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Rationalising inefficiency in dairy production: evidence from an over-time approach

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Abstract

We argue that inefficiency can be part of a strategic self-repositioning adjustment process beyond the general interpretation of poor performance. Based on the rational inefficiency hypothesis, we examine the simultaneous dynamics of efficiency and animal welfare improving investments over time in dairy farms. Using rotating panel data from Swedish dairy farms and implementing multidirectional efficiency analysis and Markov transitional dynamic analysis, the paper provides evidence that for some farms inefficiency is temporary and part of rational decision along their trajectory towards multi-efficiency (high efficiency-high animal welfare). The findings show the importance of time dynamics in efficiency achievements with implications to cross-sectional view.

Keywords: rational inefficiency, Markov transitional dynamics, dairy farming, multidirectional efficiency analysis

JEL classification: Q12, Q18, C12

1. Introduction

Technical and economic efficiency analyses (henceforth efficiency analyses) constitute a common way of evaluating the economic performance of farms. In the agricultural economics literature, efficiency studies have not only focused on the observed levels of efficiency but also focused on explaining the existence of inefficiency by investigating how farm-level efficiency scores are related to farm and farmer characteristics, and to characteristics of agricultural policies under which the farm operates. Examples include housing system characteristics (Labajova *et al.*, 2016); management routines, practices and

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control (Rougoor *et al.*, 1998; Trip *et al.*, 2002; Hansson, 2008; Manevska-Tasevska and Hansson, 2011; Labajova *et al.*, 2016); financial management (Davidova and Latruffe, 2007) and subsidies (Latruffe and Nauges, 2014). Such insights are often used to develop recommendations about how to encourage agriculture that is more efficient. The interest in efficient agricultural production is not only academic; ensuring efficient agricultural production has also been highlighted from the perspective of contributing to the implementation of the common agricultural policy (CAP) (Latruffe *et al.*, 2016). Indeed, some of the CAP measures in the current programme are directly related to ensuring the productivity of agriculture and the optimal use of its production factors (Massot, 2000). Efficient resource use at the farm level is also highlighted in the coming CAP period (DG Agriculture and Rural Development, 2019). Efficiency studies are also interesting from the perspective of developing farm advisory services.

Departing from a microeconomic model of the farm firm, efficiency analyses build on behavioural assumptions of cost minimisation (under the so-called input perspective) and of revenue maximisation (under the so-called output perspective). An efficiency score for each farm is obtained by comparing the position of each farm in relation to an efficient isoquant or production possibility frontier (Coelli *et al.*, 2005). Based on available data, the efficient isoquant or production possibility frontier is determined empirically and is thus dependent on the structure of the data. This also means that the frontier represents the best practice in the available data set.

Efficiency studies thus centre on the idea that any deviations from the efficient frontier can be interpreted as non-optimal use of production factors in comparison to the best practice in the available sample. In particular, the assumption is that input-oriented inefficiency can be interpreted as overuse of production factors and that the same level of production can be achieved from a smaller set of production factors. On the other side, output-oriented inefficiency can be interpreted as under-exploitation of production factors and that a higher level of production, and thus revenue, can be obtained from a given level of production factors (Coelli *et al.*, 2005). The relevance of efficiency studies as a tool for analysing farm economic performance is, therefore, highly dependent on the accuracy of the underlying assumptions. Among others, on the accuracy of the assumption that an observed inefficiency can automatically be interpreted as originating from irrational decision making behaviour, which causes non-optimal use of production factors, and on that inefficiency can and should always be reduced.

In the agricultural economics literature, these assumptions were recently challenged by Hansson, Manevska-Tasevska and Asmild (2020) using Swedish dairy agriculture as an empirical example. Building on the work of Asmild, Bogetoft and Leth Hougaard (2013) and using cross-sectional data, Hansson, Manevska-Tasevska and Asmild (2020) tested hypotheses about the patterns of inefficiency among the production factors and put forward the idea that at least some of the observed inefficiency in Swedish dairy agriculture may indeed originate from rational behaviour among farmers. This means that the

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farms, at least to some extent, could be classified as being rationally inefficient (Bogetoft and Hougaard, 2003).

The challenges presented to the assumptions are in line with the rational economic behaviour, which states that economic units make decisions in a way that maximise their objective functions (Gasson, 1973; Burton, 2004). As such, the rational inefficiency idea, beyond efficiency optimisation objectives, highlights the rational economic behaviour that farmers also maximise the utility they drive from the use of production factors beyond use in the production process. An example put forward by Hansson, Manevska-Tasevska and Asmild (2020) involves high animal welfare (AW) standards where decision-making among farmers involves engagement in the trade-off between achieving high efficiency and high AW.

The idea of the existence of *rational inefficiency* in production processes is not new and can be traced back to the work by Stigler (1976). Criticising the notion of X-efficiency (Leibenstein, 1966, 1978) where inefficiency was considered to represent waste, Stigler (1976) put forward that productivity variations can be attributable to overlooked factors in the analysis, for instance entrepreneurial capacity. Building on these ideas, Bogetoft and Hougaard (2003) later introduced the idea that observed inefficiency may indeed result from rational decision-making. This can for instance include seemingly overuse of production factors by firms to ensure sufficient buffer against risks and uncertainties. It may also relate to allowing slack in, for example, the use of labour to make the firm a more attractive employer and through that avoid expenses related to high personnel turnover.

Ideas related to rational inefficiency are also put forward in the literature on dynamic efficiency estimations (Emvalomatis, Stefanou and Lansink, 2011; Skevas, Emvalomatis and Brümmer, 2018) although this literature does not speak about rational inefficiency as such and the underlying behavioural explanations for its existence. However, the literature on dynamic efficiency (Ang and Lansink, 2018) highlights that farms may temporarily position themselves in inefficient space due to finding it non-optimal to currently adjust the production processes.

To the best of our knowledge, the study by Hansson, Manevska-Tasevska and Asmild (2020) is the only study so far testing the rational inefficiency hypothesis (RIH) in the agricultural sector. However, that study was based on a cross-sectional data set and no attempts were made to investigate the concept of rational inefficiency from a dynamic perspective. Investigating the over-time dynamics of rational inefficiency would be highly relevant from a policy perspective by providing evidence on the dynamics of inefficiency and farmers' preferences for where to position themselves in the production possibility set at a certain point in time, and how and why they potentially move over time in the production possibility set. Such an analysis would also significantly add to the literature on efficiency in agricultural production by problematising and advancing the understanding about how inefficiency should be interpreted, and how efficiency scores can be used as measures of farm economic performance.

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The overall aim of this paper is, therefore, to test the RIH using an over-time approach. The analysis uses production economic data on dairy farming in Sweden from 2009 to 2016. This paper extends the approach first suggested by Asmild *et al.* (2003) and adopted to cross-sectional dairy agriculture data by Hansson, Manevska-Tasevska and Asmild (2020). We test the possible existence of rational inefficiency from a dynamic perspective by testing hypotheses about the structure and logic behind patterns of inefficiency in the use of production factors over time. In comparison to work by Asmild *et al.* (2003) and Hansson, Manevska-Tasevska and Asmild (2020), we conduct the efficiency analysis repeatedly for several years using a rotating panel data set to examine the transitional dynamics over time. In particular, we classify farms into efficiency groups as suggested in Hansson, Manevska-Tasevska and Asmild (2020) and examine the over-time patterns and dynamics in efficiency group classification for individual farms. Specifically, using a Markov chain approach, the paper investigates the transition over time that the same farms would make between efficiency classes, i.e. whether a farm would be classified as being rationally inefficient repeatedly over time or move between efficiency classes. This allows us to investigate the underlying question whether a farm could be identified as being 'rationally inefficient' in the sense that observed inefficiency is only temporary and, in fact, the farm is on a trajectory towards higher levels of efficiency.

This study is useful in the following ways. First, it exemplifies how an over-time analysis of farmers' behaviours can be conducted using a production economic data set to provide insights about patterns in efficiency of farms, which possibly originate from rational behaviours of farmers. Future studies can use this approach to investigate the possible existence of rational inefficiency in their data sets. This is useful to avoid misinterpreting estimated inefficiency as an ultimate indicator of poor economic performance among farms. Second, by providing over-time insights about patterns of inefficiency types, this study puts forward evidence that standard interpretations of efficiency and inefficiency using insights from cross-sectional data sets may be misleading and should be re-considered. In particular, findings presented here suggest that efficiency studies based only on cross-sectional data do not sufficiently take the dynamics of patterns of farmers' adaptations to investments into consideration and may accidentally classify some as being inefficient although evidence points to the fact that they are in an adaptation process.

The remainder of the paper is structured as follows. Section 2 provides the theoretical framework of the paper. This section explains how the concept of rational inefficiency is linked to the operations of the dairy farms and how we aim to capture rational inefficiency patterns in the dairy sector. This section also outlines a framework to examine farms' transition across different efficiency classes over the years. Section 3 presents the data and the methodology applied in the paper. Section 4 presents and discusses the results, and Section 5 presents the concluding remarks of the paper.

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2. Conceptual background and hypotheses

2.1. Rational inefficiency in the dairy sector

The concept of rational inefficiency signifies that inefficiency can result from rational decision-making processes of production units. Such decisions, labelled as rational decisions, can vary across the sector under consideration to qualify as potential contributors to rational inefficiency. In the dairy sector, for example, the use of animals in the production process brings farm AW standards in to play, and the increased use of AW standards as criteria to evaluate farms in the sector (Lusk and Norwood, 2011) makes the sector particularly interesting for testing the RIH. Nowadays, public awareness for AW is high and improved AW is used as a standard to justify modern husbandry (Curtis, 2007; Allendorf and Wettemann, 2015). However, AW improving measures come at high costs that could jeopardise the performance of the decision-making units (DMUs) in economic standards. In this study, we build on arguments put forward by Hansson, Manevska-Tasevska and Asmild (2020) to investigate the existence of rational inefficiency in dairy farming by focusing on farmers' investments in AW improving measures.

