffe, 2007) and farmers' personal characteristics (e.g. Puig-Junoy and Argiles, 2004; Galanopoulos *et al.*, 2006). Through investigating associations between TE and various aspects of the farm and/or the policy environment in which it operates, such studies often ultimately aim at providing policy recommendations about measures that can help push farm businesses closer to the efficient isoquant (production possibility frontier), or at providing insights into how various policies prevent or improve the TE of farms.

However, if the ultimate goal of most TE studies is to identify possibilities to reduce waste in the utilisation of production factors and/or to provide normative advice about how such waste may be reduced, the practical utility of those studies depends on the accuracy in the behavioural assumptions underlying the TE findings. Of particular importance for the present study is the more or less implicit assumption that inefficiency in the use of production factors can be interpreted as waste and consequently that it is desirable to reduce inefficiency. However, this way of interpreting the observed deviations of firms from the efficient isoquant (or production possibility frontier) has previously been challenged in the literature. Bogetoft and Hougaard (2003) argued that what is considered inefficiency in firms' use of production factors may indeed be the result of rational production choices. For instance, seemingly overconsuming certain production factors may in fact be a rational decision to buffer against future risk and uncertainty. Some slack in the utilisation of labour in particular may also be allowed, in order to make the firm more attractive to employees and thereby avoid future expenses associated with high personnel turnover. Bogetoft and Hougaard (2003) therefore introduced the notion of rational inefficiency as an explanation for certain deviations from efficient levels of production. Asmild *et al.* (2013) explored the hypothesis of rational inefficiency among Canadian bank branches and found empirical support for the existence of such rational inefficiency among the branches studied.

Despite numerous TE studies in agriculture, the hypothesis of rational inefficiency has so far not been explored in an agricultural setting. However, previous research has suggested that farmers are not driven solely by financial considerations, but rather by a set of both financial and non-financial values of the social and lifestyle type (e.g. Gasson, 1973; Willock *et al*., 1999; Ferguson and Hansson, 2013). Howley (2015) found that such non-financial benefits can explain farmers' behaviour across a wide range of activities. Exploring the rational inefficiency hypothesis in an agricultural setting would be highly relevant from a policy perspective, as understanding whether observed inefficiency on farms is an effect of rational behaviour from the farmers' perspective would shed new light on the possibilities to push farms towards higher levels of efficiency by various policy measures. From a theoretical perspective, such an analysis would also further the current understanding of the conditions for farming by highlighting the type of considerations that may underlie farmers' production decisions and how these are reflected in the observed efficiency outcomes.

Accordingly, in this paper we move beyond the current literature related to TE in agricultural production, with the overarching aim of exploring the rational inefficiency hypothesis in the agricultural production setting. We do this in two steps within the context of dairy farming: First, we offer a theoretical explanation as to why dairy farms can be expected to be rationally inefficient, i.e. why observed inefficiency can indeed be an outcome of rational decision making. Second, we build on the approach by Asmild *et al.* (2013) and look for systematics in patterns of inefficiency among the production factors, in order to empirically explore the possible existence of rational inefficiency in dairy production in Sweden. Investigating the rational inefficiency hypothesis in this way is especially appealing because it can be done using data available through sources such as the Farm Accounting Data Network (FADN). The present investigation was based on the premise that farmers make rational production decisions and that some of these decisions cause observed deviations from the efficient isoquant (or production possibility frontier), which would be taken as inefficiency in conventional analyses of TE.

Dairy farms make a particularly interesting case for exploring the rational inefficiency hypothesis within agriculture. On dairy farms, decisions related to the management and welfare of livestock kept for milk production can significantly affect the efficiency of the farm. McInerney (2004) and Lagerkvist *et al.* (2011) have suggested that livestock farmers (including dairy farmers) recognise two types of economic value from the management of their livestock: use values and non-use values. Use values relate to productivity and profitability type measures, while non-use values comprise all other values farmers derive from managing their livestock, and include considerations related to ethics in production, farmer self-image, the perceived rights of the animals and the perceived legitimacy of farm production. Recent studies have found empirical evidence that non-use values in animal welfare are important motivational factors underlying dairy farmers' decision-making (Hansson and Lagerkvist, 2016, 2015). Moreover, Hansson and Lagerkvist (2016) classified eight of the 10 most important values motivating dairy farmers' decision making related to the well-being of their animals as being of the non-use type. In relation to the present study, those studies support an assumption that because of the existence of non-use values in animal welfare, some farmers might be reluctant to push their animals towards their maximal productivity and might be inclined, from an efficiency perspective, to overconsume certain production factors. In an efficiency setting, this counts as inefficiency, interpreted as waste, but may very well be an outcome of a rational decision by the farmer if they prioritise certain non-use values. This is exactly the issue explored in the present paper by combining these insights about use and non-use values as motivational factors for farmers' work related to their livestock with the notion of TE.

The study is based on production data for Swedish dairy farms collected from the FADN, which is a detailed dataset encompassing information from farm income statements and balance sheets and additional production data such as number of hours worked on the farm. If some inefficiency is indeed rational, we would expect some systematic patterns within the inefficiency. This, in turn, means that certain characteristics of the production system in this industry are typically not properly captured in conventional efficiency analyses and thus wrongly recorded as waste.

The study contributes to the literature by offering an alternative interpretation of estimated inefficiency within agricultural production, providing an explanation for why inefficiency may be reported and exploring empirical evidence supporting the rational inefficiency hypothesis.

