Adoption of Digital Precision Agriculture Technology and Farm Data

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MASTER THESIS

Adoption of Digital Precision Agriculture Technology and Farm Data

A case study on Swedish grain farmers and on-combine near-infrared spectroscopy for quality measurement

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Abstract

The agricultural industry is going through immense changes due to the rapid growth of the global population and climate change, creating increased pressure on the food supply chain. The use of precision agriculture (PA) technologies have shown benefits that could help solve these challenges. Despite this, there is no consensus among researchers on what aspects affect the adoption of PA technology among farmers. One PA technology that enables grain quality insights is the on-combine NIR solution. The innovation emerged 20 years ago but is, despite proven benefits, still not adopted by Swedish grain farmers. Given the agricultural challenges and the rapid advancement of PA technologies, the purpose of this thesis is to increase knowledge about what aspects affect the adoption of PA technology - focusing on on-combine NIR technology and Swedish grain farmers.

This thesis uses an exploratory, abductive and flexible method to investigate this unexplored subject through a qualitative case study. A triangulation methodology was used, consisting of a literature review, expert interviews, secondary data collection, and in-depth interviews with 22 farmers.

The research found six aspects and various factors affecting potential adoption of on-combine NIR technology. The farmers could clearly see the immediate values of the technology, though uncertainties were expressed regarding profitability, decision support and reliability. The technology was seen as most relevant for large farms producing high quality grain. Lantmännen, a cooperative company, was found to have a possible impact on adoption. Usage and sharing of farm data was shown to be crucial in realizing the value of the technology across the grain value chain. Attitudes among farmers towards sharing farm data was found to depend on the context and purpose. In addition, patterns were identified through studying the adoption of PA technologies used by the farmers today. On-combine NIR technology showed similar characteristics as the N-sensor, indicating a slow adoption rate. A high interest in technology was shown to be a key factor, and pioneers were highlighted as important for early adoption of PA technologies. Lastly, the study contributes with suggestions on how to facilitate adoption among Swedish grain farmers.

Keywords: Diffusion theory, innovation adoption, precision agriculture, near-infrared spectroscopy, grain value chain, agricultural cooperative, big farm data

Sammanfattning

Lantbruket står inför stora förändringar till följd av en snabb ökning av den globala befolkningsmängden och klimatförändringar som skapar stor press på värdekedjan för matproduktion. Användningen av teknologier för precisionsodling (PA) har visat sig ha fördelar som kan vara en del av lösningen för dessa framtida utmaningar. Trots detta råder det inte konsensus inom forskarkåren om vilka aspekter som påverkar spridningen av PA-teknologier. En PA-teknologi som möjliggör kvalitetsmätning av spannmål är NIR-teknologi på tröskan. Innovationen introducerades för 20 år sedan men har, trots bevisade fördelar, ännu inte spridits bland svenska lantbrukare. Givet framtida utmaningar inom lantbruket och den snabba utvecklingen av PA-teknologier, är syftet med denna studie att öka kunskapen om vilka aspekter som påverkar spridningen av PA-teknologier, med fokus på NIR-teknologi på tröskan och svenska spannmålsodlare.

Detta examensarbete använder en explorativ, abduktiv och flexibel metod för att undersöka detta outforskade ämne genom en kvalitativ fallstudie. Studien baseras på en trianguleringsmetodik bestående av en litteraturstudie, expertintervjuer, sekundärdata samt djupintervjuer med 22 lantbrukare.

Undersökningen resulterade i sex aspekter och ett antal faktorer som påverkar spridningen av NIR-teknologi på tröskan. Lantbrukarna kunde tydligt se det direkta värdet av teknologin, men uttryckte osäkerhet angående lönsamhet, beslutsstöd och pålitlighet. Teknologin var mest relevant för stora lantbruk med produktion av högkvalitativt spannmål. Studien visade att Lantmännen, ett kooperativt företag, har möjligheten att påverka spridningen. Användning och delning av kvalitetsdata visade sig vara avgörande i förverkligandet av teknikens värde över spannmålsvärdekedjan. Lantbrukarnas inställning till datadelning berodde dock på kontexten och syftet med delningen. Vidare identifierades mönster genom att studera spridningen av den PA-teknologi som lantbrukarna använde idag. NIR-mätning på tröskan visade likheter med N-sensorn, vilket indikerar att spridningen kan bli långsam. Ett stort teknikintresse visade sig vara en nyckelfaktor och särskilda pionjärer lyftes fram som betydande för tidig spridning av PA-teknologier. Studien bidrar slutligen med förslag för att underlätta spridningen av NIR-teknologi på tröskan bland svenska spannmålsbönder.

Nyckelord: diffusionsteori, spridning av innovation, precisionsodling, nära infraröd spektroskopi, spannmålsvärdekedjan, jordbrukskooperativ, lantbruksdata

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Lastly, we want to express gratitude towards our thesis supervisor Jessica Lagerstedt Wadin at the Faculty of Engineering of Lund University. Thank you for always making us see the bigger picture and for being a veritable cornerstone of this thesis. Also, thank you for being positive and for enabling a feeling of celebration despite these challenging times.

Lund, May 2020
Ludvig Dietmann & Julia Stålhammar

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List of Definitions

Term	*Definition*
Combine harvester (combine)	A complex farm machine that both cuts and threshes grain (Augustyn, 2020)
Hagberg falling number (falling number)	A metric indicating the presence of a specific enzyme, which is used to determine suitability of wheat for bread making, with higher numbers preferred by millers (Yara, n.d.) Swedish: *falltal*
Near-infrared spectroscopy (NIR)	A method using electromagnetic radiation between 780 to 2500 nm, widely applied in agriculture to screen quality of agricultural products by quantifying their composition (Burns & Ciurczak, 2007)
On-combine near-infrared spectroscopy (on-combine NIR)	A measuring device placed on a combine, using near-infrared spectroscopy for quality assessment on the field (Wågstam, 2020)
Precision agriculture (PA)	The adjustment of inputs on farm site that are made as precisely as possible after the requirement of soil and crop potentials on a high spatial resolution of the field (Stenberg et al., 2002)

1 Introduction

This chapter introduce the topic of the master thesis by describing relevant background information and the problem statement. In addition, the research questions and delimitations are presented.

1.1 Background

The agricultural industry is going through immense changes (Accenture Strategy, 2017). Firstly, the world population is growing rapidly and creating an increased demand for affordable food. By 2030, 6 out of 7 people are expected to consume more than 3000 calories per person a day while the global population is expected to reach nearly 10 billion people in 2050, creating an increased pressure on food production volumes and the food supply chain. In addition to this, climate change will affect the agricultural industry due to rising temperatures, water stress and drought (2017). At the same time, agriculture stands for 20 percent of global greenhouse gas emissions. It is clear that the agricultural industry will have to go through large changes to be able to keep up with these challenges. Smart technology is suggested as a part of the solution (Accenture Strategy, 2017; Castle et al., n.d.).

The agricultural industry has gone through large technological changes in the last generation (Castle et al., n.d.). The development of digital solutions to monitor and optimize input and increase profitability, so called precision agriculture (PA), has been rapid (Accenture Strategy, 2017). The use of PA technologies that help produce more from less have shown several benefits for the farmer (Accenture Strategy, 2017; Castle et al., n.d.). These “smart farming” technologies have been shown to reduce environmental impact and improve productivity and profits on the farm (Castle et al., n.d.). It has also been shown that using digital solutions and advanced data analytics can improve yields, cut costs and increase crop resilience (Accenture Strategy, 2017). Except for making the production more efficient and environmentally sustainable at farm site, the advance of agricultural technology have been claimed to be beneficial for the entire food value chain. It can lessen insecurity and reduce distance between the stages in the value chain.

With the advance of digital PA technologies, the farmer has access to more information and data than ever before (Castle et al., n.d.). Large amounts of data are already collected through sensors at many farm locations, and through data analysis it is possible to gain important insight (Accenture Strategy, 2017; Magnin, 2016). The intersection between PA technologies, on-farm data and the internet could be of much benefit when battling future challenges (Castle et al., n.d.). The president of the agricultural tech company DuPont Pioneer, Paul E. Schickler, note in an article: *with more mouths to feed using less land and fewer resources, the use of on-farm data has the potential to be a gamechanger for the world's farmers* (Schickler, 2014).