Theoretically, two types of economic value sets are associated with the well-being of livestock: use and non-use values (McInerney, 2004; Lagerkvist *et al.*, 2011). Use values represent the economic value in AW that farmers realise from the direct use of livestock/animals in their production, while the non-use value in AW includes all other economic values that farmers derive from the well-being of their livestock, irrespective of their use in production processes. However, one might ask whether these values compete against each other. While the exact answer remains an empirical one, the need to achieve a certain level of AW for animals is inherent to achieve better performance in the production process. At the same time, the imbalance between the two value sets, for example, higher weight-to-non-use values than use value in AW could lead to rational but inefficient, or what is being framed as rational inefficiency, behaviour.

To examine the RIH and analyse the dynamics over time, we adopt the approach used in Hansson, Manevska-Tasevska and Asmild (2020) to categorise farms into four efficiency groups. The approach categorises DMUs in to four groups based on their farm AW improving measures and efficiency scores attained by each DMU. Based on the two-dimensional space (AW improving measures and efficiency scores), and using the median values of the two dimensions, as the cut-off value, four efficiency groups are established. Accordingly, the first group represents the welfare-oriented or rational inefficiency (RI) group that includes DMUs that exhibit high AW improving measures and low efficiency scores, while the second group is the efficiency-oriented or efficiency (EF) group that represents those with a low level of AW improving measures, but high efficiency. Note that 'high' and 'low' scaling represent values for above and below the median values of the two dimensions,

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respectively.[1] The third and fourth groups are the inefficiency (IE) group with low levels of both AW improving measures and efficiency, and the multi-efficiency (ME) group that represents DMUs with a high level of both AW improving measures and efficiency, respectively.

Building cost (measured by building cost per livestock unit) and pasture access (measured by pasture size per livestock unit) are the two AW improving measures considered to categorise farms into respective efficiency groups in combination with their efficiency scores (see the data section for the details on the use of these variables as AW improving measures). Based on these established efficiency groups, this paper examines the trajectory of dairy farms across these groups over time. Given the evidence on the existence of rational inefficiency in the Swedish dairy sector (Hansson, Manevska-Tasevska and Asmild, 2020), here we examine whether this rational inefficiency state is a transitional state or the ultimate goal of farmers in the dairy sector. In so doing, this paper provides insights into the interpretation of inefficiency from a time dynamic perspective. In particular, should observed inefficiency in a cross-sectional data set be interpreted as inefficiency or as an occasional reduction in efficiency in a trajectory towards higher levels of efficiency?

2.2. RIH: over-time dynamic perspective

The literature on efficiency studies primarily focuses on a direct interpretation of inefficiency as non-optimal use of production factors with no consideration for a 'strategic' inefficiency that DMUs can experience while aiming for better performance in the future. Such 'strategic' inefficiencies could result from a rational decision in the production process. The question is how we can capture such inefficiencies for a better understanding and interpretation of efficiency estimates. Building on the concept of rational inefficiency (Bogetoft and Hougaard, 2003; Asmild, Bogetoft and Leth Hougaard, 2013; Hansson, Manevska-Tasevska and Asmild, 2020), here we aim to examine the existence of rational inefficiency from a dynamic perspective. Given the categorisation of DMUs into four groups at a given period in time, discussed above, we develop hypotheses on the likely trajectory of movement over time that rationally inefficient DMUs can take, and test for empirical evidence for that trajectory as compared to the movement of efficiency-oriented DMUs. Figure 1 presents the categorisation and positioning of the efficiency groups with respect to AW measure-efficiency score dimensions.

In addition to the growing pressure on the dairy and livestock sector from policy makers and consumers to maintain high AW standards and produce more efficiently (Dawkins, 2017), farmers' own preferences for a high level

1 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. This is testable and does not require the assumption of a linear relationship between the two variables. As such, the use of median is rationalized and the use of other measures like first or third quartile may not be logical. One could also suggest the use of mean values for the categorization. However, this makes the distribution of DMUs across efficiency groups to base on the skewedness of variables and hence, bias the categorization.

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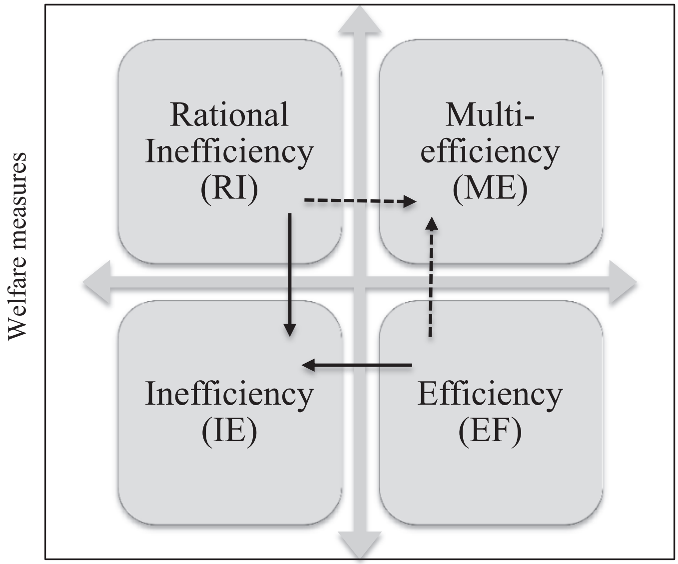

Fig. 1. Efficiency groups over AW measure-efficiency space and hypothetical mobility across groups.

of AW can drive their decisions in AW improving measures (Hansson and Lagerkvist, 2015, 2016). Given these forces, it is our theoretical argument that achieving multi-efficiency is the steady/ideal state that all rational dairy farmers would aim for to remain in operation. However, in cross-sectional data set, we may observe farms in any of the four groups and from the perspective of RIH; the key question is whether or how standing in the RI group can ever be considered rational.

In this paper, we focus on the transitional dynamics of farms between the efficiency groups and argue that behaviour consistent with the RIH would imply a movement over time from the rational IE group to the ME group. Being in the rational IE group could potentially be due to reasons such as new investments in AW improving measures, to which the farm has not yet adapted. In other words, farms that, at a given point in time, are observed as low in efficiency and high in AW measures, and thus considered candidates for being rationally inefficient, are likely to transition to the ME group once they have adjusted to the level of the AW improving measures. Implicitly, the RI to ME transition argument states that AW improving measures (building costs and pasture size), among others, are not optimally utilised in the RI group and are associated with low efficiency. Figures B1a and b in Appendix B present this relationship. Therefore, a significant movement from the RI group to the ME group would suggest that a temporary positioning in the RI group can be rationalised in the sense that the farm is on a trajectory towards the ME group. That means the farms' positioning in the RI group could be due to the rational

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reason of prioritising AW improving measures over efficiency while being on a trajectory towards multi-efficiency.

The other potential scenario for farms in the rational IE group is falling to the inefficient category over time, instead of transitioning to the ME group. For the RIH to be even stronger, we should be able to show that RI farms are not the ones likely to fall to the IE group compared to other groups, especially to EF group.

However, to counter the assumption of a movement along a trajectory from the RI group to the ME group, let us instead focus on a counter hypothesis: a movement along a trajectory that we would observe if inefficiency could not be rationalised in the sense described above. Under normal business circumstances, farms in the high efficiency–low welfare measure space (EF group) are likely associated with higher profit margins and, hence, have more resource to reinvest to improve AW and achieve multi-efficiency than farms in the RI group. Therefore, the first hypothesis (H1) can be stated as follows:

H1: Dairy farms in the EF group are more likely to attain a state of multi-efficiency in subsequent periods than dairy farms in the RI group.

At the same time, we argue that for farms in the RI group (low efficiency–high AW measure) ensuring high AW in subsequent periods can only come at extra cost and challenge their sustainable operation. This could lead rational inefficient farms to fall back to the IE category rather than farms in the EF group, signalling that they are not on a trajectory towards multi-efficiency. In other words, our second hypothesis can be presented as follows:

H2: Farms in the RI group are more likely to fall to the IE group in subsequent periods than those in the EF group.

Given these hypotheses, for the rational efficiency hypothesis to hold in the sense described above, we should be able to reject the two hypotheses. At the same time, we have to be able to show that more farms in the RI group tend to end up in the ME group compared to those in EF group and do not fall back to the IE group relative to EF group. More precisely, to rationalise the state of being in the RI group, more farms in the RI group should move to the ME group and should not fall back to the IE group in subsequent periods, compared to those in EF groups. As such, we aim to investigate if farms in the RI group are on a trajectory towards the ME group, and whether being in the RI group can be due to a rational reason of temporarily prioritising AW over efficiency.

3. Method and data

3.1. Method

Methodologically, the estimation of efficiency scores applies a data envelopment analysis (DEA) approach (Charnes, Cooper and Rhodes, 1978) and a

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multidirectional efficiency analysis (MEA) approach (Bogetoft, Du and Leth Hougaard, 1998). The standard commonly known DEA approach estimates a single composite efficiency score for each farming unit, while the MEA approach accounts for directional potential improvement in multi-input–output space and provides variable-specific (input and output-specific) efficiency scores for each DMU. This use of MEA merits a detailed and multidirectional analysis and understanding of the inefficiency of the production process of the DMUs. Both approaches are non-parametric in construction in contrast to the parametric stochastic frontier analysis approach, which is not used in this paper given its demanding assumptions on the functional form of the production function and the distribution of the inefficiency term. The use of both methods of MEA and DEA is to check the robustness of our results for different estimation approaches and of implications from further analysis.