The findings can be useful in two different ways: First, they may be of value to actors in agribusiness and to policy makers, by highlighting why advice and measures to push inefficient farms to the efficient isoquant (or production possibility frontier) may not be effective approaches for these farms if the inefficiency is in fact rational. Second, findings illustrating that economic production considerations may not be the only determinant of farmers' behaviour, but rather farmers allow some production slack, in order to achieve something that is also valuable to them. This is especially interesting in light of the poor economic performance many farmers are currently experiencing and could indicate that this partly results from rational production decisions.

2 Theoretical background: rationalising inefficiency in dairy farming

Measuring farm performance in terms of TE means that a farm's actual performance is compared against an efficient isoquant (or production possibility frontier). As defined in the influential paper by Farrell (1957), technical inefficiency measures the amount by which production could be increased given the observed level of production inputs (output-orientated measure) or by how much production inputs can be reduced given the observed level of output production (input-orientated measure). Technical efficiency is typically measured in the range [0;1] with 1 representing the maximum attainable efficiency.

Livestock farming involves the use of animals as production factors. Farmers' recognition of economic value in terms of both use values and non-use values (McInerney, 2004; Lagerkvist *et al.*, 2011) related to the wellbeing of their animals can be expected to explain their provision of animal welfare (AW) (Lagerkvist *et al.*, 2011). Economic value in this sense is defined as "a weighting that people place on something, and reflects the benefit (pleasure, satisfaction, gain, virtue, advantage) – or what economists call ‘utility’ – that they gain from it” (McInerney, 2004:5). Use values in AW represent the economic value farmers derive from recognising animals as production factors and is the economic value associated with treating the animals in such a way that they can produce. The rationale for sustaining a certain level of AW is then similar to the rationale of actions taken to maintain the productivity of any production factor. Non-use values represent any other economic value farmers derive from the welfare of the animal. These types of values may explain why farmers take actions to provide AW beyond the requirements imposed by productivity and profitability considerations. Lagerkvist *et al.* (2011) further developed the notion of non-use values in AW by defining it as consisting of five theoretically distinct types: Pure non-use values, existence values, bequest values, option values and paternalistic altruism.

Improving AW on the farm can be expected to lead to higher levels of non-use values being realised. Non-use values are not readily measurable from farm income statements. As farmers nevertheless receive economic value from realising those non-use values, we argue that a decision to improve AW and realise higher levels of non-use values is the outcome of a rational decision-making process. Consequently, the presence of non-use values related to AW in dairy farmers’ decision making could explain why farmers might seemingly overconsume certain production inputs, as an outcome of rational decision making, in order to improve AW and thereby realise certain non-use values, but as a consequence appear technically inefficient. The presence of non-use values in AW implies the presence of two central decision parameters in farmers’ decisions about how to position their farms in production space: the level of non-use values ($nonuse$) and the level of farm profit (π) to produce. We assumed that each farmer f has an underlying (but unobservable) utility function $U_f = U_f(nonuse_f\,, \pi_f)$, which is strictly increasing in both of its arguments. Each farm’s technically efficient use of production factors and level of produced outputs can be determined from the production possibility set, which can be empirically estimated using the non-parametric data envelopment analysis (DEA) framework, but which typically ignores the unobservable non-use values produced. Any deviations from the technically efficient vector of production factors, given the outputs produced, would be considered overconsumption of production factors in a general TE framework, where the presence of non-use values is ignored. However, following the above line of argument and considering farmers as rational, and thus utility-maximising in both non-use values and profit, any deviations from the efficient isoquant (or production possibility frontier) can be assumed to result from rational production decisions where utility is gained from production of non-use values, even if this means that profit is reduced.

From a rational inefficiency perspective, we assumed here that the presence of non-use values of AW in dairy farmers' decision making gives rise to certain systematic patterns within the inefficiency. From a input-orientated TE perspective, AW-improving measures can be expected to require more of some production inputs, but may reduce the need for other production inputs, for instance due to associated positive effects on animal health. However, it can be expected that, from a certain level, additional AW-improving measures will start reducing TE. If farmers apply AW-improving measures beyond this level, the rational reason for this would be the presence of non-use values in their decision making. Thus, assuming that decision making is rational, negative associations between AW-improving measures and TE can be taken as an indication of rational inefficiency. From an output-orientated TE perspective, the general interpretation is that production output can be increased given the current levels of production inputs. However, in the presence of non-use values in AW, one type of utility obtained from production is unobserved, implying that the actual output delivered is underestimated. Furthermore, what is interpreted as under-production of outputs in a traditional TE analysis, when it comes to the use of animals in production may be due to farmers' reluctance to push their animals towards their biological maximal production, due to possible adverse effects on non-use values. Thus, a conventional TE analysis would suggest that less efficient farms could become more efficient by adopting the AW practices of the most efficient farms. In practice, due to the presence of non-use values in AW, these farms may have chosen not to do so in order to maximise their utility (economic value).

3 Method

3.1 Multidirectional efficiency analysis

In our analysis, we used multidirectional efficiency analysis (MEA) (Asmild *et al.*, 2003, Bogetoft and Hougaard, 1999) to assess the variable-specific TE of each farm. The MEA approach has been used previously in the agricultural economics literature, e.g. by Labajova *et al.* (2016) to assess the production efficiency of a sample of Swedish pig farms and by Asmild *et al.* (2003) to assess production efficiency on Danish dairy farms. Compared with the more commonly used data envelopment analysis (DEA) employed by e.g. Charnes *et al.* (1978), MEA has the advantage that it permits assessment of TE in each production input and output and thus offers a more detailed analysis of production efficiency, which is especially relevant in this study[1]. We based our analysis on farm accounting data, which meant that it was only possible to account for the use of production inputs at aggregated level on the farm: for instance, the amount of labour used in the dairy enterprise could not be distinguished within the total amount of labour used in the whole farm operation. This means that to correctly represent the studied farms, we needed to account also for the possibility that they produce other types of outputs from the production inputs recorded. In this setting, the more detailed analysis enabled by MEA was advantageous, because it allowed us to analyse separately the TE in production output from dairy, without confounding this with TE in the production of other outputs. For completeness, the TE in other types of production was included in the analyses, but was not interpreted in relation to AW.