Hence, precision agriculture and the big farm data it can generate, is clearly seen as a way forward for farmers today. There seems to be clear benefits for both the farmer, the entire food value chain and the larger society. Still, there is no consensus among researchers about what factors affect the adoption of PA technologies (Borges et al., 2019). Findings within this research field seems to be largely context dependent, making it difficult to draw consistent conclusions of what aspects hinder or facilitate adoption. Moreover, the perspective of the farmer is often missing (Wolfert et al., 2017), and former research has pointed out a gap in knowledge about farmers opinions on data sharing (Castle at al., 2016). It is therefore of great interest to take on the perspective of the farmer in the aim to further try to understand adoption of PA technologies.

In addition, much former research on adoption of PA technologies is set in an American or Australian context (Barnes et. al., 2019), creating a gap of research in other geographical areas. The European agricultural market is characterized by a larger influence of cooperative companies compared to the USA (Tortia, Valentinov, & Iliopoulos, 2013). As of 2013, cooperative companies represented 50 % of the turnover of input products and 60 % of processing of products from the farm, compared to 26 % and 28 % respectively in the USA. This further indicates differences in market structures and a need to conduct new studies set in locations apart from USA and Australia.

In the United Nations Agenda 2030 for sustainable development, increased food security and security as well as technological development within agriculture is called for (UNDP, 2020). Grain has an especially important role in ensuring food supplies and food security (Jordbruksverket, 2020). Grain is a staple commodity that is directly consumed as food by people, but also act as animal feed for animals in meat and milk production. The significance of grain in assuring food security and safety, makes it important to consider the grain value chain and grain production when looking at adoption of new PA technologies.

New PA technologies are continuously introduced, however not all technologies seem to break through (Wågstam, 2020). The quality measurement method near-infrared spectroscopy (NIR) has been used in the grain industry since the 1960s (O'Donnell et al., 2014). However, the on-combine application of the technology for grain quality measurement is still in the early stages of adoption (Algerbo, 2020), even though it was introduced and proven beneficial 20 years ago (Algerbo & Thylén, 2000; Edling, 2002; Thylén & Rosenqvist, 2002). The application enables data insight about grain quality on the field that can be beneficial for both the farmer and the whole value chain (Wågstam, 2020). Australia is the country where on-combine NIR measurement has spread the most (Eriksson, 2020). The Australian farmers using the solution are mapping grain protein levels over the field to generate data insights and blend different qualities of grain to maximize payment (Leonard, 2017). Several farmers witnessed they had achieved a quick payback of the technology thanks to the financial benefits from grain separation and blending. Despite the possible benefits, no Swedish farmers use the technology today (Wågstam, 2020), making it an interesting technology to study when investigating adoption of PA technologies.

1.2 Problem Statement

There seems to be consensus among scholars that PA technologies can be of large benefit for both the farmer, the value chain and the environment, while being part of the solution for some of the main future challenges within agriculture. At the same time, not all of these technologies are being adopted. For instance, NIR technology for quality measurement has been in use for decades, and an on-combine application has been on the way for quite a long time, though it is not yet in use by farmers in Sweden. The reasons behind this gap thus need to be investigated.

1.3 Purpose

The overall purpose of this master thesis is to expand diffusion theory through increasing the knowledge about innovation adoption and the use of new digital PA technology in agriculture, from a farmer perspective. More specifically, the purpose is to use the case of on-combine NIR measurement for grain farmers in Sweden to provide insight into what factors affect the adoption of PA technology. Moreover, the aim is to explore which role the big amount of data generated by PA technologies plays in adoption. Further, the thesis addresses which impact a cooperative stakeholder such as Lantmännen can have on adoption. Lastly, the purpose is to support Lantmännen and its members towards a data driven grain value chain.

1.4 Research Questions

This thesis aim at answering one main research question that can be divided into two sub-questions, as viewed in Table 1.1.

Table 1.1 The research questions of this study.

RQ 1	***What aspects affect the adoption of precision agriculture technology among farmers?***
1.1	What positive and negative factors affect adoption of on-combine NIR technology among Swedish grain farmers?
1.2	What can be learned from previous adoption of precision agriculture technologies in Swedish grain farming?

1.5 Delimitations

This study is centered on a specific case setting including on-combine NIR measurement, the Swedish grain market and farmers that are members of the agricultural cooperative Lantmännen. It is further focused on PA technologies on the market for Swedish grain farmers. The focal cooperative stakeholder is Lantmännen. A certain focus has been put on the role of farm data.

1.6 Audience

This master thesis is conducted at the institution of innovation engineering at Lund University and thus the audience is partly students and professors at the faculty of engineering. However, the main audiences are agricultural stakeholders such as farmers, agricultural tech providers, crop advisers, and Lantmännen, the collaborative partner of this report. In addition, researchers within diffusion theory and adoption of innovation related or unrelated to agriculture is a suiting audience.

1.7 Report Structure

The structure of this report is designed to make the thesis easy to follow. An overview can be viewed below in Figure 1.1. Firstly an introduction is presented, including the background of the study. The theory chapter is then placed before the methodology, so that the reader have a sense of context in order to follow the methodology chapter. The case study setting is then presented so that the results can be interpreted in the correct context. This is followed by the results chapter, which is a synthesis of the qualitative data gathered from the interviews. Important to note is that this chapter does not aim to answer the research questions or relate the interviews to the theory, but to present the data in a structured way. Following the result, the discussion contains the outcome of the analysis based on the theory chapter and interpretations of the findings within the case study setting. Lastly, conclusions are presented covering answers to the research questions, practical implications, generalizability, suggestions for future research, limitations and validation.

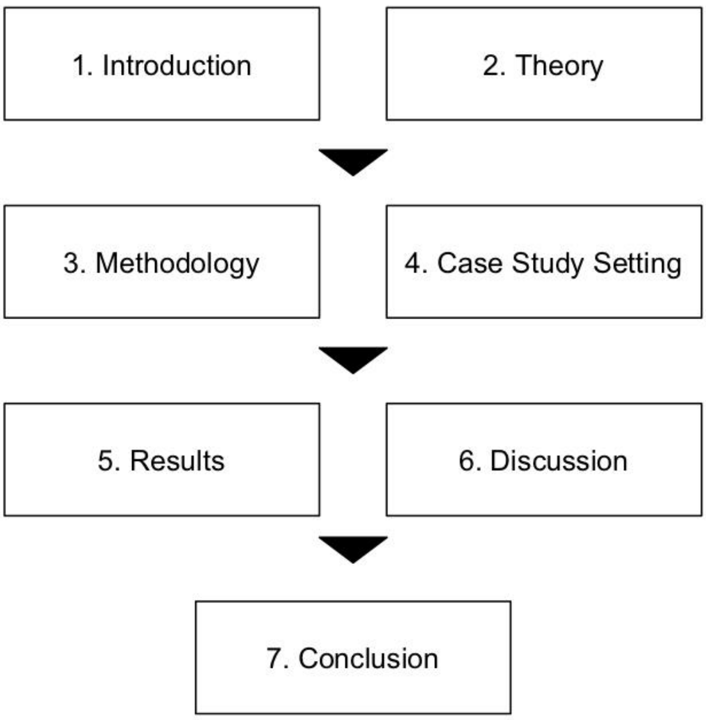

Figure 1.1 Report structure of the master thesis.

2 Theory

This chapter outlines the theoretical framework used in this thesis: diffusion theory. Furthermore, a literature review on previous findings is presented regarding adoption of innovation in agriculture, big farm data and NIR technology.

2.1 Diffusion Theory

There are several theories investigating adoption. One major theory is diffusion theory (Tatnall & Davey, 2001). Scholars have stated that no discussion about innovation would be complete without considering diffusion theory. Innovation diffusion is defined as the process by which an innovation is communicated over time among members of a social system (Rogers, 1995). The theory describes how innovations are spread and adopted by individuals in a certain social context. Diffusion theory is a suitable lens to look through for this master thesis, given it aims at identifying aspects affecting why technological innovations are adopted or not, hence how they diffuse.

Ryan and Gross (1943) were the first to identity adoption of innovation as a process. The theory was then popularized by Everett Rogers through his book, Diffusion of Innovation, which was first published in 1962.

The adoption process is defined as *the mental process an individual passes from first hearing about an innovation to final adoption* (Rogers, 1962). Further it is identified that the rate of adoption occurs through five steps: knowledge, persuasion, decision, implementation, and confirmation. He also identifies five types of adopters: innovators, early adopters, early majority, late majority and laggards as can be seen in Figure 2.1. The adoption of innovation generally follows an S curve when plotted over time.