3.1.1. *Efficiency estimation: MEA and DEA approaches*

To formalise the MEA approach to efficiency estimation in our case, assume a set of K farms or DMUs ($k = 1, 2, 3, \ldots, K$) that employ five inputs (i), $x_{i,k}$ ($i = 1, 2, \ldots, 5$) to produce two outputs (j), $y_{j,k}$ ($j = 1, 2$). Assume that the production plan of a given production unit under analysis is given by input–output vector (x_0, y_0) where the technology set, T, is defined as follows: $T = \{(x_0, y_0) : x_0 \textit{ can produce } y_0\}$ and constant returns to scale (CRS) governs the production function in the sector.[2] Given this, the input- and output-specific optimal references are obtained by optimising a linear programming (LP) problem for each of the variables. For input, x_i, the LP problem is given by, say, input problem:

$$
\begin{gathered}
\min_{\lambda, \theta_k^i} \theta_k^i \\
s.t \\
\sum_{k=1}^{K} \lambda_k x_{k,i} \leq \theta_k^i, \qquad i = 1,2,3,4,5 \\
\sum_{k=1}^{K} \lambda_k x_{k,-i} \leq x_{0,-i} \\
\sum_{k=1}^{K} \lambda_k y_{k,j} \geq y_{0,j}, \quad j = 1,2 \\
\lambda_k \geq 0,
\end{gathered}
\tag{1}
$$

where $-i$ denotes all inputs other than input, i, under optimisation.

2 The assumption of a CRS is because it was desirable to base the analysis on efficiency scores that reflect the full inefficiency of the farms. From the perspective of animal welfare, it is also possible that farmers choose to operate too large farms to provide more space and grazing areas for their livestock, as a means to realize more non-use values (Hansson, Manevska-Tasevska and Asmild, 2020).

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At the same time, for output, y_j, the LP problem is given by, say, output problem:

$$\begin{gathered}\max_{\lambda_k,\theta^j_k} \theta^j_k \\ s.t \\ \sum_{k=1}^{K} \lambda_k y_{k,j} \geq \theta^j_k, \quad j = 1,2 \\ \sum_{k=1}^{K} \lambda_k y_{k,-j} \geq y_{0,-j} \\ \sum_{k=1}^{K} \lambda_k x_{k,i} \leq x_{0,i}, \quad i = 1,2,3,4,5 \\ \lambda_k \geq 0,\end{gathered} \tag{2}$$

where $-j$ denotes all outputs other than output, i, under optimisation.

The above LP problems solve to provide optimal values of (λ^*, θ^{i*}) for input problem and (λ^*, θ^{j*}) for output problem for a given production unit given by (x_0, y_0).

Given these optimal reference points, we formulate an LP problem, which brings the two results together in the following way:

$$\begin{gathered}\max_{\lambda,\beta} \beta \\ s.t. \\ \sum_{k=1}^{K} \lambda_k x_{k,i} \leq x_{0,i} - \beta\left(x_{0,i} - \theta^{i*}_k\right), \quad i = 1,2,3,4,5 \\ \sum_{k=1}^{K} \lambda_k y_{k,j} \geq y_{0,j} + \beta\left(\theta^{j*}_k - y_{0,j}\right), \quad j = 1,2\end{gathered} \tag{3}$$

This problem solves to the value set of (λ^*, β^*), which are used to estimate variable-specific MEA scores for our production unit, (x_0, y_0). Specifically, the scores are given for inputs and outputs as $\frac{x_{0,i} - \beta^*\left(x_{0,i} - \theta^{i*}\right)}{x_{0,i}}$ and $\frac{y_{0,j}}{y_{0,j} + \beta^*\left(\theta^{j*} - y_{0,j}\right)}$, respectively.

Intuitively, the MEA approach implements two sequential steps to estimate input- and output-specific efficiency scores. In the first step, the optimal input and output coordinates are determined by solving an LP problem for each input and output as given by equations (1) and (2), respectively. The optimal values express the maximum possible reduction in each input and maximum possible expansion in output. In the second step, given the optimal values in step one, a single LP problem is set up and solved to determine input- and output-specific efficiency scores.

On the other hand, DEA-based efficiency estimation approach calculates a single efficiency score for each individual DMU. Given K farms $(k = 1, 2, 3, \ldots, K)$ that employ five inputs (i), $x_{i,k}$ $(i = 1, 2, \ldots, 5)$ to produce

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two outputs (j), $y_{j,k}$ $(j = 1, 2)$, under CRS operation the input-oriented efficiency is estimated by optimising a LP problem for each DMU and is given by

$$\begin{gathered}
\min_{\lambda,\theta} \theta_k \\
s.t \\
\sum_{k=1}^{K} \lambda_k y_{mk} \geq y_{mk}, \qquad m = 1, 2, \ldots, M \\
\sum_{k=1}^{K} \lambda_k x_{nk} \leq \theta_k x_{nk}, \qquad n = 1, 2, \ldots, N \\
\lambda_k \geq 0
\end{gathered} \tag{4}$$

where θ is the efficiency score estimated for each farm and satisfies the condition that $\theta \leq 1$, with value 1 indicating a farm on the frontier and hence efficient. Note that in the DEA model, the LP model is solved for each farm and one efficiency score is estimated for each farm, while the MEA estimation provides input- and output-specific efficiency scores for each farm (i.e. $M + N$ number of efficiency scores for each farm). It is also important to note that DEA and MEA scores are estimated for years separately to account for technological change over the period under consideration in the data.

3.1.2. Estimation of the transition matrix

To examine the mobility of DMUs across efficiency groups over time, we implemented the Markov chain approach to estimate the transition matrices, which shows how each of the farms in the respective efficiency groups at a given point in time move to other groups over the time duration under consideration. Here, we should note that we are not interested in testing weather the Markov assumption is satisfied in our analysis.[3] We are interested in understanding historic movement rather than prediction, and in providing evidence on the actual transitional dynamics of DMUs with respect to the RIH outlined above.

In our analysis, we are interested in examining the transitional dynamics over one and two-year periods that are, respectively, given by

$$S_t = M_1 S_{t-1} \ \ and \ \ S_t = M_2 S_{t-2} \tag{5}$$

where M_1 and M_2 represent the transitional probabilities of being in a given state S, at time t, from a given state, 1 year $(t-1)$ or 2 years $(t-2)$ earlier, respectively. States, in our case, represent efficiency groups attained by DMUs in respective years under analysis.

3 The Markov assumption is satisfied if the Markov matrix or the first transition matrix is sufficient to describe the transitional probability at any longer transitions. In other words, history does not matter for transition probabilities or it assumes that $S_{t+1} = M_1 S_t = M_1 M_1 S_{t-1} = M_1^2 S_{t-1}$, and for any time, $t + n$, $S_{t+n} = M_1^n S_t$.

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The transitional matrix gives us information on level and direction of mobility, as well as on the extent of state dependence among efficiency groups/states. It captures the probability of a farm in state S at time $t-1$ ends up in the other states or remains in state S at time t. This transitional matrix is built by mapping the total number of farms in each state at time $t-1$ or $t-2$ and tracing in which state they end up at time t. Therefore, the number of farms that ends up in a given state at time t divided by the total number of farms in the original state at time $t-1$ gives us the probability of transition. The sum of transition probabilities should sum to 1 on the row or column where of the original state at time $t-1$ is presented.

However, we are interested in testing hypotheses on the likelihood that some groups move to a target group compared to other groups in light of the RIH. Practically, given the Markov transition rates, we test the equality of transition rates between two likely moves. For example, for H1, we test whether the transition rates from RI to ME, $p\left(RI\_ME\right)$, and EF to ME, $p\left(EF\_ME\right)$, are equal. If we are able to reject this (or accept the alternative that the transition rates are significantly different), then we can see from the transition rates which movement between groups is more likely. The same logic goes to testing H2 with H_0: $p\left(RI\_IE\right) = p\left(EF\_IE\right)$.

Therefore, for RIH to hold, we have to be able to reject the null hypotheses for equality and show that $p\left(RI\_ME\right) > p\left(EF\_ME\right)$ and $p\left(RI\_IE\right) < p\left(EF\_IE\right)$. In line with this, we can also further examine how mobile the DMUs are, once they reach the ME group. In other words, what is the likely state that the farms in ME group are going to end up in?

3.2. Data

The paper used data from the Swedish Farm Accountancy Survey (FAS), which is the Swedish raw data for EU level Farm Accountancy Data Network (FADN) database. We used a sample of specialist dairy farms in Sweden from 2009 to 2016. The data set is a rotating panel where a small proportion of the sample is dropped and replaced every year to ensure the representativeness of the sample over time. On the general FAS data, which capture representative samples of the Swedish agriculture per respective sector, the following restrictions are applied to come up with the final sample of analysis. First, given our focus on the dairy sector and specialist dairy farms, we use farms whose dairy output accounts for more than half of their total agricultural output. Second, the panel restriction of 2009 to 2016 is based on samples with no missing values for variables of interest and on the latest reliable data available. These restrictions produced a total sample of 2,191 observations over 8 years. Lastly, outlier detection is conducted using the Mahalanobis distance approach (Yuan and Zhong, 2008), resulting in a total sample of 2,058 observations, which corresponds to an average of 257 observations per year. The restriction on the data period is based on the availability of key variables of interest.