For estimation of MEA scores for the farms, we considered a set of n farms $(s = 1, \dots, n)$ that all use four production inputs $x_{j,s}(j = 1, \dots, 4)$ in the production of two outputs $y_{i,s}(i = 1,2)$ and assumed that production takes place under constant returns to scale. We then derived the relative variable-specific TE scores for each production input and output, using linear programming models as shown in equations 1 to 4.

First, for each input $j = 1, \dots, 4$ solve for each $DMU = (x_0, y_0)$:

$$
\begin{aligned}
& a_j^* = min_{\lambda,a_j}\, a_j \quad \text{s.t.} \\
& \textstyle\sum_s \lambda_s\, x_{j,s} \le a_{j,0} \\
& \textstyle\sum_s \lambda_s\, x_{-j,s} \le x_{-j,0} \\
& \textstyle\sum_s \lambda_s\, y_{i,s} \ge y_{i,0} \quad i = 1, 2 \\
& \lambda_s \ge 0
\end{aligned} \tag{1}
$$

where $(-j)$ denotes all inputs except input j and DMU denotes Decision-making unit (farms).

Next, for each output $i = 1,2$ solve for each $DMU = (x_0, y_0)$**:**

$$
\begin{aligned}
& \alpha_j^* = max_{\lambda,\alpha_i}\, \alpha_1 \quad \text{s.t.} \\
& \textstyle\sum_s \lambda_s\, x_{j,s} \le x_{j,0} \quad j = 1, 2, 3, 4 \\
& \textstyle\sum_s \lambda_s\, y_{i,s} \ge \alpha_{i,0} \\
& \textstyle\sum_s \lambda_s\, y_{-i,s} \ge y_{-i,0} \\
& \lambda_s \ge 0
\end{aligned} \tag{2}
$$

where $(-i)$ denotes the other output besides output i.

[1]For comparison, the input-orientated DEA TE results are also presented.

Combining the solutions to the equations above results in an ideal reference point $(\alpha_{1,0}^*, \dots, \alpha_{4,0}^*, \alpha_{1,0}^*, \alpha_{2,0}^*)$ for observation $(x_0,\ y_0)$.

In the second step, use the ideal reference point for $(x_0,\ y_0)$ calculated in the first step to solve the following programme:

$\beta_0^* = max_{\lambda,\beta_0}\ \beta_0$ s.t.

$$\textstyle\sum_s \lambda_s\, x_{j,s}\ \leq\ x_{j,0} - \ \beta_0\left(x_{j,0} - \ a_{j,0}^*\right),\ j = 1,2,3,4 \qquad (3)$$

$$\textstyle\sum_s \lambda_s\ y_{i,s}\ \geq\ y_{i,0} + \beta_0\left(\alpha_{i,0}^* - \ y_{i,0}\right), \qquad i = 1,2 \qquad (4)$$

$\lambda_s \geq 0$

Finally, use the solution (λ^*, β_0^*) from equation 3 to determine the vector of relative variable-specific MEA efficiencies for unit $(x_0,\ y_0)$ as:

$$\left(\frac{x_{1,0} - \beta_0^*(x_{1,0} - a_{1,0}^*)}{x_{1,0}}, \dots, \frac{x_{4,0} - \beta_0^*(x_{4,0} - a_{4,0}^*)}{x_{4,0}}, \frac{y_{1,0}}{y_{1,0} + \beta_0^*(\alpha_{1,0}^* - y_{1,0})}, \frac{y_{2,0}}{y_{2,0} + \beta_0^*(\alpha_{2,0}^* - y_{2,0})}\right) \qquad (5)$$

3.2 Exploring rational inefficiency: Analytical framework

In the present analysis, we explored the rational inefficiency hypothesis by investigating the patterns within inefficiencies in production inputs and outputs on the sample of dairy farms. In particular, we explored associations between TE, AW-improving measures and indicators of the actual levels of AW, in a two-step process.

First we investigated, graphically and statistically, the relationships between the levels of AW-improving measures and the TE, in order to determine whether some farmers apply potentially AW-improving measures to the extent that it reduces TE, and therefore potentially exhibit rational inefficiency by assigning relatively high importance to non-use values as opposed to use values. To determine this, for each comparison between an AW-improving measure and a TE score, we divided the resulting area into four quadrants based on the median value of the AW-improving measure and the median value of the TE score[2]. The farms located in the quadrant with relatively high levels of AW-improving measures while attaining relatively low levels of TE emerged as potentially being rationally inefficient (the Rational Inefficiency (RI) group). The farms which apply relatively low levels of AW-improving measures while attaining relatively high levels of TE emerged as potentially obtaining low utility from non-use

[2]The reason for using the medians to divide the two-dimensional space into four quadrants is that, if there is no relationship between the two dimensions, then there will be the same number of observations in each of the four quadrants (which in turn becomes the null hypothesis in the subsequent chi-square test, which does not require the assumption of a linear relationship between the two variables, unlike e.g. the correlation).

