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Delaying investments in sensor technology: The rationality of dairy farmers' investment decisions illustrated within the framework of real options theory

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ABSTRACT

The adoption rate of sensors on dairy farms varies widely. Whereas some sensors are hardly adopted, others are adopted by many farmers. A potential rational explanation for the difference in adoption may be the expected future technological progress in the sensor technology and expected future improved decision support possibilities. For some sensors not much progress can be expected because the technology has already made enormous progress in recent years, whereas for sensors that have only recently been introduced on the market, much progress can be expected. The adoption of sensors may thus be partly explained by uncertainty about the investment decision, in which uncertainty lays in the future performance of the sensors and uncertainty about whether improved informed decision support will become available. The overall aim was to offer a plausible example of why a sensor may not be adopted now. To explain this, the role of uncertainty about technological progress in the investment decision was illustrated for highly adopted sensors (automated estrus detection) and hardly adopted sensors (automated body condition score). This theoretical illustration uses the real options theory, which accounts for the role of uncertainty in the timing of investment decisions. A discrete event model, simulating a farm of 100 dairy cows, was developed to estimate the net present value (NPV) of investing now and investing in 5 yr in both sensor systems. The results show that investing now in automated estrus detection resulted in a higher NPV than investing 5 yr from now, whereas for the automated body condition score postponing the investment resulted in a higher NPV compared with investing now. These results are in line with the observation that farmers postpone investments in sensors. Also, the current high adoption of automated estrus detection sensors can be explained because the NPV of investing now is higher than the NPV of investing in 5 yr. The results confirm that uncertainty about future sensor performance and uncertainty about whether improved decision support will become available play a role in investment decisions.
Key words: dairy, sensor, investment, adoption, economics

INTRODUCTION

A sensor for cow management can be defined as a device that measures a physiological or behavioral condition (related to health or estrus) of an individual cow and enables automated, on-farm detection of changes in this condition that are related to a health event and require action on the part of the farmer (Rutten et al., 2013). In recent years, several sensors were developed, such as electrical conductivity sensors, SCC sensors, and color sensors for the detection of clinical mastitis (e.g., Hogeveen et al., 2010). Also, sensors were developed for measuring activity to detect estrus (e.g., Firk et al., 2002; O'Connell et al., 2010; Holman et al., 2011) and lameness (e.g., Pastell et al., 2009; Chapinal et al., 2010; Miekley et al., 2012). In addition, camera systems with automated image analysis were developed, such as the automated BCS (e.g., Bercovich et al., 2013; Spoliansky et al., 2016).

The adoption of sensors by farmers is in general low. Activity meters or pedometers are an exception to this general rule as they are adopted for detection of estrus (Borchers and Bewley, 2015; Steeneveld and Hogeveen, 2015). Around 20% of the Dutch farmers have activity meters or pedometers for detection of estrus (Steeneveld and Hogeveen, 2015). Other sensors are adopted much less frequently (e.g., weighing platforms) or hardly adopted yet (e.g., automated BCS; Steeneveld and Hogeveen, 2015). Earlier research by Steeneveld and Hogeveen (2015) showed that the main reasons for not investing (yet) for Dutch dairy farmers were having other investments priorities on the farm, uncertainty about the profitability of the investment, expecting poor integration of sensors with other farm

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systems and software, and waiting for improved versions of the sensors (Steeneveld and Hogeveen, 2015). The most important reasons for nonadoption of sensors by US dairy farmers were being unfamiliar with available technologies, expecting an undesirable cost-benefit ratio, and being provided with too much information without clear relevance for management (Russell and Bewley, 2013). These results indicate that economic considerations and waiting for improved versions, which provide better interpretable data or information, are important reasons for not adopting sensors on dairy farms.

Waiting for improved versions can be a rational choice for farmers and can explain why they do not yet adopt, particularly when one realizes that estrus detection performance improved considerably over the last 20 yr. In 1998, sensors for estrus detection were reported to have a sensitivity of 70% at a specificity of 60% (Frost et al., 1997), whereas Kamphuis et al. (2012) found a sensitivity between 62 and 75% at a specificity of 99%. This means that sensors for estrus detection did undergo an enormous technological progress, and that less further improvement in detection performance can be expected. Hence, postponing the investment in estrus detection sensors is expected to have fewer advantages, and this may explain the currently high adoption rate. In contrast, sensors such as the automated BCS have been introduced much more recently and are still in the phase, as defined by Rutten et al. (2013), "of a technique measuring something about the cow." Body condition score is an assessment of the proportion of body fat a dairy cow possesses, and is associated with the incidence of ketosis (Roche et al., 2009). For pasture-based seasonal production systems, the importance of BCS is mentioned (Macdonald and Penno, 1998). For other systems, interpretable information with clear decision support on what to do with BCS is lacking in the scientific literature and not commonly known. Therefore, technological progress and more informed decision support, and thus a gain of postponing the investment, can be expected. The expected gain of postponing the investment may explain the currently low adoption rate.

Sensor technologies bear a great potential, but are generally characterized by low adoption rates on dairy farms. For sensor manufacturers it is important to realize that uncertainty about future technological progress may influence the adoption of sensors by farmers, and thus ultimately sales. The role of uncertainty about future technological progress in investment decisions can by structured by real options theory, which describes the problem structure, timing, linkage of decisions, and underlying uncertainties (Trigeorgis and Reuer, 2017). The overall aim of the current study was to offer a plausible example of why a sensor may not be adopted now. To explain this, the effects of uncertainty about future technological progress for sensors that are highly adopted (sensors for estrus detection) and are hardly adopted (automated BCS) were illustrated by using the real options theory. This illustration can help especially manufacturers to understand the effect of uncertainty of future technological progress on the adoption of sensors by dairy farmers.

MATERIALS AND METHODS

Real Options Theory

The real options theory is a method of option pricing from financial theory (Buhl et al., 2016). In corporate investment decisions and strategic management under uncertainty, real options theory can be used to clarify the problem structure (e.g., the different options, management decisions, and their timing), to appraise the options [i.e., estimating the net present value (**NPV**) of each option] and to plan the implementation (i.e., a strategic timeline that defines at which moment what option should be executed) (Trigeorgis and Reuer, 2017). Previously, the real options theory has been used to determine the timing of investment in information technology (**IT**) solutions. The real options theory was very well suited for this problem because the future developments in IT solutions are highly uncertain, and therefore timing of investment is complex (Buhl et al., 2016). Investing in sensors on dairy farms can be seen as a specific example of IT investment decisions. Also, the future technological progress is uncertain for sensors, and this makes timing of investment a difficult decision. Therefore, the real options theory was used to illustrate the effects of uncertainty about future technological progress in sensor systems on investment decisions of dairy farmers.

Net Present Value

In the real options approach, different investment options are compared quantitatively. In the current analysis the NPV was estimated for "investment now" and "postponed investment" (investment in 5 yr) for sensors for estrus detection and automated BCS. The NPV is the sum of discounted cash flows that are attributable to the investment and the costs of the initial investment. For the estimation of the NPV, the cash flow that was attributable to the investment in a sensor technology on a dairy farm was estimated with a simulation model. This cash flow in year t (CF_t) was estimated as the difference in gross margin between a simulated average dairy herd with and without the