For our analysis, we identify five input variables: variable cost, fixed cost, asset, labour and land, and two output variables: output 1 (milk and meat outputs), and output 2 (other outputs in farm production). Table 1 presents yearly

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Table 1. Descriptive statistics of variables used in the analysis per year

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Variable cost (SEK)	Mean	1,659,986.06	1,685,739.23	2,360,380.53	2,491,800.71	2,593,644.09	3,014,888.57	2,689,969.60	3,247,141.21
	SD	1,308,452.92	1,188,511.94	1,644,057.38	1,591,318.91	1,637,194.39	2,135,277.70	1,769,386.95	2,158,422.22
Fixed cost (SEK)	Mean	405,932.84	438,571.33	655,520.42	684,623.91	664,533.24	495,024.18	433,016.42	482,094.08
	SD	463,986.17	450,337.09	637,342.36	610,094.53	589,596.06	481,393.65	388,937.66	424,038.47
Asset (SEK)	Mean	5,382,273.70	5,925,085.46	7,746,010.89	8,109,203.18	6,971,008.61	5,778,126.97	5,882,696.73	6,992,008.70
	SD	4,847,445.52	4,917,021.52	6,081,181.42	5,917,241.49	5,288,814.51	4,187,057.93	4,253,779.22	5,273,034.02
Labour (hours worked)	Mean	4,726.39	4,857.08	5,314.65	5,243.15	5,360.98	6,314.20	6,305.39	6,762.49
	SD	2,216.07	2,270.42	2,525.52	2,327.10	2,391.14	3,398.34	3,336.40	3,605.83
Land size (ha)	Mean	97.86	98.31	116.19	116.61	122.11	132.30	135.99	142.99
	SD	71.09	65.23	76.51	71.39	74.92	89.65	90.13	95.06
Output (milk and meat) (SEK)	Mean	1,455,191.30	1,741,919.87	2,245,166.71	2,153,511.04	2,385,441.16	2,956,238.13	2,555,858.42	2,916,613.82
	SD	1,231,346.59	1,435,206.55	1,761,764.18	1,537,714.71	1,653,809.03	2,365,637.61	1,923,706.57	2,222,808.88
Output (others) (SEK)	Mean	974,527.34	1,018,161.23	1,391,626.19	1,433,538.18	1,472,329.61	1,766,310.14	1,589,325.21	1,977,110.35
	SD	773,148.00	735,879.16	969,998.26	952,979.48	933,052.45	1,238,094.93	1,105,044.48	1,398,541.45

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Table 1. (Continued)

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Building cost per TLU (SEK)	Mean	16,002.53	17,051.54	21,251.94	22,302.80	21,212.13	4,003.63	4,327.42	4,999.52
	SD	16,782.29	14,733.41	19,900.56	20,582.03	20,691.42	4,437.50	4,605.42	5,831.79
Grazing land area per TLU (ha)	Mean	16.07	16.83	16.59	16.27	14.82	5.14	5.07	5.33
	SD	20.81	23.20	22.94	23.03	16.67	7.19	5.96	6.17
Culling revenue per cow (SEK)	Mean	710.97	1,146.43	961.59	1,198.72	1,174.32	1,495.95	1,689.70	2,251.21
	SD	465.32	629.43	559.76	587.77	563.00	947.17	685.44	1,149.68
N		262	280	269	254	283	270	242	198

SEK, Swedish kronor; SD, standard deviation.

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summary statistics of the variables used in our analysis. The detailed descriptive statistics of these variables in each efficiency group (based on DEA-based efficiency scores) across the years is given in Appendix A. Tables A1–A4 in Appendix A provide summary statistics of variable in EF, IE, ME and RI groups for each year, respectively.

The variable cost accounts for overheads and specific costs, while the fixed cost captures depreciation, rent and interest payments. The asset variable includes farm building, machinery and equipment, breeding and non-breeding livestock, and working capital. Labour is captured in the model in terms of total hours worked by both hired and non-hired labour and, lastly, land size utilised for farming measured by hectares is used. Regarding the two outputs: output 1 includes cow milk and milk products as well as beef and veal, and output 2 includes the other outputs that include agricultural productions (crop production and livestock outputs other than those in output 1), entrepreneurial outputs, and subsidies.[4] Given our sample targets specialised dairy farms (dairy income accounting more than 50 per cent of their agricultural income), this procedure ensures that all revenue-generating activities derived from production inputs used by the farm are captured.

To capture AW improving measures in our analysis, we use building cost per total livestock unit (TLU) and pasture size per TLU. Practically, for building cost variable, we used the closing value of buildings at the farm level. These variables are used under the assumption that higher building costs and/or access to pasture land are associated with improved AW (Hansson, Manevska-Tasevska and Asmild, 2020). High building costs signal building quality and spacing (low density of animals), which are related to AW components of freedom to express natural behaviour and freedom from discomfort among the five freedoms that conceptualise AW (Botreau *et al.*, 2007; Veissier *et al.*, 2008). Similar logic follows the relation between pasture access and AW, where pasture access is associated with reduced lameness (Hernandez-Mendo *et al.*, 2007), is valuable as fresh feed (Von Keyserlingk *et al.*, 2017), and facilitates animals' practice of natural behaviour.

To measure the actual AW, we use culling revenue per cow as indicator variables. The use of this indicator is in line with suggestions by experts to capture AW, which include cow mortality, fertility and health problems, and veterinary treatments (Nyman, Lindberg and Sandgren, 2011; Thomsen and Houe, 2018). The assumption is that higher culling rates are associated with higher health and mortality problems and hence lower levels of actual AW (Hansson, Manevska-Tasevska and Asmild, 2020).[5] Statistical descriptions of

4 In Sweden, subsides are conditional on environmental services provisions, which normally require inputs for their production. Therefore, the use of subsidies as part of agricultural output accounts for such productions.

5 Descriptive analysis of the relation between AW improving measures and actual AW indicators shows supportive evidence that higher building costs and larger pasture size are related to lower culling revenue, which implies a better AW (Figure B2a in Appendix B).

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variables used to capture AW improving measures and the actual AW (culling revenue per cow) are given in Table 1.[6]

4. Results

Table B1 in Appendix B presents the summary statistics of input- and output-specific efficiency scores using MEA and input-oriented DEA. Despite the use of different approaches and point of reference in the efficiency calculation, the efficiency scores are widely similar across efficiency types/dimensions in a given year, even though DEA scores are relatively lower than MEA scores.

When we look at results regarding our hypotheses, Table 2 presents 1-year and 2-year period transition rates in relation to the first hypothesis (H1), which states that dairy farms in the EF group are more likely to transition to ME group than those in the RI group in subsequent periods. The table provides transition rates for eight grouping schemes created using different efficiency components estimated using MEA and DEA in combination with two AW-improving measures.

The results in two blocks of the table provide strong evidence against our hypothesis that EF group farms are more likely to transition to the ME group in subsequent periods than the RI group. The results, rather, suggest that dairy farms in the RI group are three to four times more likely to transition to the ME group in 1-year and 2-year periods than those in the EF group. The results are consistent irrespective of the group categorisation scheme and are statistically significant. In a 1-year period, on average, 22.9 per cent of the farms in the RI group are likely to transition to the ME group compared to 6.1 per cent from the EF group based on building cost-based grouping. These figures are almost similar in pasture access-based groups with corresponding statistics of 21.6 per cent and 4 per cent. For a 2-year period transition, on average, these figures are 22.5 per cent and 7.2 per cent for building cost-based groups, and 23.2 per cent and 5.4 per cent for pasture access-based groups.

In other words, the result for the first hypothesis (Table 2) shows that farms with higher AW improving measures and low efficiency are highly likely to transition to the high AW–high efficiency group in the subsequent periods than farms with high efficiency–low AW measures. This evidence suggests that farms being in the RI group can be interpreted as a result of a rational decision that prioritises better AW, while those in the EF group seem to prioritise efficiency. As a result, in subsequent periods, farms in the RI group seem to strive to achieve better performance on top of high AW, which reinforces the argument that they are in this group rationally and temporarily as part of their transition to towards higher efficiency. On the other hand, farms in the EF group seem to have exploited the resource to the extent that low AW and/or resource over-utilisation counteracts the efficiency objectives and hence they

6 In general, the use of culling rate (or culling revenue) is a proxy measure for AW and may not be a perfect measure of AW. A better measure would be on-farm AW assessment variables, which we do not have data on. Future research could be needed to validate such proxy variables using on-farm measures of AW.

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Table 2. Transition rates for RI and EF groups towards the ME group in 1-year and 2-year periods

		Building cost-based group			Pasture access-based group		
		Transition rates			Transition rates		
Efficiency components used as basis to create efficiency classes	Transition period	Rational inefficiency	Efficiency	Significance F-test	Rational inefficiency	Efficiency	Significance F-test
Variable cost efficiency	1 year	0.247	0.065	56.00***	0.239	0.037	70.21***
	2 years	0.235	0.071	33.67***	0.231	0.057	37.71***
Fixed cost efficiency	1 year	0.190	0.061	34.92***	0.222	0.050	49.56***
	2 years	0.205	0.069	26.61***	0.250	0.073	36.44***
Asset efficiency	1 year	0.184	0.055	38.24***	0.213	0.038	57.32***
	2 years	0.214	0.075	27.70***	0.240	0.057	41.29***
Labour efficiency	1 year	0.214	0.056	44.79***	0.215	0.039	59.07***
	2 years	0.218	0.064	30.29***	0.215	0.059	32.83***
Land efficiency	1 year	0.219	0.060	45.26***	0.197	0.044	49.49***
	2 years	0.240	0.069	36.17***	0.241	0.042	56.15***
Output 1 efficiency	1 year	0.270	0.067	59.65***	0.235	0.037	67.47***
	2 years	0.237	0.088	24.22***	0.255	0.061	43.72***
Output 2 efficiency	1 year	0.249	0.056	62.14***	0.208	0.035	62.66***
	2 years	0.231	0.068	32.45***	0.206	0.036	46.78***
DEA efficiency	1 year	0.262	0.069	44.02***	0.201	0.037	53.07***
	2 years	0.217	0.071	27.62***	0.215	0.048	38.52***

Notes: The table reports the probability that farms in RI and EF groups transition to ME group in a 1-year and 2-year period, and the significance test of the difference in transition rates. Significance levels: $***p<0.01$, $**p<0.05$, $*p<0.1$. DEA efficiency indicates efficiency scores based on the DEA estimation approach, rather than the MEA approach.