values, but high utility from profit (the Efficiency group). Farms with low TE and low levels of AW-improving measures simply appear inefficient (the Inefficiency group). Finally, farms with both high TE and high AW-improving measures were taken to be 'multi-efficient' (the Multi-efficiency group). Having many farms located in the Multi-efficiency group (and also in the Inefficiency group) would challenge the assumption of a trade-off between TE and AW-improving measures, whereas over-representation of farms in the RI and the Efficiency groups would provide empirical evidence of this trade-off. We used chi-square tests to formally analyse whether the farms were equally distributed between the groups or whether there was an over-representation of farms on either diagonal: over-representation on the Multi-efficiency and Inefficiency diagonal would indicate that AW-improving measures and TE are complements, rather than substitutes, while over-representation on the RI and Efficiency diagonal would indicate that there is indeed a trade-off between the two. If the latter is the case, then the farms in the RI group apply AW-improving measures to a higher degree than is efficiency improving, which in turn can only be rationalised if this actually leads to higher AW and if the farmers assign value to this by having high non-use values of AW (in particular compared with the farmers in the Efficiency group).

Second, for any over-representation on the RI and Efficiency diagonal, we then investigated whether what could be perceived as over-investment in AW-improving measures (at the expense of TE) is potentially rational in the sense that it improves actual AW. So, using t-tests, we analysed whether the farms belonging to the RI group had higher actual AW than the farms in the Efficiency group in particular (but also than the farms in the Multi-efficiency and Inefficiency groups). Higher actual AW in the RI group compared with the other groups was interpreted as a potentially rational explanation for their inefficiency, consisting of two parts: Choosing high AW measures at the expense of low efficiency can be rationalised by assigning higher weight to non-use values; and those non-use values could very well be related to AW if actual AW is higher in that group.

3.3 Data

For the analysis, we used farm-level production data for a set of specialist dairy farms, following the EU Commission typology for agricultural holdings (EU Commission Regulation, 2008), obtained from the Swedish Farm Accounting Survey (FAS). That survey is carried out by Statistics Sweden on behalf of the Swedish Board of Agriculture and constitutes the Swedish input to the EU-wide FADN. In FAS, data are available for a sample of about 1000 Swedish farms and are stratified according to farm size and geographical location. The panel is rotated, with about 10% of the participating farms replaced every year. The FAS data contain detailed production information on the farms, based on their accounting information. For the present analysis, we used data from 421 specialist dairy farms represented in FAS in 2013. From the FAS data, we defined four production inputs (labour, variable costs, fixed costs and assets) (Table 1). As in the FADN definitions of variables (European Commission, 2010), the labour input represents total hours of unpaid and paid labour engaged on the farm; variable costs comprise the total specific costs and overheads on the farm; fixed costs represent the accounting costs in terms of depreciation, rents and interests; and the asset value includes the total assets value of land, machinery, buildings, breeding and non-breeding livestock, and represents the opportunity cost of the capital. We also defined two production outputs (Table 1): output 1 defined as the revenue from milk and beef production, and output 2 defined as the revenue from all other agricultural and diversified activities on the farm (as in Barnes *et al.* (2015)). Furthermore, based on the information in FAS, we derived one potentially AW-improving measure, buildings cost per livestock unit (LU)[3], assuming that higher costs are associated with higher levels of AW, and two indicators of actual AW: revenue from culling of dairy cows (measured relative to the value of dairy cows) and veterinary costs per dairy cow. Animal welfare is a multidimensional construct, where one dimension relates to the functioning of the animal (for instance in terms of health and production) (von Keyserling, *et al.*, 2009). Animal health problems lead to increased veterinary costs and health and production problems, such as impaired cow fertility, resulting in involuntary culling of dairy cows. In the type of accounting data used in this study, we were able to trace poor actual AW by these indicators on the grounds that poor AW would be associated with relatively higher rates of veterinary treatments and with relatively higher rates of culling. Higher levels of both indicators of actual AW can thus be considered to be associated with lower levels of actual AW.

[3]Based on the production data used in this study, we isolated two variables considered as AW-improving measures: building costs per livestock unit (LU) and pasture per LU. Thus, initially we also included in the analysis the variable accounting for pasture per LU. Findings (not shown but available from the authors upon request) of the chi-square tests used to formally analyse whether farms were equally distributed between the groups or whether there was over-representation of farms on the diagonals did not yield statistically significant results based on TE for the production factors. For TE for production outputs, the findings supported over-representation of farms on the RI and Efficiency diagonal for TE in Output 1, thus suggesting a trade-off between TE and the AW-improving measure pasture per LU. However, because only one of the variables considered supported the RI hypothesis, this AW-improving measure was not further evaluated in this exploratory study of systematic patterns in production data.

Table 1: Description and descriptive statistics on variables used

	Description	Unit	Mean	Std dev
Inputs				
Variable costs	Total amount of variable costs, including: total specific costs and farming overheads (supply costs linked to production, but not linked to a specific line of production)	SEK*	3181665	3642511
Fixed costs	Total amount of fixed costs, including: depreciation, rents and interests	SEK	1152102	1656106
Assets	Total value of assets in ownership, including: agricultural land, buildings, machinery and equipment, breeding and non-breeding livestock, and circulating capital	SEK	11115457	11573519
Labour	Total amount of labour used for production	hours	5965	4253
Outputs				
Output 1	Total revenue obtained from milk and meat (beef and veal) production	SEK	2887343	3857286
Output 2	Total revenue obtained from: other agricultural production, entrepreneurial output (leased land, contract work, hiring equipment, tourism, etc.), and subsidies	SEK	1804858	1724919
AW-improving measure				
Building costs	Total amount of building costs, normalised per livestock unit (LU)	SEK/LU	44501	75475
Indicators of actual AW				
Rate of culling		%	11.58	.09
Veterinary costs		SEK/LU	279.00	202.67

*10 SEK (Swedish krona) is equivalent to approximately 1.1 €; ** The number of livestock units is calculated following the definition of variables used in the FADN standard results.