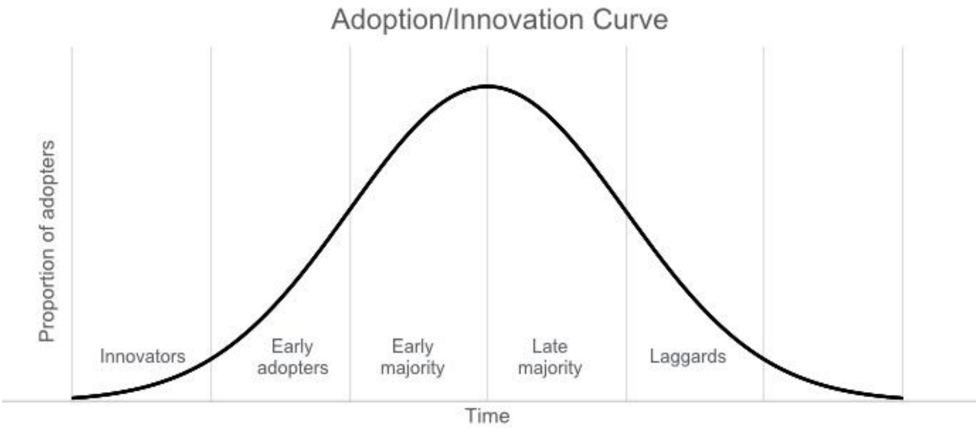

Figure 2.1 Adoption/Innovation Curve (Rogers, 1995), recreated by authors.

Rogers (1995) also presents five perceived characteristics of innovations: relative advantage, compatibility, complexity, observability, and trialability. These characteristics help determine the adoption rate of an innovation. Definitions and impact on adoption can be seen in Table 2.1.

Table 2.1 Rogers (1995) five characteristics of innovations and impact on adoption rate

Characteristic of innovation	***Definition***	***Impact on adoption rate***
Relative advantage	*the degree to which an innovation is perceived as better than the idea it supersedes*	The adoption rate is faster if the user regard it as superior to what he or she currently have.
Compatibility	*the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters*	The adoption rate is faster if the innovation fits with current values, norms or systems.
Complexity	*the degree to which the innovation is perceived as difficult to understand and use*	The adoption rate is faster if the innovation is easy to understand and learn how to use.
Observability	*the degree to which the results of the innovation are visible to others*	The adoption rate is faster if it is easy to view the relative advantage of the innovation. Especially, observability increases the diffusion affect after some adoption.

Trialability	*the degree to which an innovation may be experimented with on a limited basis*	The adoption rate is faster if it is possible to try the innovation before committing to a full adoption.

However, researchers have pointed out that it is important to specify the finding of Rogers and distinguish between individual adoption and aggregate adoption (Feder, Just, & Zilberman, 1985). Individual adoption describes the adoption process and use of a specific new technology for the individual (the farmer for this thesis). Aggregate adoption describes the aggregated level of use of a specific new technology within a given geographical area or a given population. Final adoption at an individual level is described as the degree of use of the new technology in the long run when the usage has reached an equilibrium. This is assuming that the farmer has full information about the new technology and its potential. This further relies on the assumption that there is a general disequilibrium when a new technology is introduced to an individual, and that there is initial difficulties in utilizing the technology efficiently (Schultz, 1975).

Most research to date have focused on the adoption decision as binary (adoption or non-adoption), but since adoption is a process, for many innovations it could be more interesting to focus on the intensity of the adoption (Feder, Just and Zilberman, 1985). Further, most studies measure the intention to adopt an innovation rather than the actual adoption (Borges, Oude Lansink, & Emvalomatis, 2019). This thesis explores the farmers view on adoption (including intention and actual adoption) rather than adoption as binary, due to the novelty of the focal technology and thus absence of adoption.

A psychological perspective of adoption of new products was presented by Gourville (2006), describing underlying reasons why new innovations fail or succeed by placing innovations in four categories. The framework includes two axises, one representing degree of product change involved and the other representing degree of behavioural change required for the new product to be adopted. The dimensions, ranging from low to high, create a four-box model which can be viewed in Figure 2.2, with the corresponding product categories: easy sells, sure failures, long hauls, and smash hits.

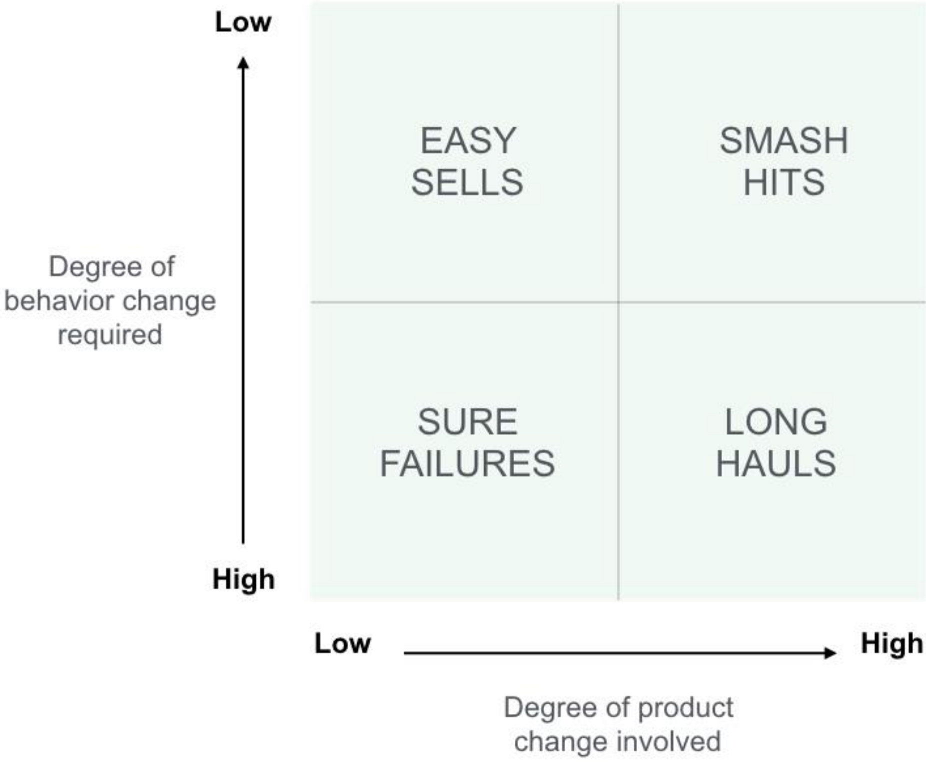

Figure 2.2 Product Innovation Categories (Gourville, 2006), recreated by authors.

Further, Gourville (2006) argues that companies can anticipate to minimize customer resistance by the following strategies: i) making behaviorally compatible products, ii) target customers who are not yet using competing alternatives, and iii) try to find true believers who value advantages by a given innovation the most.
If resistance is an inevitability, the company should accept that its product is a long haul, brace for slow adoption and not waste resources on aggressive marketing (Gourville, 2006). Additionally, the product should offer benefits at least ten times greater than existing products since customers usually overvalue existing solutions by a factor of three, while companies overvalue their solution by the same factor, creating a disparity of perception by a factor of nine.

2.2 Adoption of Innovation in Agriculture

There is vast research that tries to explain farmers adoption of agricultural innovations and new technology (Knowler & Bradshaw, 2007). Many have tried to explain what factors affect farmers' adoption of certain innovations. It could usually be expected that as the number of studies increase, the result would converge towards a particular finding, but this is not the case when studying innovation adoption in agriculture (2007). On the opposite, when studying adoption within agriculture, it seems like the more studies are done the larger the uncertainty gets about what individual variables affect the adoption rate due to varied results.

One widely spread fundamental assumption is that farmers make decisions about adoption based on the aim to maximize utility (Borges, Oude Lansink, & Emvalomatis, 2019). The idea is that the farmer adopts an innovation if the utility from adopting the innovation exceeds the utility from not adopting it. This assumption might seem self-evident, but farmers' decisions about adoption are complex and are affected by various factors.