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end up in the low efficiency–low AW corner in subsequent periods instead of achieving multi-efficiency targets.

Table 3 presents transition rates related to the second hypothesis (H2), which hypothesises that dairy farms in the RI group are more likely to fall to the IE group than those in the EF group in subsequent periods. The table provides transition rates for eight grouping schemes created using different efficiency components estimated using MEA and DEA in combination with two AW improving measures.

Against our hypothesis, the results presented in the two blocks of Table 3 provide strong evidence that dairy farms in the EF group are more likely to fall back to the IE group in 1-year and 2-year periods than the RI group. This result is consistent for both building cost and pasture access-based categorisation schemes, except the difference in transition rates and significance levels. In a 1-year period, on average, 8.9 per cent of the farms in the RI group are likely to fall back to the IE group, compared to 17.1 per cent from the EF group based on building cost-based grouping. For pasture access-based groups, the corresponding statistic is 2.4 per cent and 21.6 per cent, which has a wider margin than the building cost-based grouping. For a 2-year period transition, on average, these figures are 10.4 per cent and 18.1 per cent for building cost-based groups, and 4.8 per cent and 25.8 per cent for pasture access-based groups.

In general, our findings in relation to the two hypotheses provide consistent evidence to support the RIH. Farms with high efficiency and low AW are highly likely to fall back to the low AW–low efficiency group than high AW–low efficiency farms. This is in contrary to our theoretical argument and business logic that better performing businesses should not fall back compared to low performing farms. However, in light of the RIH, efficiency sacrificed to achieve better farm AW in the RI group seems to be a conscious rational decision and is not inefficiency per se. The results also present an important story that detects the likely routes that dairy farms take to achieve their objective, depending on their priorities of efficiency or better AW standards. The evidence shows that the state of RI is not the ultimate goal of AW-oriented farmers but rather an indicator that they prioritise AW and continue their trajectory to multi-efficiency objectives. To augment our evidence and check if the likely movement from RI to ME is unique to the RI-group, we also tested the transition from IE to ME relative to transition from RI to ME. The result, given in Table B2 in Appendix B shows that farms in the RI group are more likely to move to ME than farms in the IE group.

Furthermore, we examined the likely source of farms in the RI group. Table B3 in Appendix B presents the results. The result shows that farms in RI group are more likely to originate from IE group than EF group. However, such evidence is more robust in building cost-based grouping than in pasture-based grouping of farms. It is also important here to mention that there is high state dependence in our transition analysis among all groups (results not presented).

Moreover, to test the robustness of our results, we test the RIH over a 3-year period transitional dynamics. Tables B4 and B5 in Appendix B present the

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Table 3. Transition rates of RI and EF groups towards IE group in 1-year and 2-year periods

Efficiency components used as basis to create efficiency classes	Transition period	Building cost-based group: Transition rates: Rational inefficiency	Building cost-based group: Transition rates: Efficiency	Building cost-based group: Significance F-test	Pasture land-based group: Transition rates: Rational inefficiency	Pasture land-based group: Transition rates: Efficiency	Pasture land-based group: Significance F-test
Variable cost efficiency	1 year	0.094	0.206	18.27***	0.024	0.249	91.43 ***
	2 years	0.106	0.191	7.92***	0.050	0.266	57.05***
Fixed cost efficiency	1 year	0.080	0.175	15.21***	0.027	0.188	54.47***
	2 years	0.093	0.195	11.98***	0.052	0.262	56.27***
Asset efficiency	1 year	0.076	0.113	3.04*	0.031	0.200	55.59***
	2 years	0.088	0.134	3.20*	0.055	0.259	50.69***
Labour efficiency	1 year	0.103	0.197	11.78***	0.028	0.213	68.24***
	2 years	0.122	0.187	4.13**	0.050	0.261	58.33***
Land efficiency	1 year	0.093	0.184	11.87***	0.022	0.213	84.25***
	2 years	0.114	0.187	5.40**	0.042	0.251	66.46***
Output 1 efficiency	1 year	0.080	0.163	12.12***	0.027	0.227	75.15***
	2 years	0.099	0.190	9.87***	0.047	0.272	63.72***
Output 2 efficiency	1 year	0.091	0.164	8.86***	0.017	0.221	89.46***
	2 years	0.103	0.171	5.63**	0.041	0.239	58.42***
DEA efficiency	1 year	0.093	0.167	8.81***	0.015	0.215	82.70***
	2 years	0.110	0.193	7.31***	0.048	0.250	54.02***

Notes: The table reports the probability that farms in RI and EF groups transition to IE group in 1-year and 2-year period, and a significance test of the difference in transition rates. Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. DEA efficiency indicates efficiency scores based on the DEA estimation approach, rather than the MEA approach.

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results for hypotheses H1 and H2, respectively. The results are consistent to the 1-year and 2-year transitional dynamics presented above.

5. Conclusions and policy implications

This study aims to investigate the concept of rational inefficiency from a dynamic perspective using data from a sample of Swedish dairy farms. Taking an over-time perspective, we postulate that farms could prioritise taking better AW improving measures without subsequently abandoning efficiency objectives. However, such farms could be labelled as inefficient by looking at one shot cross-sectional data. The novelty of this paper comes from its attempt to fill this gap by examining an over-time dynamics of farm performance in relation to AW improving measures and by presenting and testing the trajectory that DMUs should take in a likely scenario of the RIH. In particular, we test if a positioning in a group with low efficiency but a high level of AW improving measures is a behaviour associated with inefficiency over time or indeed behaviour on trajectory towards a state of multi-efficiency, where high levels of AW improving measures can be combined with high efficiency. This dynamic approach to the RIH is the novel contribution of this paper, even though the idea of rational inefficiency has been dealt with under different settings and sectors in the literature (Bogetoft and Hougaard, 2003; Asmild, Bogetoft and Leth Hougaard, 2013; Hansson, Manevska-Tasevska and Asmild, 2020). As a result, we are able to make an original contribution to the literature by challenging the urge for conclusions based on cross-sectional data in efficiency analysis and by questioning the relevance of recommendations drawn from such cross-sectional studies in subsequent periods. Not all inefficiencies are the result of bad decision-making and recommendations provided are not relevant for all farms labelled inefficient, without considering the time dynamics and reasons behind their decisions.

Our empirical evidence suggests that farms that apply relatively high levels of AW improving measures, but with low levels of efficiency, achieve higher efficiency while maintaining higher AW measures in subsequent periods compared to farms with high efficiency and low AW improving measures, which we found falling back to inefficiency comparatively. Specifically, based on our RIH and using the Markov chain transitional probability approach, we found that farms are more likely to move from the RI group to the ME group over time, than moving from the EF group to the ME group. Backing up this evidence, we also found that, in subsequent periods, farms in the EF group are more likely to fall back to inefficiency than farms in the RI group. These results imply that for some DMUs inefficiency as observed in cross-sectional data can indeed stem from rational behaviour, where a farmer has made investments in, for example, AW improving measures but not yet fully adapted to these, and is, therefore, on a trajectory towards higher levels of efficiency, which are realised at a later stage. Given that farmers realise utility both from use and non-use values, DMUs could make decisions based on their own priorities while maintaining the ultimate goal of achieving highest utility from both

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values by attaining high efficiency and AW. Therefore, our evidence suggests that rational inefficient farms seem to prioritise achieving high utility from improved AW on their trajectory towards multi-efficiency and hence higher utility. However, in comparative terms, we do not see evidence of farms in the EF group achieving the multi-efficiency target. These pieces of evidence all suggest that farms in the RI group are there by their rational decision-making rather than poor uncalculated decisions.

Given the evidence on the transitional dynamics farms over time, one could suggest that eventually farms in RI and EF groups disappear into ME and IE groups. In other words, farms in the long run should achieve high AW while maintaining high efficiency or end up in IE group, which could signal incompetence and lead to total closure of the farm's business operation. This is a plausible argument given the ever-growing consciousness of the public about AW and the pressure on livestock farms to maintain high AW. However, we could not test this hypothesis, first, because of the nature of our data, which is a rotating panel where we cannot follow each farmer over the entire period of our analysis. Second, we have relatively short panel data to analyse such structural change and from our data, we have strong state dependence in our transitional analysis. Therefore, this topic could be a research agenda for the future.

Based on the evidence, we question if RI farms should be considered inefficient as such, and that policy recommendations to push such 'rationally inefficient' farms towards full efficiency would make sense. The evidence suggests that some farms among the farms labelled as inefficient (i.e. rational inefficient farms) are highly likely to achieve higher efficiency in subsequent periods without any policy interventions, which makes the recommendations irrelevant for these farms or might result in unintended consequences. With regard to policy implication, first, any policy recommendations designed to improve the efficiency of farms should consider the underlying reasons for their inefficiency and design farm-specific policy advice rather than depending on efficiency scores per se. Second, achieving high efficiency during a current production year is not a guarantee for the next period. In other words, farms in the EF group should get equal attention in policy recommendations, given their prospects for, or lack of, future success.

