Extended Abstract

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Paper/Poster Title	The impact of Automatic Milking Systems (AMS) adoption on farm-level eco-efficiency

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Abstract	*200 words max*
In Norwegian dairy farming, the usage of automatic milking systems (AMS) has increased during the last decades. AMS is primarily a productivity increasing and labour reducing technology, but previous research shows that AMS can have other (secondary) effects that could impact the environmental performance of farms. Those effects include increased total production, increased farm size, changes in grazing patterns and feed mix and changes in energy consumption. Each of these secondary effects is likely to affect farm-level GHG-emissions. Using a difference-in-difference approach, this paper provides evidence of the presence of secondary effects and shows that AMS-adoption affects farms' eco-efficiency negatively, particularly by increasing enteric fermentation. The causal effect is identified by considering adopting farms and non-adopting farms observed at two periods in time. Beyond those results, the paper also presents a general procedure of how to go about evaluating farm-level effects of technology adoption taking into account secondary effects.	

Keywords	Eco-efficiency, Automatic milking systems, livestock farming, agricultural technology
JEL Code	Agriculture Q1 see: www.aeaweb.org/jel/guide/jel.php?class=Q)

Introduction	*100 – 250 words*
Farm-level consequences of having adopted a new technology can be complex and diverse. Apart from the objective a technology is set out to reach, structural and behavioural changes induced by technology adoption and usage are likely to occur. Given that those changes are usually not the objective we refer to them as secondary effects. Previous research has pointed to the presence of secondary effects, but when evaluating economic or environmental impacts of technology, these effects remain largely unexplored. One technology where existing literature has shown the presence of secondary effects is AMS. AMS is set out to decrease labour costs, but also allows for intensifying production which can result in less grazing, more high energy feed, increased energy consumption and creates motivation for expansion. These secondary effects likely impact farms economic and environmental performance. The concept of eco-efficiency is employed to deal with the trade-off between economic and environmental performance. On one hand, some changes have positive implications for sustainability, such as expansion and intensification which have been associated with higher eco-efficiency. On the other hand, the consumption of more high-energy feed increases enteric fermentation, and the	

increased consumption of energy also has a negative impact on farms' GHG emissions. We aim to identify how the adoption of AMS affects eco-efficiency in conventional Norwegian dairy farms using FADN data between the years 2013-2019, and to identify what structural and behavioural changes associated with AMS-adoption drive those changes in eco-efficiency.

Methodology	***100 – 250 words***

We use the first and last period each farm is observed and compare adopting farms to farms not adopting AMS. All farms adopting AMS are observed at least one period before the adoption takes place such that the time of adoption is known. Since adopting and non-adopting farms differ in several covariates, propensity score matching is used to obtain a sample of non-adopters similar and comparable to the adopters when observed before adoption, based on these covariates. The dataset contains information on 48 adopting farms, and the matching procedure identifies 48 comparable non-adopters. This results in a dataset of in total 192 observations as each farm is observed in two time-periods. Having obtained a sample of adopters and comparable non-adopters, an eco-efficiency evaluation is computed using data envelopment analysis (DEA) comparing all farms towards the same efficiency frontier. As environmental variables, energy, fertilizer and enteric fermentation are included to reflect farm-level GHG-emissions. Net income is used as the economic indicator. A difference-in-difference is conducted considering two time periods and two groups of farms. AMS-adopters and non-adopters. Since farms adopt AMS in different periods, this is controlled for in the regression as "years until adoption" when the farm is first observed (in time=0) and "years after adoption" when the farm is last observed (in time=1). By controlling for this, effects of anticipating adoption and effects variation in effects after adoption are accounted for.

Results	***100 – 250 words***

After the matching, the groups of adopters and non-adopters have no significant difference in means of the covariates in the pre-treatment period. The eco-efficiency evaluation yields a mean eco-efficiency of 0.4. However, the focus is not to evaluate the efficiency of the farms, but how this is changed by AMS-adoption. Results indicates a significant reduction in eco-efficiency scores in the post-adoption period among the adopters compared to the non-adopters. To answer the question of what structural and behavioural changes cause this association between eco-efficiency and AMS adoption, indicators included in the eco-efficiency assessment and drivers of eco-efficiency are also used as outcome variables in the same difference-in-difference framework. While no significant effect on net income, energy usage and fertilizer usage are detected, a large positive and significant effect is estimated for enteric fermentation, which contributes to higher GHG-emissions and thus have a negative influence on eco-efficiency scores. Further, for the drivers of eco-efficiency, the amount of feed (expressed in feed units) shows a significant positive effect. Notably, the effect on labour is small in magnitude and insignificant.

Discussion and Conclusion	***100 – 250 words***

AMS is a labour-saving technology and not directly set out to impact farms' sustainability. We show that AMS-adoption affect farms' eco-efficiency and thus induce secondary effects. Specifically, AMS adoption increases farms' enteric fermentation and consumption of high energy feed. On the other hand, no effect is detected on net income, which would have generated a positive effect on eco-efficiency. Literature on evaluating consequences of technologies on farm-

sustainability is scarce. We present a general procedure of how to go about evaluating the effects of a technology on farm sustainability by applying propensity score matching, DEA eco-efficiency evaluation and difference-in-difference regression. It is one of the first evaluations of a causal effect of AMS adoption, and opens up a discussion about whether this technology is contributing to making farms more sustainable.