Scholars have investigated several factors that could affect the adoption rate of innovation for farmers (Borges, Oude Lansink, & Emvalomatis, 2019; Prokopy et al., 2008). Farmer demographics and farm characteristics are the main areas of investigation, while some also have added a macro analysis through a perspective of external factors as well as a perspective of attitudes. Age, education level, farm size, assets and assistance are especially common variables to measure (Prokopy et al., 2008). This might be due to that these variables are generally easy to measure, however many researchers fail in motivating the choice of these variables, but simply include them because it is expected (2008).

Feder, Just, and Zilberman (1985) investigated variables such as farm size, risk and uncertainty, human capital, labor availability, the credit constraint, tenure, supply constraints, and aggregated adoption over time. The effect of most variables were found to vary depending on context, type of innovation, measurement method or affected by dependencies of other factors (e.g. farm size generally increase the access of credit). However, more education and scarcity of available labor resources was found to increase the adoption rate.

Knowler and Bradshaw (2007) reviews current research by investigating four types of variables that could affect the adoption of conservation agriculture: farmer and farm household characteristics, farm biophysical characteristics, farm financial/management characteristics and exogenous factors. They point out that a regular hypothesis is that the adoption of any new technology (especially the ones requiring new equipment) requires a certain financial well-being. But in fact, there has been research showing that financial variables could be insignificant or even have a reverse effect on adoption rate. When looking at exogenous factors the authors have identified several interesting aspects affecting the adoption rate of new innovation. Firstly, studies of adoption and diffusion have long recognized that the availability of information (e.g. from other farmers, media or partners) affects adoption rate positively. However, information alone does not necessarily affect the rate, but rather how well it is distributed. Secondly, government regulation such as subsidies can fasten the innovation adoption process, if carefully made. Lastly, social capital, such as partnerships and memberships of producer organizations, could have a positive impact on adoption rate, although not all studies find this significant (2007).

Another study combines farmer demographics and farm characteristics with aspects of environmental attitudes, environmental awareness and utilization of social networks (Prokopy et al., 2008), adding qualitative parameters.

Paustian and Thuevsen (2017) investigate precision agriculture and takes on a classic approach through looking at farm characteristics and farmer demographics. They find that farmers are generally hesitant to adopt precision agriculture due to a lack of expected benefits. Barnes et al. (2019) further investigate adoption of precision agriculture technologies, more specifically machine guidance and variable rate nitrogen technologies in a cross regional EU study. They point out that adoption vary depending on what region and which type of technology is examined and emphasize that most former research on adoption of precision agriculture technologies have studied farmers in Australia or the USA. In their research, studying farmers in five EU countries (Belgium, Germany, Greece, the Netherlands, and the UK), it was found that attitudinal differences, meaning level of optimism towards financial return of the technology, affected likelihood of adoption. Furthermore, innovative and information seeking behaviour has significant effect on likelihood of upgrading to a variate rate technology. Subsidies and taxation showed positive effects and also non-financial support, e.g. informational support or demonstration to prove the investment case was showed to may have positive effects as well. Hardly surprising, differences in size and income imposed barriers for adoption (2019).

In conclusion, there is generally no consensus about what variables affect the adoption rate of innovation in agriculture, rather the results seem to be largely context dependent. Borges, Oude Lansink, and Emvalomatis (2019) summarize the general findings within this subject in a review and note that the effects of independent variables are frequently insignificant and the significant effects are often contradictory. They find that household characteristics generally had an insignificant effect. Further, the only two farmer characteristics that showed a significant and consistent result was risk-aversion and experience in farming. It is also pointed out that the reason that so few consistent results are found can be the different measuring methods and the dependency between the variables (e.g. increasing experience could correlate with increasing age) (2019). This fragmentation in the research about adoption of innovation in agriculture, emphasize the importance of studies performed in different geographical and cultural settings. To be able to gain a deeper knowledge within the field, there is a need for research in new contexts.

2.3 Adoption of Precision Agriculture in Sweden

Precision agriculture (PA), also site-specific agriculture, refers to the adjustment of inputs that are made as precisely as possible after the requirement of soil and crop potentials on a high spatial resolution (Stenberg et al., 2002). PA can be beneficial due to that the yield within one field can vary with several tons of cereals per ha.

A rapid technological development within precision agriculture has taken place in Sweden since the 1990s, but the actual implementation among farmers have not been as rapid (Lindblom et al., 2017). Most new machines have built-in technology that can measure several variables, but the functions are not always used, which makes Sweden of interest within adoption research, but the studies are few.

Researchers have especially investigated the adoption of the N-sensor and assisted GPS auto steering systems in a Swedish context, finding several differences and similarities (Lindblom et al, 2017). The N-sensor was introduced in Sweden in the end of the 1990s and can measure nitrogen content in growing crops. Since crop quality and payment is strongly linked to nitrogen content, this can provide value for farmers through enabling optimization. The technology was continuously promoted by farming press, exhibitions and manufacturers, but few farmers adopted the technology. Generally, farmers recognized that the yield within one field varied, and in theory they should therefore not have had trouble realizing the benefits of the N-sensor. Part of the reason for slow adoption could be the lack of field experiments to secure reliability of the technology. Further, higher costs, extra work, doubts of the credibility or cost-benefit could explain the lack of adoption.

Recently, the adoption of the N-sensor has increased (Nissen, 2020). Speculations have been made concerning that the contrasting years of 2015 and 2016 (that brought increased volatility in yield and protein levels) acted as a catalyst for the adoption of the N-sensor, since it was clear that the farmers using the N-sensor ensured higher profitability during those years (Nissen, 2020; Lundström, 2020; Martinsson, 2020). Thus, depending on the outcome in volume or quality of a certain year, it could fasten or slow down the adoption of the N-sensor.

Assisted steering systems, such as GPS auto steering, was introduced on the Swedish market in the early 2000s (Lindblom et al., 2017) . The innovation quickly reached beyond early adopters and became highly popular. Both the N-sensor and the assisted steering system require that the farmer gains new technological knowledge but differ when it comes to decision making support. The N-sensor needs input data to work while the steering system only needs an estimation of the distance to the new track, to be useful. Also, the steering system creates tangible and immediate value to the farmer, through steering the tractor and making sure no part of the field is missed. The value of the N-sensor is less tangible and it is therefore harder to grasp the environmental and economic benefits. The examples of the N-sensor and GPS auto steering shows how the adoption rate of innovations can vary largely, and present a few theories of factors that can affect adoption rate of PA technologies in a Swedish context.

2.3.1 On-Combine NIR Technology

Near-infrared spectroscopy (NIR), is a method using electromagnetic radiation between 780 to 2500 nm which has a wide range of applications in place today (Esteve Agelet & Hurburgh, 2010). In agriculture, it is widely applied to screen quality of agricultural products by quantifying their composition (Burns & Ciurczak, 2007). The wide adoption of NIR technology can be explained by its accuracy, rapidness, non-destructive nature, reliability and relatively low cost (Burns & Ciurczak, 2007). In the grain industry specifically, NIR technology has been in place since the 1960s for routine quality screening by measuring moisture and protein levels at laboratories (O'Donnell et al., 2014).

NIR technology has been used for decades with different applications in agriculture (O'Donnell et al., 2014), and the research on the subject has mainly been investigating the technical capabilities. Research for the on-combine applications of the technology has been conducted since the early 2000s, when it was pioneered by researchers of the former Institute of Agricultural and Environmental Engineering (JTI) in Sweden (Algerbo & Thylén, 2000; Edling, 2002; Thylén & Rosenqvist, 2002). They investigated how sensors using NIR spectroscopy potentially could enable farmers to sort their grain based on protein levels by installing them directly on the combine or at the drying facility.

Thylén and Rosenqvist (2002) suggest that varying farm conditions affect the potential gains a farm could realize from adopting on-combine NIR technology. Enabling quality assessment and sorting of grain was found to be more valuable for farms with heterogeneous soils than farms with homogenous soils. Moreover, it was found to be valuable for farms producing feed for their own animals since grain for feed purposes, of both high and low protein levels, is interesting to sort. Being able to identify grain with high protein levels reduce the need for the farmer to buy protein supplements for the feed. Edling (2002) argues that while sorting on the combine could have the most impactful effect since the grain protein level varies mostly in the field, it would potentially reduce the capacity of the combine. Thus sorting in a later production stage (after the drying process) was seen as a better option.