4 Results

4.1 Technical efficiency analysis

Descriptive statistics of the combined input- and output-orientated MEA scores for the dairy farms in the sample, along with the input-orientated DEA scores for comparison, are presented in Table 2.

Table 2: Descriptive of multidirectional efficiency analysis and data envelopment analysis scores

Variable	Average score	Std dev
MEA scores		
Production inputs		
TE Variable costs	0.93	0.04
TE Fixed costs	0.83	0.09
TE Assets	0.81	0.09
TE Labour	0.83	0.08
Production outputs		
TE Output 1	0.86	0.13
TE Output 2	0.79	0.17
DEA score		
Input-oriented	0.81	0.11

Among the production inputs, the highest level of TE was attained for input variable costs. For the production outputs, the highest level of TE was obtained for output 1 (revenue obtained from milk and meat). From this, it appears as though the farms are overconsuming, especially as regards the production inputs labour, fixed costs and assets. However, provided that the farmers are maximising utility, and thus base their production choices on rational decisions, these inputs may only appear to be overconsumed because they are in fact used to generate non-use values in AW.

4.2 Exploring the rational inefficiency hypothesis: Analysis of the patterns of inefficiency

We explored the rational inefficiency hypothesis by investigating the patterns within the estimated inefficiencies on the farms, based on the arguments presented in our analytical framework.

4.2.1 Classifying farms into the RI group and the Efficiency group

The levels of the AW-improving measure (building costs per LU) plotted against the TE of each of the inputs and outputs are shown in Figure 1. In each diagram, the farms are divided into four quadrants based on the median value of the AW-improving measure and of the TE measure. Farms located in the upper-left quadrant (Q1 in Figure 1) have higher levels of the AW-improving measure, but at the same time lower levels of TE; these were classified into the

RI group. Similarly, farms located in the lower-right quadrant (Q4 in Figure 1) have lower levels of the AW-improving measure, but also the higher levels of TE; these were classified into the Efficiency group. Farms located in quadrant Q2 have relatively high levels of the AW measure, but still succeed in attaining higher levels of TE (the Multi-efficiency group) and farms located in quadrant Q3 apply relatively lower levels of the AW-improving measure but still do not succeed in attaining higher levels of TE (the Inefficiency group).

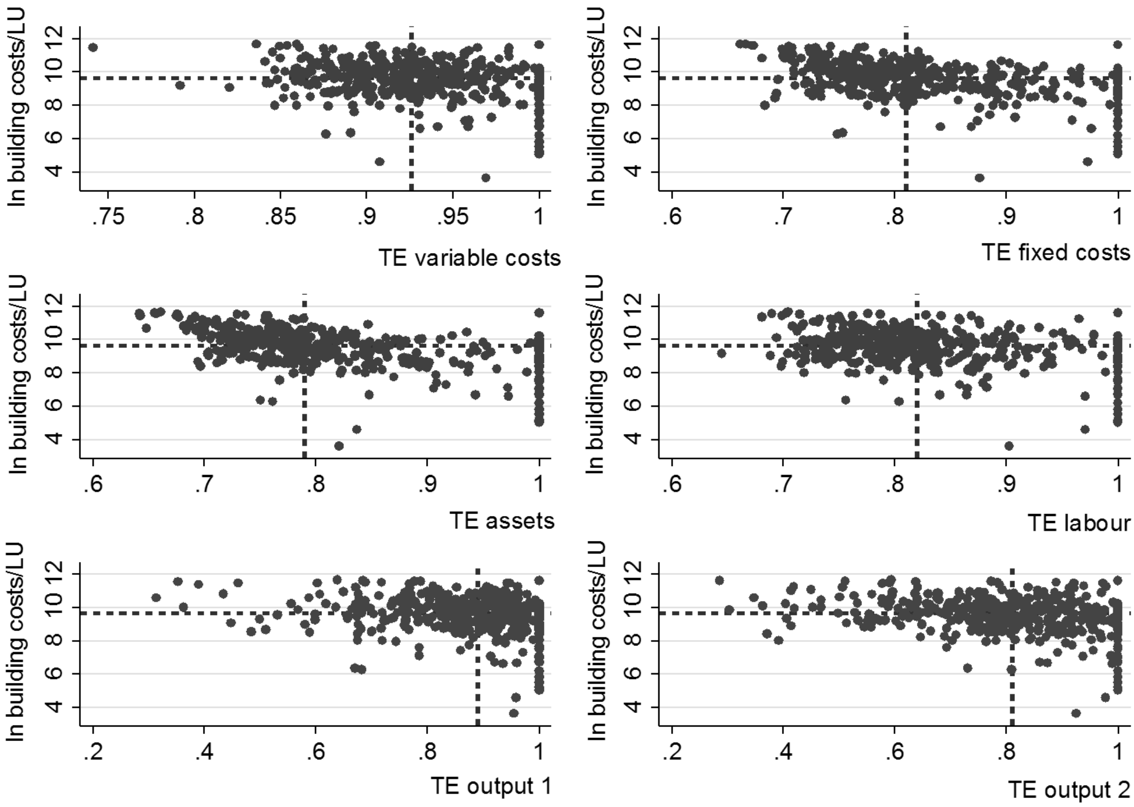

Figure 1: Illustration of the animal welfare (AW)-improving measure building costs per LU, plotted against the TE of each input and output. The upper-left (Q1) quadrant represents the Rational Efficiency (RI) group, Q2 the Multi-efficiency group, Q3 the Inefficiency group and the lower-right (Q4) quadrant the Efficiency group.