Moreover, given growing pressure on livestock production, including dairy, to achieve better performance and satisfy the growing food demand, and at the same time to live up to the AW standards imposed from regulators and AW conscious consumers, the study opens a new research frontier to further examine efficiency gains from AW and sustainability issues in the dairy sector. In this respect, our study provides only suggestive evidence for the existence of the potential efficiency gains of achieving better AW measures, alongside the story of the trade-off between farm AW improving measures and efficiency.

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Appendix A: Descriptive statistics of farm variables in each efficiency group per year

Table A1. Descriptive statistics of variables in EF group per year

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Variable cost (SEK)	Mean	1,525,008.00	1,458,258.00	2,091,253.00	2,439,100.00	2,417,608.00	2,915,480.00	2,543,148.00	3,228,275.00
	SD	1,176,968.00	1,118,303.00	1,559,235.00	1,667,364.00	1,554,940.00	2,324,616.00	1,705,307.00	2,248,146.00
Fixed cost (SEK)	Mean	252,158.00	258,718.00	399,130.00	485,360.00	430,243.00	492,516.00	388,772.00	441,497.00
	SD	302,746.30	317,817.50	446,586.30	451,607.80	377,534.80	565,103.40	408,404.00	417,614.60
Asset (SEK)	Mean	3,509,950.00	3,604,529.00	4,772,968.00	5,941,090.00	4,188,151.00	3,990,617.00	3,852,903.00	5,321,702.00
	SD	2,637,920.00	2,580,108.00	3,666,444.00	4,201,186.00	2,537,368.00	3,238,982.00	2,784,192.00	3,979,973.00
Labour (hours worked)	Mean	4,672.00	4,666.00	4,920.00	5,302.00	5,094.00	6,370.00	5,736.00	6,568.00
	SD	1,906.53	1,992.72	1,977.45	2,322.38	2,189.93	3,457.05	3,021.29	4,262.79
Land size (ha)	Mean	90.00	82.00	102.00	120.00	111.00	134.00	123.00	136.00
	SD	67.48	55.65	73.07	78.29	67.76	109.68	84.16	93.82
Output (milk and meat) (SEK)	Mean	1,304,869.00	1,563,499.00	1,990,122.00	2,122,603.00	2,209,276.00	2,992,434.00	2,556,027.00	3,087,454.00
	SD	949,323.10	1,328,156.00	1,603,283.00	1,515,478.00	1,483,060.00	2,527,654.00	1,883,514.00	2,376,314.00
Output (others) (SEK)	Mean	941,828.00	859,492.00	1,249,161.00	1,490,973.00	1,401,481.00	1,730,360.00	1,440,507.00	1,968,082.00
	SD	754,015.50	619,500.50	928,574.30	1,049,477.00	864,720.70	1,318,973.00	971,442.60	1,293,937.00

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Table A1. (Continued)

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Building cost per TLU (SEK)	Mean	5,011.00	5,691.00	5,628.00	5,886.00	6,612.00	553.00	711.00	1,283.00
	SD	2,783.13	3,219.09	3,551.18	3,807.28	4,073.21	451.66	563.94	1,067.68
Grazing land area per TLU (ha)	Mean	17.00	17.00	16.00	14.00	15.00	6.00	5.00	5.00
	SD	27.29	26.45	17.68	16.51	19.19	7.79	4.42	5.90
Culling revenue per cow (SEK)	Mean	760.00	1,041.00	1,067.00	1,164.00	1,224.00	1,338.00	1,682.00	2,177.00
	SD	451.78	580.78	780.10	598.55	654.41	762.28	749.72	1,145.36
N		58	66	62	60	75	57	54	58

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Table A2. Descriptive statistics of variables in IE group per year

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Variable cost (SEK)	Mean	1,067,090.00	1,154,414.00	1,548,236.00	1,671,443.00	1,552,903.00	1,822,868.00	2,042,435.00	2,205,256.00
	SD	587,610.40	637,883.60	1,226,646.00	1,267,129.00	1,033,981.00	1,294,084.00	1,844,882.00	1,733,800.00
Fixed cost (SEK)	Mean	199,858.00	224,368.00	326,960.00	341,481.00	302,101.00	280,476.00	320,887.00	293,871.00
	SD	173,826.30	172,996.20	373,772.70	356,371.10	311,351.00	406,024.10	394,160.70	318,599.70
Asset (SEK)	Mean	2,859,712.00	3,292,897.00	4,131,989.00	4,295,662.00	3,385,968.00	2,872,287.00	3,592,798.00	4,050,827.00
	SD	1,550,533.00	1,770,979.00	3,164,843.00	3,310,693.00	2,250,204.00	1,815,871.00	3,082,010.00	2,915,764.00
Labour (hours worked)	Mean	4,210.00	4,302.00	4,735.00	4,547.00	4,405.00	4,559.00	5,420.00	5,490.00
	SD	1,417.54	1,660.53	2,699.62	1,924.52	1,850.06	2,351.39	3,534.66	3,158.26
Land size (ha)	Mean	70.00	72.00	87.00	82.00	84.00	93.00	121.00	108.00
	SD	42.69	39.98	72.28	58.47	57.99	65.42	95.98	93.52
Output (milk and meat) (SEK)	Mean	871,981.00	1,036,928.00	1,383,125.00	1,316,302.00	1,305,483.00	1,526,748.00	1,709,893.00	1,716,886.00
	SD	542,129.20	628,726.50	1,244,363.00	1,057,832.00	943,448.20	1,078,577.00	1,825,727.00	1,487,851.00
Output (others) (SEK)	Mean	573,910.00	653,713.00	854,184.00	921,864.00	853,154.00	1,059,331.00	1,213,322.00	1,298,833.00
	SD	329,476.30	391,530.10	665,520.30	727,222.80	559,236.70	787,078.60	1,054,186.00	1,159,475.00

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Table A2. (Continued)

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Building cost per TLU (SEK)	Mean	5,777.00	7,068.00	7,093.00	7,270.00	8,212.00	527.00	931.00	1,704.00
	SD	2,427.72	2,557.85	2,818.82	3,045.24	3,707.33	464.78	562.90	1,049.74
Grazing land area Per TLU (ha)	Mean	17.00	19.00	19.00	19.00	19.00	7.00	8.00	6.00
	SD	13.85	24.16	15.39	19.95	19.50	6.49	10.14	7.10
Culling revenue per cow (SEK)	Mean	746.00	1,276.00	981.00	1,308.00	1,181.00	1,440.00	1,643.00	2,185.00
	SD	502.82	634.46	436.96	552.02	544.90	949.61	786.64	1,028.21
N		49	65	52	46	66	32	31	41

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Table A3. Descriptive statistics of variables in ME group per year

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Variable cost (SEK)	Mean	2,243,164.00	2,317,255.00	3,113,124.00	3,037,603.00	3,267,586.00	3,688,967.00	3,206,207.00	3,897,134.00
	SD	1,632,013.00	1,366,234.00	1,939,863.00	1,708,603.00	1,617,905.00	2,617,544.00	2,049,868.00	2,437,613.00
Fixed cost (SEK)	Mean	604,500.00	696,496.00	961,426.00	995,924.00	976,609.00	592,333.00	512,704.00	632,563.00
	SD	553,702.80	548,758.40	803,478.00	742,787.10	639,054.40	539,254.50	453,375.20	495,069.80
Asset (SEK)	Mean	7,862,557.00	9,515,075.00	11,352,047.00	11,692,271.00	10,504,480.00	7,584,724.00	8,002,346.00	10,560,319.00
	SD	5,857,959.00	6,008,279.00	7,376,932.00	6,801,647.00	5,317,235.00	4,890,324.00	4,975,479.00	6,470,232.00
Labour (hours worked)	Mean	5,354.00	5,329.00	5,724.00	5,564.00	5,873.00	6,952.00	6,916.00	7,465.00
	SD	2,483.88	2,781.60	2,689.71	2,555.17	2,584.96	4,115.66	3,577.57	3,787.92
Land size (ha)	Mean	125.00	128.00	141.00	133.00	153.00	149.00	157.00	178.00
	SD	81.37	70.52	77.19	72.02	79.35	98.68	95.24	104.06
Output (milk and meat) (SEK)	Mean	2,155,773.00	2,672,551.00	3,208,392.00	2,809,835.00	3,245,386.00	3,898,843.00	3,328,341.00	3,877,319.00
	SD	1,538,567.00	1,813,688.00	2,215,649.00	1,731,745.00	1,816,776.00	3,037,990.00	2,349,610.00	2,646,998.00

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Table A3. (Continued)

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Output (Others) (SEK)	Mean	1,393,208.00	1,457,637.00	1,918,763.00	1,829,038.00	2,028,353.00	2,233,291.00	2,026,831.00	2,654,587.00
	SD	919,995.60	803,544.20	1,121,408.00	1,056,343.00	1,014,247.00	1,504,452.00	1,297,433.00	1,715,404.00
Building cost per TLU (SEK)	Mean	22,518.00	25,635.00	29,984.00	36,084.00	33,104.00	5,222.00	5,631.00	9,250.00
	SD	16,122.45	12,766.22	14,539.92	19,205.44	18,509.52	4,446.18	3,826.12	8,829.75
Grazing land area per TLU (ha)	Mean	13.00	15.00	17.00	16.00	11.00	4.00	4.00	5.00
	SD	22.18	26.23	37.36	33.64	12.76	8.99	3.58	5.09
Culling revenue per cow (SEK)	Mean	665.00	1,135.00	843.00	1,117.00	1,185.00	1,419.00	1,708.00	2,462.00
	SD	461.19	676.14	476.04	636.14	572.92	753.93	648.50	1,096.96
N		68	70	63	71	66	77	66	41