According to Per-Anders Algerbo (2020), researcher at RISE (Research Institute of Sweden), one of the reasons the on-combine application has not yet been implemented in Sweden is that it is hard for the farmers to benefit from measuring grain quality. In addition, how to use the insights gained by the quality data has been unclear, and at the time of his research at JTI, grain pricing did not reward quality sorting of grain based on protein levels or other quality parameters. Furthermore, the need for calibration and updates of the mobile NIR sensors could not be fulfilled continuously due to a lack of network connections on the field at the time. He points out that connectivity of the sensors is a possibility today.

More recently, studies of NIR applications has primarily been focusing on quality assessment at harvest and its implications on classification and blending of grain (O'Donnell et al., 2014). Other recently developed applications of NIR technology include non-destructive evaluation of cereal grains such as wheat and barley, measuring quality parameters including protein levels (Caporaso, Whitworth & Fisk, 2018).

An adoption perspective of the on-combine NIR application is so far unexplored in published research, to the best knowledge of the authors.

2.4 Big Farm Data

The use of precision agriculture and new digital technologies generates large amounts of data, creating a new information-based farming, mentioned in the literature as farming 4.0, smart farming, digital agriculture, digital farming, and precision agriculture (Wiseman et al., 2019; Paustian & Theuvsen, 2017). This data creates possibilities to optimize processes and make informed farm management decisions, though it also creates difficulties (Paustian & Theuvsen, 2017). It has been shown that many farmers have "mixed feelings" towards farming and digitalization (Wiseman et al., 2019).

The rapid increase of technology within farming has boomed the amount of data available, creating big farm data (Castle, Lubben, & Luck, 2015). Big data is defined as high-volume, high-velocity and/or high-variety information assets (Castle, Lubben, & Luck, 2016). This type of data creates a demand for new services and analytical tools to be able to gain insight from the vast amount of data collected (Castle, Lubben, & Luck, 2015).

The value of big farm data expands beyond precision agriculture at farm site, involving the entire supply chain (Castle, Lubben, & Luck, 2015). Farm data is not only providing the farmer with decision support on a farm level but could also be used in marketing on a regional level or for forming regulation on a state level (Wolfert et al., 2017). Researchers have gone so far as to say that big data in agriculture can shift the power structure in the industry (2017). However, farmers seem to lack basic knowledge about what big data is, which could serve as a limitation for the future (Castle, Lubben, & Luck, 2016). Moreover, one of the main future issues regarding farm-level data is understanding how to use and interpret the data.

These large possibilities have created an interest among many players within agriculture to get a hand on big farm data, sparking the discussion about who the data really belongs to (Wolfert et al., 2017). In a study from 2015, 90 % of questioned farmers considered the data to belong to the farmers (Castle, Lubben, & Luck, 2015), which might not be so surprising. Also, Castle, Lubben, and Luck (2016) finds that an overwhelming majority of food producers think the data belongs to the farmer. However, it might not be as self-evident as it sounds. Already in 2014, several machine providers, such as John Deere and DuPont, gathered in the US to discuss data ownership in agriculture (Banham, 2014). Should it be the machine manufacturers, the sensor makers or the farmers that own and use the data?

Wolfert, Ge, Verdouw, and Bogaardt (2017) points out that ensuring privacy and security is one of the biggest challenges within farm data for the future. Due to security issues it is common that companies refrain from making data publicly available which slows the development down. To be able to build trust with farmers, new collaborations across the food value chain have to be formed to open up for data sharing.

The issue of privacy circles around the question of data sharing, hence who has access to farm data and to whom it belongs (Castle, Lubben, & Luck, 2016). Companies in the agricultural sector are already offering farmers the possibility to access farm data from precision agriculture equipment, and it often comes with an agreement that gives data access to the equipment provider as well as a third party (Castle, Lubben, & Luck, 2015). There isn’t necessarily a tension when it comes to data sharing between the farmer and the machine provider (Banham, 2014). However, a concern among farmers is that the data could be accessed by a third party. Many farmers are concerned that the data might end up with a rival or the government, that they didn’t give permission in the first place. Another concern is that the data could be used for regulatory purposes if the government gets a hand on it, either to find noncompliant behaviors or as a basis for more strict regulation.

The trust farmers have in sharing their data generally depends on who the receiver is (Castle, Lubben, & Luck, 2015). In a study from 2016, the respondents were comfortable with sharing their data with trusted partners such as university researchers, educators, relatives and local cooperatives (Castle, Lubben, & Luck, 2016). On the other hand, they would rather not share their data at all than sharing it with equipment dealers, manufacturers or neighbors.

Castle, Lubben and Luck (2016) finds that two factors are statistically significant when it comes to the propensity to share farm data: operator age and irrigation use.

Younger farmers seem to be more likely to share their data probably because they are more used to new technologies. Farmers not using irrigation could generally have a lower production intensity and therefore rely less on data for efficiency. The study also finds (although not significantly) that farmers with large tech knowledge were more skeptical towards data sharing, probably because of more knowledge about the risks.

The future of digital farming could generally result in two extreme scenarios: either a closed system where the farmer is part of a highly integrated supply chain, or an open collaborative system where the farmer and other stakeholders are flexible in choosing business and tech partners (Wolfert et al., 2017). The development of platforms and standards within agriculture will be crucial in pointing in which direction the industry is heading towards. In fact, until the legal and regulatory framework is set for big farm data, it is likely that farmers keep on having "mixed feelings" towards digital agriculture (Wiseman et al., 2019).

Castle, Lubben, and Luck (2016) emphasize that studying producers opinions on data sharing would be of great interest, strengthening the importance of this thesis. Further, Wolfert et al. (2017) note that the perspective of farmers concerns often is missing in current research.

3 Methodology

This chapter describes the chosen strategy as well as method to answer the research questions of this thesis. The research strategy is exploratory, flexible, and abductive, and the research method is a case study including a number of qualitative interviews. How the data was collected and analyzed is also described. Lastly, research ethics and credibility is discussed.

3.1 Research Strategy

A research strategy can be described as a plan which broadly describes the logic and reasoning of a thesis (Denscombe, 2017). This thesis takes on an exploratory, flexible and abductive strategy through conducting a qualitative case study.

According to Höst, Regnell and Runesson (2006), there are four different ways of designing research studies: descriptive, exploratory, explanatory and problem-solving. To answer the research questions for this thesis, an exploratory design was chosen. An exploratory study has the purpose to understand a subject on a deeper level and is often used for subjects relatively unexplored in previous research (Höst et al., 2006). Even though research addressing adoption of innovation and NIR technology separately has been conducted for decades, the combination of the two, addressing on-combine NIR technology is so far unexplored, to the best of the knowledge of the authors. This further strengthens the argument to choose an exploratory design. Given that diffusion of technologies are hard to generalize in agriculture in general as well as precision agriculture in particular, new perspectives can potentially be generated. An exploratory design furthermore means that purpose, scope and methodology of the thesis have formed along the whole duration of the research, for example based on initial interviews with experts from the agricultural industry. The exploratory method was viewed as suitable for understanding the unexplored subject of this thesis.

The approach in research can either be fixed or flexible, meaning the methodology is either pre-defined or can be adjusted during execution (Höst et al., 2006). Given the exploratory nature of the thesis, a flexible research approach was chosen. The agricultural context, including needs of stakeholders, underlying obstacles and the grain value chain in Sweden, was uncovered in the initial weeks of the study. This was mainly because the authors had limited prior knowledge regarding grain production, grain market and agricultural digital technologies. The flexibility thus allowed for the scope to be adjusted through iterations as knowledge was gained.

In research, inductive, deductive and/or abductive reasoning can be used (Denscombe, 2017). Inductive reasoning uses empirical observations, draws conclusions from it and tries to generalize the findings. Deductive reasoning on the other hand starts in theoretical frameworks, hypothesize rules that are then tested to examine the validity of a specific case. Abductive reasoning starts from empirical observations that are deviating from existing theoretical framework and then aim to develop new understandings and present new suggestions for the future (2017). The approach for this research is abductive, given that the observations cannot be fully generalized into new theories but rather provide suggestions for the future.

Two types of data can be collected: qualitative and quantitative (Denscombe, 2017). Qualitative data is non-numerical data such as words and images which gives a contextual perspective on how factors are related. Quantitative data is numerical data to be used for mathematical and statistical analyses to test hypotheses and variables. In contrast to most research in this field, using mainly quantitative methods aiming to draw statistical conclusions, this thesis use qualitative data in order gain deep insights of the farmer perspective. Using qualitative data enables the process to be flexible and iterative for questions, data gathering and analysis (Denscombe, 2017).