The numbers of farms located in each of the different groups (for each of the different TE scores) are presented in Table 3, together with the results of the chi-square tests used to analyse whether farms were equally distributed across the groups (the null hypothesis in the test) or not. The chi-square test was statistically significant in all cases, which shows that there was an over-representation in some of the groups, such that there was no independence between having high compared with low levels of the AW-improving measure and having high compared with low TE. Specifically, we found over-representation of farms located on the diagonal containing the Rational Inefficiency group and the Efficiency group. This provides empirical evidence of a trade-off between the AW-improving measure in terms of building costs per LU and TE. There were also many farms located in the quadrant with the higher levels of the AW-improving measure but with low levels of TE, which indicates that some farms may in fact sacrifice TE for AW, which could be a rational decision due to non-use values in AW. Therefore we next analysed whether the farms in the RI group actually achieve higher levels of actual AW.

Table 3: Distribution of farms across the groups. Results from Chi-square tests

	TE Variable costs				TE Fixed costs		
AW: building costs/LU	Low	High	Total	**AW : building costs/LU**	Low	High	Total
High	**116**	97	212	High	**140**	73	210
Low	96	**112**	209	Low	70	**138**	211
Total	212	209	421	Total	210	211	421
Pearson chi2	2.9044			Pearson chi2	43.3038		
Pr	0.088			Pr	0.000		
	TE Assets				**TE Labour**		
AW: building costs/LU	Low	High	Total	**AW: building costs/LU**	Low	High	Total
High	**140**	73	212	High	**122**	91	209
Low	72	**136**	209	Low	87	**121**	212
Total	212	209	421	Total	209	212	421
Pearson chi2:	40.7481			Pearson chi2:	10.0486		
Pr	0.000			Pr	0.000		
	TE Output 1				**TE Output 2**		
AW: building costs/LU	Low	High	Total	**AW: building costs/LU**	Low	High	Total
High	**119**	94	210	High	**123**	90	210
Low	91	**117**	211	Low	87	**121**	211
Total	210	211	421	Total	210	211	421
Pearson chi2:	6.1819			Pearson chi2:	10.6681		
Pr	0.013			Pr	0.001		

Note: Low if technical efficiency (TE) and animal welfare (AW) measure < 50th percentile; High if TE and AW measure >= 50th percentile. The group: TE=1ow and AW=high represents RI group; TE=high and AW=1ow represents Efficiency group; TE=1ow and AW=low represents Inefficiency group; and TE=high and AW=high represents Multi-efficiency group.

4.2.2 Comparison of differences in indicators of actual AW between the RI group and the non-RI groups

To test the hypothesis that the mean level of actual AW differs between the RI group and the other groups of farms, two-sample t-tests for unpaired data were used. A variance comparison test suggested unequal variance among the groups, and therefore the Satterthwaite and the Welch approximations for unequal variances were used (Ruxton, 2006). The average levels of the indicators of actual AW in the RI group and in the Efficiency group are shown in Table 4. As is evident from the values in Table 4, the RI group mostly had significantly higher values of the indicators of actual AW compared with the Efficiency group. These higher levels of actual AW in the RI group indicate that the farms in the RI group, as a consequence of choosing higher levels of the potentially AW-improving measure, but at the expense of TE, actually achieve higher levels of AW. This can be taken as an indication of the existence of rational inefficiency in this group. Thus this empirical evidence supports the existence of rational inefficiency.

For comparison, we also investigated differences in indicators of actual AW between the RI group and the Multi-efficiency group. The findings suggested that the indicators of the actual level of AW were significantly more favourable in the RI group compared with the Multi-efficiency group in all cases when actual AW was indicated by rate of culling (Table 5). When indicating actual AW by veterinary costs in SEK/LU the findings were not equally clear, with significant evidence of higher AW in four cases and lower AW in two. Taken together, in most cases the findings in Table 5 indicate significantly better AW in the RI group than in the Multi-efficiency group. This implies that while the RI group sacrifices in terms of TE compared with the Multi-efficiency group, it gains in terms of attaining higher levels of actual AW.

It was found that the RI group also achieves significantly more favourable levels of actual AW compared with the Inefficiency group, when considering AW in terms of rate of culling (Table 6). This confirms the finding above that the observed inefficiency in the RI group is compensated for by higher levels of actual AW and lends further support to the suggestion that the position of the RI group is due to rational production considerations. When considering actual AW in terms of veterinary costs in SEK/LU, the findings based on the DEA TE scores suggested more favourable actual AW in the Inefficiency group. However, the MEA scores, which allow more detailed analysis of production patterns, indicated significantly more favourable AW for the RI group in two cases and insignificant results in three cases. Thus, based on the more detailed MEA analysis, there is some support for the claim that the RI group succeeds in achieving higher levels of actual AW compared with the Inefficient group.