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Table A4. Descriptive statistics of variables in RI group per year

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Variable cost (SEK)	Mean	1,628,085.00	1,753,382.00	2,485,322.00	2,519,678.00	3,085,900.00	2,937,070.00	2,623,269.00	3,543,035.00
	SD	1,235,911.00	1,176,345.00	1,445,377.00	1,394,088.00	1,693,565.00	1,617,819.00	1,464,342.00	1,895,727.00
Fixed cost (SEK)	Mean	469,313.00	536,531.00	804,535.00	757,846.00	939,472.00	490,367.00	439,673.00	549,379.00
	SD	511,380.40	463,967.70	592,248.80	546,630.20	629,038.70	382,114.50	310,490.90	394,666.30
Asset (SEK)	Mean	6,112,630.00	6,848,499.00	9,322,941.00	8,772,994.00	9,762,033.00	6,314,348.00	6,329,937.00	8,219,000.00
	SD	5,218,324.00	4,864,631.00	5,675,110.00	5,366,874.00	5,656,303.00	3,784,407.00	3,881,769.00	5,016,106.00
Labour (hours worked)	Mean	4,563.00	5,055.00	5,628.00	5,317.00	6,010.00	6,351.00	6,502.00	7,360.00
	SD	2,464.71	2,344.13	2,576.05	2,288.21	2,544.78	2,869.96	3,201.10	2,788.33
Land size (ha)	Mean	97.00	107.00	126.00	119.00	139.00	131.00	133.00	149.00
	SD	71.14	72.60	74.32	66.44	75.28	72.81	86.32	82.77
Output (milk and meat) (SEK)	Mean	1,336,300.00	1,646,427.00	2,244,686.00	2,072,564.00	2,750,353.00	2,678,353.00	2,283,683.00	2,914,738.00
	SD	1,176,669.00	1,198,315.00	1,447,086.00	1,352,689.00	1,624,404.00	1,613,643.00	1,401,109.00	1,797,281.00
Output (others) (SEK)	Mean	894,718.00	1,061,174.00	1,430,433.00	1,329,777.00	1,597,089.00	1,657,800.00	1,488,411.00	1,986,705.00
	SD	692,894.40	782,941.30	845,693.50	713,586.80	861,871.90	932,775.80	956,731.20	1,189,960.00

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Table A4. (Continued)

Variables	Statistics	2009	2010	2011	2012	2013	2014	2015	2016
Building cost per TLU (SEK)	Mean	23,997.00	27,152.00	33,804.00	31,369.00	36,582.00	6,063.00	6,685.00	8,041.00
	SD	20,113.50	16,017.56	22,725.79	21,058.69	23,640.17	4,574.85	5,219.63	4,080.52
Grazing land area per TLU (ha)	Mean	18.00	16.00	15.00	17.00	14.00	5.00	5.00	5.00
	SD	17.80	15.65	15.77	16.30	13.58	5.30	6.00	6.51
Culling revenue per cow (SEK)	Mean	695.00	1,138.00	961.00	1,236.00	1,110.00	1,657.00	1,697.00	2,224.00
	SD	459.09	614.69	485.71	550.35	469.87	1,136.09	644.95	1,276.18
N		87	79	92	77	76	104	91	58

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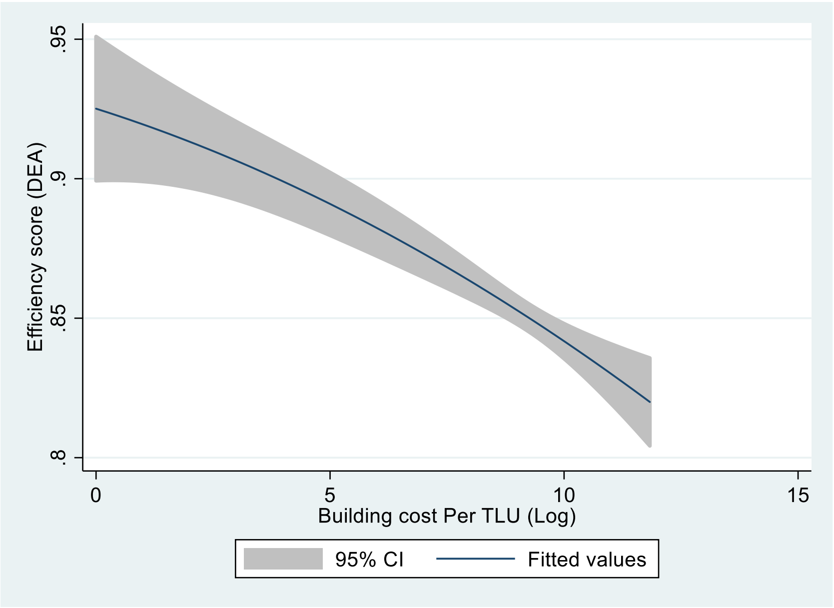
Appendix B

(a)



(b)

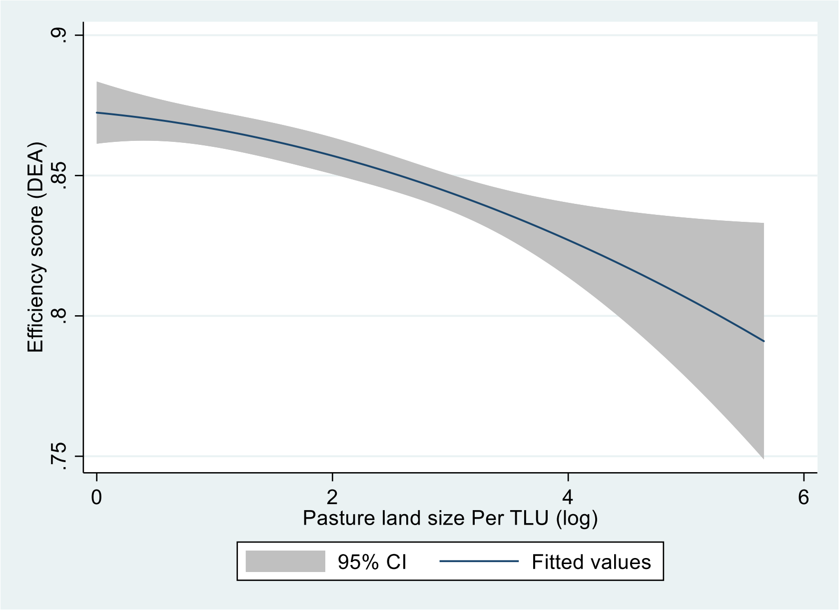


Fig. B1. (a) Relation between efficiency score and AW measures: building cost. (b) Relation between efficiency score and AW measures: pasture land.

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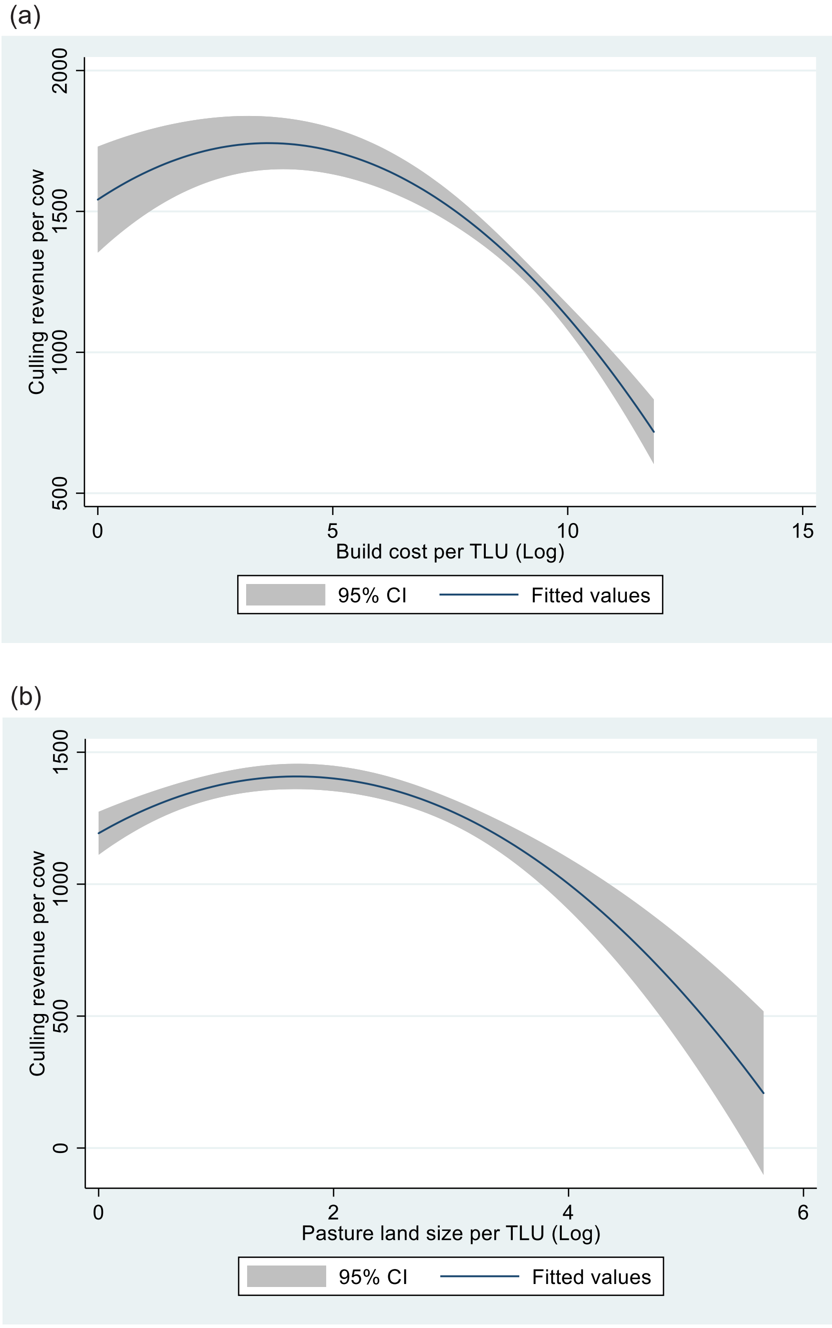

Fig. B2. (a) The relation between building cost and culling revenue per cow. (b) The relation between pasture size and culling revenue.