3.1.1 **Research Design**

Given the exploratory approach, and adoption of agricultural innovations being highly context dependent, a case study design was viewed as suitable. The case study method is a common method for small scale research projects, focusing on one specific setting by preferably using different methods for data collection to get an holistic view (Denscombe, 2017). Using the case study method, the aim is to investigate in-depth rather than breadth.

The case study design focus is suitable for answering questions of “why” or “how” and must have a logical design, pre-described data collection techniques and predetermined data analysis methods (Yin, 2009). This thesis aim at gaining a deep understanding about a number of complex factors from a farmer perspective, and understand “why” farmers adopt certain technologies, making a case study design suitable.

When creating the research design, surveys and focus groups and in-depth interviews were discussed as possible methods for gathering data. Surveys would have been a way to quantify attitudes towards the technology, and make it possible to draw statistical conclusions (Höst et al., 2006). On the other hand, it would not have been possible to gain detailed and nuanced insight by solely using this method. Surveying was thus ruled out since the aim of this study is to provide a farmer perspective towards new digital technology qualitatively. Focus groups were also considered but was not chosen as it is not a preferred method for potentially sensitive subjects (such as data handling) and for target respondents that are hard to gather (Bjerseth, 2020), which was the case for this thesis. In-depth interviews was thus found to be the most suitable method since it allowed for a qualitative flexible approach and deep insights.

3.2 Data Collection

Denscombe (2017) describes the research method triangulation as a way of using contrasting sources of information and methods to investigate a subject. For this thesis, the triangulation was performed through collection of data in three different ways, by conducting a thorough literature review, by interviewing agricultural experts and gathering facts from secondary sources, and through interviewing farmers. An illustration of the triangulation of data gathering for this thesis can be viewed below in Figure 3.1.

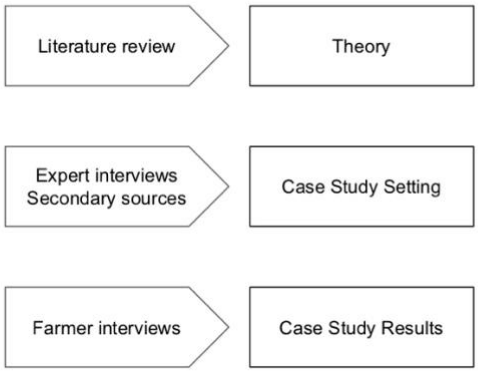

Figure 3.1 Illustration of data gathering triangulation.

3.2.1 **Literature Review**

When starting research, it is important to familiarize with the subject at hand and also ensure that the scope and research question addresses something which has not been investigated earlier (Höst et al., 2006). To ensure that, a thorough literature review was conducted covering diffusion theory, adoption of agricultural technology, NIR technology and data sharing in agriculture. To identify relevant research, LUBSearch (Lund University's search engine) and Google Scholar was used. Additional sources such as news articles covering non-analytical purposes for background and agricultural context were also collected by using Google. The literature review had a contextualizing purpose which generated a thorough understanding and steered the design of the study.

3.2.2 Secondary Sources

To clearly set the scope of the thesis in the right context, secondary data was collected. Google was mainly used to gather these facts and information. Secondary data was also provided by experts and Lantmännen. This information was important in order to draft the interview guide, since knowledge about on-combine NIR technology, the Swedish grain industry and Lantmännen was central. These insights were included in the case study setting for the reader to easier understand the results. To avoid possible bias from secondary sources, they were not included in the results of this study, but rather helped to set the study in the right context.

3.2.3 Interviews

Grain farmers and experts were interviewed for this thesis. Experts were initially interviewed when drafting the research scope and methodology. These conversations were also guiding when designing the question list for the grain farmer interviews and provided facts regarding the grain value chain and the current status of technological use in agriculture. In the later stages of the study, additional experts were interviewed in order to complement knowledge and validate findings from farmer interviews. The experts were affiliated with agricultural stakeholders, including Lantmännen, research institutes, and technology providers. The objective facts presented by the experts have been included in the background, theory and case study setting. However, subjective opinions and speculations have not been included.

Given that the scope of the thesis is to provide a farmer perspective, these interviews were the basis for the result. The interviews conducted with grain farmers used a semi structured approach, which enables the interviewee to speak freely while still being led by the interviewer (Höst et al., 2006). This allowed for perspectives and ideas unrelated to the interview guide to emerge.

Before starting to conduct farmer interviews, an interview guide was drafted based on the research questions as well as the relevant theoretical frameworks for adoption, theory about precision agriculture, and expert interviews. An additional perspective of farm data and the cooperative company Lantmännen was addressed in the guide. An expert who had studied adoption within agriculture was also consulted to discuss which questions to ask the interviewees. To further ensure relevance and completeness of the guide, it was sent for feedback to academic professionals at the university, to company representatives at Lantmännen as well as one farmer. The interviews were performed and recorded in order to be able to later analyze them in full, observing all nuances in the answers. All interviews were conducted in Swedish. The interviews were transcribed capturing the most important points and word-by-word when needed, including quotes that were found extra interesting to be used in the report. The final version of the interview guide can be viewed in the Appendix A.

3.2.3.1 Sample Selection

When selecting respondents, the aim was to include grain farmers with varying characteristics, such as level of technological interest, farm sizes, age, and geographical location. The interviewees were identified using several sources. Employees at Lantmännen recommended specific farmers as well as well-connected people within the industry that could provide additional farmer contacts. During initial expert interviews, referrals to relevant farmers were received. Additional farmers were encountered and identified at a Lantmännen local association meeting outside of Lund. The method to find farmers was a sort of stratification, which means that interviewees are selected from predefined categories (Höst et al., 2006).

The number of interviews needed with grain farmers thus had to be determined. In qualitative research, saturation is widely used as a principle to determine when further data collection is not needed based on additional responses not generating new perspectives (Saunders et al., 2017). Although the concept has been questioned due to its equivocal nature, it was a guiding principle when determining whether new interviews needed to be added. Given the ambition to include diverse farmer profiles, the initial target number for farmer interviews was set to 15, and it ended up being 22 interviews conducted based on both the saturation principle and how many leads were generated when searching for farmer contacts.

3.3 Data Analysis

According to Höst et al. (2006), the process of qualitative research is separated into the steps: data collection, coding, grouping and drawing conclusions. After the data collection described in section 3.2, the coding for this study was performed in several steps. Using the qualitative analysis framework by Miles, Huberman, and Saldaña (2014), the coding was performed in two cycles. The first cycle of coding consisted of three steps. Firstly, the in-depth farmer interviews were transcribed. Secondly, the transcribed text was coded on the basis of the themes that the farmer brought up. This was done through identifying certain keywords or phrases in the text documents. These themes were a compilation of both the answers to the interview questions, and factors the farmers brought up which were not directly connected to the theoretical framework, since the farmers were given space to steer the interviews. Thirdly, the themes and keywords were transferred and compiled in a spreadsheet to be able to get a better overview for the second round of coding. The second cycle of coding was done through identifying recurring themes and keywords in the data material. The second cycle of coding resulted in a number of factors affecting the adoption of on-combine NIR technology.

The next step was grouping. This was done through clustering the factors in the spread sheet and transferring them to a text document. The grouping was made column by column and summarized in a result synthesis, which was the basis for the identified aspects affecting adoption.

Lastly, conclusions were drawn by processing the result synthesis using the theoretical frameworks and the research questions of this study. The discussion was drafted with the theory as a lens and the research questions as a guide. The analysis was an iterative process where the discussion and the result continuously where examined to ensure relevance of all content included in the final report. Except for general diffusion theory and theory from the literature review, the frameworks used were Rogers five characteristics of innovations, Rogers adoption types, the adoption/innovation curve and Gourville product innovation categories. Lastly, the answers to the research questions were structured in the conclusion.

3.4 Research Ethics

According to Denscombe (2017), there are four key ethical principles in research. Firstly, it is important to protect the interests of all participants. Secondly, participation should be voluntary and based on informed consent. Thirdly, deception is to be avoided and the research should be conducted with scientific integrity. Lastly, laws in the country or countries where the research is conducted need to be complied with. These principles were considered during this study and several steps were included in the research process to ensure compliance, especially in the data collection phase of the thesis.