Table 4: Comparison of indicators of actual animal welfare (AW) between the Rational Inefficiency group and the Efficiency group

AW indicator: Rate of culling in %					
RI group	**Efficiency group**	**Mean rate of culling, RI group**	**Mean rate of culling, Efficiency group**	**t-test[a,b]**	**Support for RI hypothesis**
High build. costs & low TE VC	Low build costs & high TE VC	9.06	12.56	-33.65***	Yes
High build. costs & low TE FC	Low build. costs & high TE FC	9.93	11.85	-22.97***	Yes
High build. costs & low TE Assets	Low build. costs & high TE Assets	10.01	12.33	-25.67***	Yes
High build. costs & low TE Labour	Low build. costs & high TE Labour	9.82	11.52	-18.07***	Yes
High build. costs & low TE Output 1	Low build. costs & high TE Output 1	9.90	12.09	-21.55***	Yes
High build. Costs & low TE Output 2	Low build. costs & high TE Output 2	9.47	12.67	-29.52***	Yes
Low build. costs & high TE DEA	Low build. costs & high TE DEA	9.56	12.57	-29.34***	Yes

AW indicator: Veterinary costs in SEK/LU					
RI-group	**Efficiency-group**	**Mean vet costs RI group**	**Mean vet costs Efficiency group**	**t-test[a, b]**	**Support for RI hypothesis**
High build. costs & low TE VC	Low build. costs & high TE VC	279.37	283.73	-1.64*	Yes
High build. costs & low TE FC	Low build. costs & high TE FC	268.43	285.04	-7.26***	Yes
High build. costs & low TE Assets	Low build. costs & high TE Assets	272.81	276.39	-1.61*	Yes
High build. costs & low TE Labour	Low build. costs & high TE Labour	282.32	283.64	-0.51	-
High build. costs & low Output 1	Low build. costs & high Output 1	266.81	291.40	-8.67***	Yes
High build. costs & low Output 2	Low build. costs & high Output 2	287.55	288.06	-0.20	-
High build. costs & low TE DEA	Low build. costs & high TE DEA	272.50	298.15	-9.17***	Yes

[a]Welch and Satterthwaite approximations for degrees of freedom; [b] Pr(T<t): * = 0.05; **=0.01; ***=0.001; high is values >= than the 50th percentile; low is values < than the 50th percentile; TE = technical efficiency, DEA = data envelopment analysis, VC = variable costs, FC = fixed costs.

Table 5: Comparison of indicators of actual animal welfare (AW) between the Rational Inefficiency group and the Multi-efficiency group

AW indicator: Rate of culling in %					
RI group	**Multi-efficiency group**	**Mean rate of culling RI group**	**Mean rate of cull. Multi-eff. group**	**t-test[a,b]**	**Support for RI ypothesis**
High build. costs & low TE VC	High build. costs & high TE VC	9.06	12.68	-40.63***	Yes
High build. costs & low TE FC	High build. costs & high TE FC	9.93	12.18	-18.71***	Yes
High build. costs & low TE Assets	High build. costs & high TE Assets	10.01	11.99	-17.15***	Yes
High build. costs & low TE Labour	High build. costs & high TE Labour	9.82	11.87	-21.31***	Yes
High build. costs & low Output 1	High build. costs & high Output 1	9.90	11.73	-20.42***	Yes
High build. costs & low Output 2	High build. costs & high Output 2	9.47	12.36	-31.51***	Yes
High build. costs & low TE DEA	High build. costs & high TE DEA	9.56	12.05	-27.55***	Yes

AW indicator: Veterinary costs in SEK/LU					
RI group	**Multi-efficiency group**	**Mean vet costs RI group**	**Mean vet costs Multi-eff. group**	**t-test[a,b]**	**Support for RI ypothesis**
High build. & low TE VC	High build. costs & high TE VC	279.37	273.85	2.09**	No
High build. & low TE FC	High build. costs & high TE FC	268.43	288.59	-6.81***	Yes
High build. & low TE Assets	High build. costs & high TE Assets	272.81	283.71	-3.86***	Yes
High build. & low TE Labour	High build. costs & high TE Labour	282.32	269.53	4.76***	No
High build. & low TE Output 1	High build. costs & high Output 1	266.81	288.44	-8.18***	Yes
High build. & low TE Output 2	High build. costs & high Output 2	287.54	263.38	9.09***	No
High build. costs & low TE DEA	High build. costs & high TE DEA	272.50	281.21	-3.31***	Yes

[a]Welch-Satterthwaite approximations for degrees of freedom; [b] Pr(T<t): * = 0.05; **=0.01; ***=0.001; high is for values >= than the 50th percentile; low is for values < than the 50th percentile; TE = technical efficiency, DEA = data envelopment analysis, VC = variable costs, FC = fixed costs.

Table 6: Comparison of indicators of actual animal welfare (AW) between the Rational Inefficiency group and the Inefficiency group

AW indicator: Rate of culling in %

RI group	Inefficiency group	Mean rate of culling RI group	Mean rate of culling Ineff. group	t-test[a]	Support for RI hypothesis
High build. & low TE VC	Low build. costs & low TE VC	9.06	12.36	-24.84***	Yes
High build. costs & low TE FC	Low build. costs & low TE FC	9.93	.1367	-22.36***	Yes
High build. costs & low TE Assets	Low build. costs & low TE Assets	10.01	12.73	-18.98***	Yes
High build. costs & low TE Labour	Low build. costs & low TE Labour	9.82	13.77	-28.48***	Yes
High build. costs & low TE Output 1	Low build. costs & low TE Output 1	9.90	12.95	-21.51***	Yes
High build. costs & low TE Output 2	Low build. costs & low TE Output 2	9.47	12.19	-22.59***	Yes
High build. & low TE DEA	Low build. costs & low TE DEA	9.56	12.33	-19.35***	Yes

AW indicator: Veterinary costs in SEK/LU

RI group	Inefficiency group	Mean vet costs RI group	Mean vet costs Ineff. group	t-test[a, b]	Support for RI hypothesis
High build. costs & low TE VC	Low build. costs & low TE VC	279.37	278.30	0.28	-
High build. costs & low TE FC	Low build. costs & low TE FC	268.43	274.26	-1.44*	Yes
High build. costs & low TE Assets	Low build. costs & low TE Assets	272.81	290.66	-4.04***	Yes
High build. costs & low TE Labour	Low build. costs & low TE Labour	282.32	278.28	1.15	-
High build. costs & low TE Output 1	Low build. costs & low TE Output 1	266.81	268.48	-0.51	-
High build. costs & low TE Output 2	Low build. costs & low TE Output 2	287.54	271.33	4.21***	No
High build. & low TE DEA	Low build. costs & low TE DEA	272.50	255.70	4.42***	No

[a]Welch's-Satterthwaite's approximations for the degree of freedom; [b] Pr(T<t): * = 0.05; **=0.01; ***=0.001; high is for values >= than the 50th percentile; low is for values < than the 50th percentile; TE = technical efficiency, DEA = data envelopment analysis, VC = variable costs, FC = fixed costs.