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Table B1. Summary of efficiency estimates: MEA (input and output efficiencies) and DEA

Efficiency types\year	2009	2010	2011	2012	2013	2014	2015	2016
Variable cost efficiency	0.914	0.924	0.925	0.955	0.953	0.947	0.928	0.942
	(0.061)	(0.052)	(0.052)	(0.041)	(0.038)	(0.041)	(0.053)	(0.045)
Fixed cost efficiency	0.868	0.862	0.865	0.884	0.877	0.843	0.845	0.846
	(0.093)	(0.086)	(0.090)	(0.090)	(0.086)	(0.100)	(0.100)	(0.099
Asset efficiency	0.883	0.884	0.874	0.890	0.885	0.893	0.882	0.878
	(0.082)	(0.071)	(0.082)	(0.081)	(0.080)	(0.078)	(0.082)	(0.083)
Labour efficiency	0.868	0.874	0.886	0.892	0.885	0.882	0.876	0.865
	(0.091)	(0.085)	(0.080)	(0.086)	(0.083)	(0.081)	(0.086)	(0.089)
Land efficiency	0.884	0.865	0.881	0.913	0.904	0.905	0.882	0.868
	(0.075)	(0.078)	(0.075)	(0.065)	(0.067)	(0.066)	(0.078)	(0.079)
Output 1 (milk and meat)	0.877	0.886	0.894	0.924	0.918	0.909	0.888	0.898
	(0.124)	(0.113)	(0.094)	(0.088)	(0.095)	(0.097)	(0.126)	(0.115)
Output 2 (Others)	0.865	0.838	0.878	0.922	0.909	0.907	0.877	0.856
	(0.121)	(0.144)	(0.126)	(0.080)	(0.086)	(0.081)	(0.109)	(0.137)
DEA efficiency	0.833	0.831	0.841	0.889	0.878	0.872	0.846	0.849
	(0.125)	(0.120)	(0.111)	(0.096)	(0.096)	(0.100)	(0.116)	(0.115)
N	262	280	269	254	283	270	242	198

Notes: The table presents yearly average efficiency scores for different efficiency types and standard deviations are given in parenthesis. It worth nothing that the standard deviations are small, indicating the efficiency scores are distributed in a narrow range of values around the mean.

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Table B2. Transition rates for RI and IE groups towards the ME group in 1-year and 2-year periods

		Building cost-based group			Pasture access-based group		
		Transition rates			Transition rates		
Efficiency components used as basis to create efficiency classes	Transition period	Rational inefficiency	Inefficiency	Significance test F-test	Rational inefficiency	Inefficiency	Significance test F-test
Variable cost efficiency	1 year	0.247	0.018	107.66***	0.239	0.010	100.77***
	2 years	0.235	0.045	46.81***	0.231	0.029	53.69***
Fixed cost efficiency	1 year	0.190	0.004	108.79***	0.222	0.000	105.35***
	2 years	0.205	0.041	41.18***	0.250	0.014	78.27***
Asset efficiency	1 year	0.184	0.014	85.17***	0.213	0.003	100.05***
	2 years	0.214	0.024	63.34***	0.240	0.017	71.68***
Labour efficiency	1 year	0.214	0.008	107.49***	0.215	0.010	89.99***
	2 years	0.218	0.035	49.33***	0.215	0.019	58.94***
Land efficiency	1 year	0.219	0.019	94.42***	0.197	0.008	86.71***
	2 years	0.240	0.045	51.61***	0.241	0.022	67.93***
Output 1 efficiency	1 year	0.270	0.035	76.46***	0.235	0.013	92.01***
	2 years	0.237	0.097	14.57***	0.255	0.022	69.31***
Output 2 efficiency	1 year	0.249	0.020	97.21***	0.208	0.014	84.78***
	2 years	0.231	0.064	29.10***	0.206	0.039	40.23***
DEA efficiency	1 year	0.262	0.013	107.91***	0.201	0.010	81.82***
	2 years	0.217	0.050	36.82***	0.215	0.027	51.12***

Notes: The table reports the proportion of farms in RI and EF groups that transition to ME group in 1-year and 2 year period and significance test of the difference in transition rates. Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. DEA efficiency indicates efficiency scores based on the DEA estimation approach, rather than the MEA approach.

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Table B3. Transition rates for IE and EF groups towards the RI group in 1-year and 2-year periods

Efficiency components used as basis to create efficiency classes	Transition period	Building cost-based group: Transition rates			Pasture access-based group: Transition rates		
		Inefficiency	Efficiency	Significance F-test	Inefficiency	Efficiency	Significance F-test
Variable cost efficiency	1 year	0.131	0.034	15.29***	0.053	0.026	2.98*
	2 years	0.174	0.095	5.32**	0.047	0.040	0.15
Fixed cost efficiency	1 year	0.155	0.029	24.37***	0.062	0.013	10.49***
	2 years	0.202	0.081	11.83***	0.059	0.025	3.50*
Asset efficiency	1 year	0.137	0.043	13.38***	0.059	0.025	4.98**
	2 years	0.194	0.095	7.69***	0.067	0.034	2.98*
Labour efficiency	1 year	0.129	0.046	11.98***	0.064	0.015	9.84***
	2 years	0.200	0.082	12.12***	0.070	0.028	4.56**
Land efficiency	1 year	0.106	0.053	5.14**	0.064	0.014	9.32***
	2 years	0.170	0.096	4.96**	0.071	0.042	1.76
Output 1 efficiency	1 year	0.140	0.027	16.59***	0.050	0.026	2.47
	2 years	0.186	0.061	10.96***	0.054	0.035	1.03
Output 2 efficiency	1 year	0.137	0.041	97.21***	0.053	0.025	3.30*
	2 years	0.173	0.091	5.43**	0.059	0.045	0.44
DEA efficiency	1 year	0.135	0.028	19.17***	0.053	0.026	2.98*
	2 years	0.200	0.071	14.24***	0.054	0.045	0.21

Notes: The table reports the proportion of farms in IE and EF groups that transition to ME group in 1-year and 2 year period and significance test of the difference in transition rates. Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. DEA indicates efficiency scores based on the DEA estimation approach, rather than the MEA approach.

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Table B4. Transition rates for RI and EF groups towards the ME group over 3-year period

Efficiency components used as basis to create efficiency classes	Building cost-based group			Pasture access-based group		
	Transition rates			Transition rates		
	Rational inefficiency	Efficiency	Significance F-test	Rational inefficiency	Efficiency	Significance F-test
Variable cost efficiency	0.219	0.073	19.58***	0.231	0.052	28.87***
Fixed cost efficiency	0.218	0.082	17.89***	0.280	0.063	39.94***
Asset efficiency	0.211	0.066	22.80***	0.257	0.053	37.25***
Labour efficiency	0.191	0.071	13.26***	0.260	0.054	38.98***
Land efficiency	0.212	0.079	15.94***	0.273	0.050	47.17***
Output 1 efficiency	0.230	0.119	8.78***	0.239	0.061	27.90***
Output 2 efficiency	0.239	0.066	26.55***	0.229	0.042	37.54***
DEA efficiency	0.200	0.070	16.27***	0.195	0.048	22.83***

Notes: The table reports the probability that farms in RI and EF groups transition to ME group in 3-year period and significance test of the difference in transition rates. Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. DEA efficiency indicates efficiency scores based on the DEA estimation approach, rather than the MEA approach.

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Table B5. Transition rates for RI and EF groups towards the IE group over 3-year period

Efficiency components used as basis to create efficiency classes	Building cost-based group			Pasture access-based group		
	Transition rates			Transition rates		
	Rational inefficiency	Efficiency	Significance F-test	Rational inefficiency	Efficiency	Significance F-test
Variable cost efficiency	0.114	0.224	8.59***	0.060	0.248	32.07***
Fixed cost efficiency	0.078	0.272	28.14***	0.061	0.308	52.99***
Asset efficiency	0.078	0.143	4.62**	0.056	0.283	44.97***
Labour efficiency	0.102	0.174	3.99**	0.064	0.257	35.02***
Land efficiency	0.118	0.213	6.40**	0.049	0.249	43.69***
Output 1 efficiency	0.112	0.202	6.43**	0.055	0.287	49.78***
Output 2 efficiency	0.097	0.194	7.85***	0.056	0.261	40.08***
DEA efficiency	0.110	0.211	7.33***	0.057	0.231	29.36***

Notes: The table reports the probability that farms in RI and EF groups transition to IE group in 3-year period and significance test of the difference in transition rates. Significance levels: ***$p<0.01$, **$p<0.05$, *$p<0.1$. DEA efficiency indicates efficiency scores based on the DEA estimation approach, rather than the MEA approach.

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Supplementary Data

Supplementary data is available at *ERAE* online.

Conflict of Interest

The authors declare that they have no conflict of interest.

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