All farmers interviewed were informed that the answers they provided were going to be anonymous, though the farmers were offered to be included in a list of participants for Lantmännen. The farmers had the possibility to add own perspectives not addressed by the questions at the end of each interview, and to receive the finished report later on. By the start of each interview, the interviewee was asked if the interview could be recorded to be kept only by the authors for transliteration. The farmers interviewed were not offered the possibility to view and adjust the results before publishing given all their answered were synthesized anonymously and recorded, and also for the authors to be able to freely interpret the answers without external influence.

The experts interviewed both within and outside of Lantmännen were not offered anonymity since insights from these interviews were primarily used as facts or assessments on a specific topic. However, the possibility was offered to the experts to view and adjust segments from their interviews, when requested. This was particularly important to avoid sensitive information to be published. Drafts of the complete report was screened by the supervisors from Lantmännen before publication to avoid this risk as well.

3.5 Research Credibility

It is important that research shows high credibility, and it can be assured in several ways (Yin, 2009; Denscombe, 2017). Firstly, validity was considered in order to guarantee that intended concepts were actually investigated. Validity can be achieved by using several sources of evidence as well as having a draft of the report reviewed by relevant stakeholders (Yin, 2009). For this thesis, triangulation of different sources was used, and drafts of the report were sent to Lantmännen representatives and the supervisor at Lund University.

Secondly, reliability was considered. Reliability means that an investigation in a similar setting with the same research tools should provide the same results (Denscombe, 2017). Given the exploratory and qualitative approach of the thesis, many interviews were conducted with different types of interviewees to ensure reliability.

Thirdly, generalizability was considered. The findings of this study may be hard to generalize, which is the situation for most case studies (Denscombe, 2017). However, Denscombe (2017) argues that one should ask how likely findings are to be found in another setting instead of asking how much of findings that can be generalized. This has been considered when discussing generalizability.

Lastly, objectivity was aimed to be achieved. This was primarily done by having two researchers, meaning two people interpreted the results. The authors of this report had no prior knowledge or preconceptions about grain production, meaning a lack of insight beforehand and a possibility to view the problem with an open mind. Given the qualitative nature of the data analysis, the results have to be interpreted by the authors which could affect the objectivity. In this regard, data could be misinterpreted and therefore the findings were openly discussed with experts and supervisors in order to mitigate this risk.

4 Case Study Setting

This chapter present the case study setting, including the Swedish grain industry, on-combine NIR technology and Lantmännen, in order to provide the reader with a suitable context.

4.1 Grain Industry in Sweden

To understand the thesis context, the most important areas to cover about the grain industry in Sweden are the grain value chain, including logistics, and the grain market, including how grain is priced. These areas are important in order to understand how the Swedish farmers may perceive the benefits and obstacles for on-combine NIR measurement.

4.1.1 The Grain Value Chain

The complete grain value chain in Sweden is complex and involves many steps and stakeholders (Jeppsson, 2020). After farming inputs, such as sowing and fertilization, the cultivation and refinement of the grain require several logistical processes, on the farm and outside of the farm. The logistical process from harvest to selling of grain can be viewed in the schematic illustration below, including possible selling opportunities for the farmer (Figure 4.1).

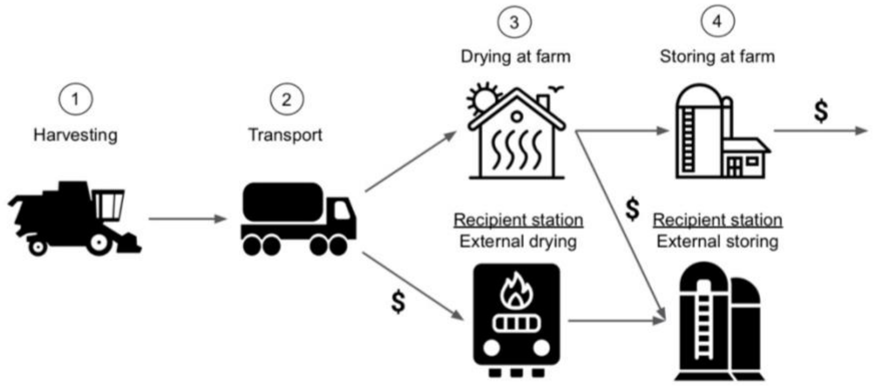

Figure 4.1 Overview of the grain production process post-harvest, the $-signs mark the possible sales transactions.

4.1.1.1 Logistics on the Farm

To cultivate grain, a number of steps needs to be undergone on the farm, such as sowing, fertilization and harvesting (Jeppsson, 2020). Perhaps the most critical phase is the harvest due to timing being crucial for optimal yield. A number of logistical steps (included in Figure 4.1) are made during and after the harvest at the farm (Wågstam, 2020):

- Step 1: Harvesting on field using a combine
- Step 2: Transportation in carriages to a drying facility or directly to the seller
- Step 3: Drying for sufficient water level
- Step 4: Storing before selling

Many farmers have a drying facility on their farm, to be able to have a better control over when to sell the grain (Jeppsson, 2020). Also, farm sizes vary and so does the possibility of storing and keeping batches separately in silos at the farm (Wågstam 2020). These aspects affect sales timing for the farmer.

4.1.1.2 Logistics Outside the Farm

Grain can be delivered to recipient stations of the buyers in two general ways: either directly from the farm during the harvesting period (before or after drying) or at a later stage from silo storage (Jeppsson, 2020). When the farmer harvest and sell directly, the buyer measures the quality and pays accordingly. Depending on the grain quality and suitability for different end products, the grain is stored in a suitable silo. The buyers then mix batches of different qualities in order to provide a desired level of quality for production. An overview of common use of grain can be seen in Figure 4.2.

It is difficult to forecast what grain qualities and quantities will arrive to the reception stations for the buyer (Jeppsson, 2020; Strömberg, 2020). This is particularly difficult during the harvest period, due to the continuous and rapid flow of grain during a short period of time. After the harvesting period, there is less time pressure, and the grain can be collected when agreed (Jeppsson, 2020). However, it is always important to determine grain quality before delivery, so that batches can be steered to correct facilities. To be able to get insights about grain quality today, the buyers send test kits to the farmers for sample testing (Wågstam, 2020). The sample is then sent to a laboratory for analysis which the buyer pays for. The farmer receives a mean value of the sample as feedback. The main methods for testing at laboratories are NIR and manual falling number tests. These tests can be done at different stages in the grain production, ideally before storage at farm site.

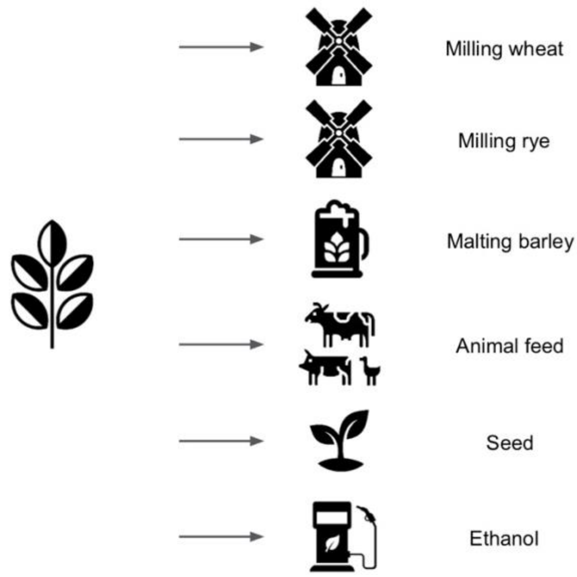

Figure 4.2 Overview of a selection of grain products.

4.1.2 Grain Market and Pricing

The most common type of grain cultivated in Sweden is wheat, accounting for 48 % of all harvested grain, followed by barley accounting for 30 %, oat for 13 % and rye for 4 % (Lantmännen, n.d.-a). In 2019, the total level of harvested grain in Sweden surpassed 6 million tonnes, almost a doubling compared to the bad harvest in 2018 caused by the extreme drought (SCB, 2020).

When making profit within the Swedish grain market, grain quality is important, since the grain prices vary depending on the demand for several quality parameters, for example protein, falling number, starch and toxins (Jeppsson, 2020). Apart from quality, the price of grain vary according to: timing, geographical location, exports/imports, freight costs, size of vehicles for transport and balance between supply and demand.