5 Discussion and conclusions

Through this study, we made a novel contribution to the literature by exploring the rational inefficiency hypothesis of Bogetoft and Hougaard (2003) in an agricultural setting, specifically Swedish dairy farms. We did this in two steps: First, we introduced a theoretical explanation of why there may be rational inefficiency in dairy farming, building on farmers' possible recognition of non-use values (McInerney, 2004; Lagerkvist *et al.*, 2011) as motivational factors in farmers' decisions related to the welfare of their livestock. Second, we explored the patterns of inefficiencies, based on observed production data, in order to find empirical evidence of the existence of rational inefficiency among dairy farms in Sweden.

Our two-stage empirical analysis provided statistically significant empirical evidence of a trade-off between an AW-improving measure (building costs per LU) and TE. When we plotted the level of the AW-improving measure against the various TE scores, we found an indication of a negative relationship between the two variables. This was further supported by the statistical tests, which showed significant over-representation of farms in the two quadrants on the diagonal of the diagrams supporting existence of such a trade-off. Furthermore, our empirical findings showed that the farms that we classified as the RI group score significantly more favourably on indicators of actual AW (measured in terms of rate of culling and veterinary costs in SEK/LU) compared with the farms that we classified as the Efficiency group. With some exceptions, the RI group also generally score significantly higher on the indicators of actual AW compared with the Multi-Efficiency group, or compared with Inefficient group. The analysis based on MEA offered a more detailed assessment of the relationships between TE and indicators of actual AW compared with the analysis based on DEA. Moreover, the use of MEA enabled us to study the TE in the output from dairy production separated from the TE in output from other types of production on the farms (output 2), which was desirable for the purposes of this study. In most cases the analyses based on MEA produced the same type of support for the RI hypothesis as the analyses based on DEA. However, there was one notable exception: when we compared the level of actual AW in the RI group to that in the Inefficiency group, the analysis based on DEA contradicted the RI hypothesis, while the analysis based on MEA supported the RI hypothesis or gave non-significant differences (Table 6). A reason for this may be the aggregated nature of the DEA analysis, where efficiency effects of all production inputs and outputs are jointly analysed, including output 2 which is not really related to AW, but has to be included in the analysis to completely represent all output produced from the inputs used.

Taken together, our explorative analyses of the patterns of inefficiency indicate that farms which apply relatively high levels of the AW-improving measure considered, but at the same time attain lower levels of TE, generally report higher levels of indicators of actual AW. This holds especially when comparing the RI group with the Efficiency group, but also when comparing the RI group with the Multi-efficiency group. The findings thus suggest that the RI group, while at first glance appearing inefficient, succeeds in attaining higher levels of AW. Provided that farmers obtain utility both from the non-use values in AW and from profit, this indicates that the total utility obtained by the RI group consists to a higher degree of non-use values, and to a lower degree of profit. Assuming that all farmers make rational decisions, the positioning of the RI group compared with the Efficiency group is thus not due to bad production choices, but to the realisation of higher AW and thus potentially higher non-use values in AW. This supports the idea of the existence of rational inefficiency. The findings thus indicate that what may appear to be inefficiency in production may instead result from rational production decisions made by the farmers. Efficiency studies should explore the possibility of such interpretation of inefficiency of farms, in order to avoid misinterpreting deviations from the efficient isoquant or from the production possibility frontier as resulting from poor management.

The emprical support for the existence of rational inefficiency in dairy farming found in this explorative study has implications for both public agricultural policies, such as the CAP, and private policy initiatives such as agricultural advice given by the advisory services. In particular, public and private policy measures that are designed to reduce inefficiency in agricultural production may not be effective because, while being based on the assumption that reducing inefficiency in the use of production factors is desirable by farmers, it may not be perceived as attractive by all farmers. Instead, for farmers of the type in the RI group such a policy may even reduce their total utility and may be perceived by the farmers as counterproductive. Measures designed to improve TE in farming should be targeted instead at farms of the type in the Inefficiency group, since unlike in the RI group their inefficiency seem to result from poor production decisions and not rational production decisions.

An important task for future research is to continue to explore the rational inefficiency hypothesis. In particular, future research should explore the possible existence of rational inefficiency among other types of farms. Previous research has found that farmers' attachment to their animals may depend on the type of animals they keep and on the purpose for keeping these animals (Bock *et al.*, 2007). As level of attachment may affect how animals are treated, this implies that farmers' motivation for treating their animals well may be affected by the type of species they keep. This in turn can affect the importance of non-use values in farmers' production decisions. Therefore, our findings cannot be readily generalised to other types of livestock producers. Future research should therefore explore the rational inefficiency hypothesis for other types of livestock farms. It should also explore the existence of rational inefficiency among other types of farms, such as arable farms, and develop theoretical explanations as to why there may be rational inefficiency among these farms.

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