For the most common grains on the Swedish market, wheat and barley, the biggest price difference is between batches that are sold for human consumption (such as food or beer) and batches for animal feed production (Wågstam, 2020; Jeppsson, 2020; Strömberg, 2020). Apart from food and feed, a common use of grain is input for production of bioenergy such as ethanol (Jeppsson, 2020). For grain delivered for animal feed or ethanol, protein is not a price distinguishing parameter, hence low protein grain is usually sold for these purposes.

As supply and demand vary, the price discrepancies between grain types and products naturally also vary (Jeppsson, 2020; Nissen, 2020). Lantmännen is the biggest buyer of grain in Sweden, annually buying 40 % of grain harvested (Björk, 2020). In 2019, the prices from Lantmännen stabilized to relatively normal levels again after the severe drought in 2018 (Brink, 2019). An example of grain pricing from Skåne county can be viewed in Table 4.1, including requested protein levels by the buyer.

Table 4.1 Lantmännen prices in Skåne 2019 for milling wheat, malting barley and animal feed (Brink, 2019), as well as requested protein levels (Lantmännen, 2019a).

Product/Grain	*Wheat (price/ton)*	*Barley (price/ton)*	*Protein level requested by buyer*
Milling wheat	1470 SEK	-	≥11 %
Malting barley	-	1550 SEK	10-11 %
Animal feed	1400 SEK	1300 SEK	N/A
Price difference	70 SEK	250 SEK	

For wheat delivered for food production, protein is an important factor and accounts for additional or deducted payment based on high or low protein levels (high being good) (Lantmännen, 2019a). Starch, falling number and specific weight also have levels for deducted or increased payments. All parameters (except for starch) have lower limits. If the average quality fall below these limits the grain is downgraded to animal feed or ethanol, lowering the price of the grain. This is a costly scenario for farmers who therefore strive to avoid it (Wågstam, 2020). Protein levels for one type of milling wheat can be viewed in Table 4.2.

Table 4.2 Example of protein surcharges for one type of milling wheat (Lantmännen, 2019a).

Protein level (%)	*Price regulation (SEK/ton)*
>11.6	Addition of 10-50 SEK
11.0-11.5	Base level
10.5-10.9	Deduction of 10-50 SEK

<10.5	Downgraded crop

For barley, protein content is basis for payment since protein between 10-11 % is the optimal level for malting processes in beer production, which in turn is the most profitable purpose to sell barley for (Lantmännen, 2019a). For malting barley, price is only deducted if protein levels deviate from the narrow span - regardless if the protein level is too high or too low. Other parameters such as peel damage and specific weight are also basis of payment for malting barley. Too high or too low protein levels, as well as too high level of peel damage, result in the grain being downgraded. An overview of the base protein level and price deductions for malting barley can be viewed in Table 4.3.

Table 4.3 Example of protein surcharges for malting barley (Lantmännen, 2019).

Protein level (%)	***Price regulation (SEK/ton)***
>12.0	Downgraded crop
11.1-12.0	Deduction of 2-85 SEK
10.0-11.0	Base level
9.0-9.9	Deduction of 2-85 SEK
<9.0	Downgraded crop

Moreover, rye and oat have quality parameters as a basis only for deduction in payment (Lantmännen, 2019a). Rye has specific weight and falling number as basis for deduction or degradation. Oat only have low specific weight as basis for price deduction. Hence, protein content is not a determinant for pricing of these grains.

4.2 On-Combine NIR Technology

As mentioned in segment 2.3.1, NIR technology can measure quality content in grain, such as protein or water levels (O'Donnell et al., 2014). NIR technology has recently become less expensive and mobile, spreading to agricultural production facilities (Wågstam, 2020). Today it is primarily used to measure contents of chopped grass, hay bales, and manure from livestock. This is because these products usually have varying and unclear content such as level of nitrogen.

Traditionally, grain quality has been unknown for the farmer until the grain has been delivered to the buyer's reception site and there tested by measuring a sample (Wågstam, 2020). However, measuring grain quality continuously during the harvest could be achieved by installing NIR sensors on the combine in the elevator stage, so called on-combine NIR technology. A picture of a combine harvester can be viewed in Figure 4.3 below, where the NIR sensor could be placed between stage 15 and 16 (in the elevator before the tank). The on-combine application of NIR is not yet implemented at farm site in Sweden.

Quality parameters that are possible to measure with NIR technology for grain include moisture (water level), starch, protein, ash, fat and fiber (Wågstam, 2020). A NIR sensor installed on the combine could include measurement of all these parameters, or measure a few of them.

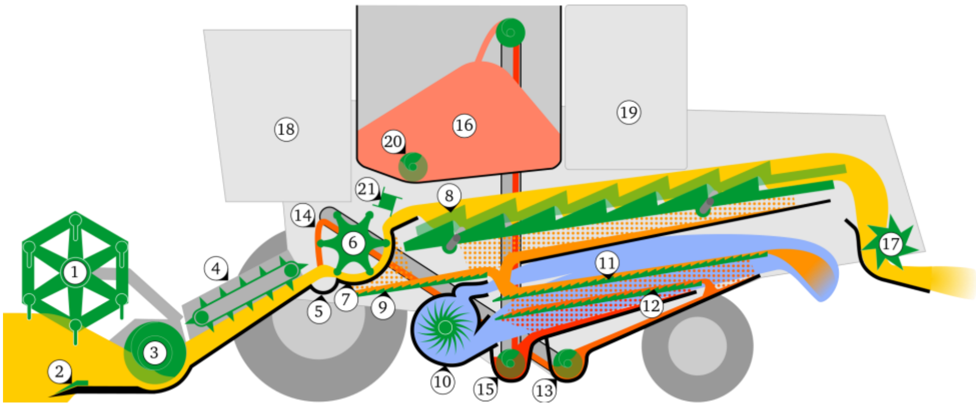

Figure 4.3 Combine design where sensor for quality measurement could be installed between stage 15 and 16 (in the elevator to the tank) (Wastlhuber, 2006).

4.2.1 **Potential Benefits and Obstacles**

On-combine NIR measurement could generally generate two values for the farmer: detailed grain sorting and data insights (Wågstam, 2020; Algerbo, 2020: Dalemar, 2020).

Firstly, early quality measurement could potentially enable farmers to divide their harvest in separate batches based on quality levels, to ensure adequate payment for high quality grain (Wågstam, 2020). However, combines only have one tank and many farms have a limited number of silos for storage and carriages for transport, implying logistical limitations for keeping grain batches separated. As previously described, the price the farmer obtains for its harvest depend on the protein levels and what the grain is to be used for. The primary value for the farmer to measure quality with an on-combine NIR sensor is thus reducing the risk for grain degradation of the whole harvest by differentiating and storing batches separately. However, concerns have been raised whether separation is practically possible due to limited transport and storing capacity at farm site.

Secondly, measuring quality levels in real-time on the combine combined with GPS-technology could also generate a map of the quality across the fields. In particular, a map of the protein levels can be produced (as seen in Figure 4.4), bridging a gap of knowledge between inputs and outputs in the grain production process (Wågstam, 2020). A protein map could be a receipt on how well fertilization has been distributed (Martinsson, 2020). Today, yield maps can be generated by measuring volume and water levels during harvest on the combine, but lack other quality parameters (Wågstam, 2020). Further, data from on-combine NIR measurement could be combined with farm data generated by other PA technologies. This is technically possible, but knowledge on how to turn all data into an understandable decision support is lacking (Martinsson, 2020).

In addition, on-combine NIR measurement is not only valuable for the farmer, but for the entire grain value chain if it is to spread (Wågstam, 2020). If quality data generated by the technology would be shared between sellers and buyers it would be possible to optimize the value chain, for example through better planning at the recipient stations. The adoption of the technology and associated data sharing would result in logistical benefits and potentially also reduce the need for quality testing at laboratories before deliveries (Strömberg, 2020; Wågstam 2020).

As described in the theory segment, one obstacle for the spread of on-combine NIR has been the need for continuous calibration, demanding service and connectivity for automated updates of software from the tech provider. Although connectivity of the sensors is not an obstacle today, calibration still remains a challenge (Martinsson, 2020; Algerbo, 2020). There is a concern regarding who should provide the calibration, which could require cooperation between different stakeholders (Algerbo, 2020). Another obstacle is that the technology would take too much time away from the farmer during harvest due to the long time needed for data collection, analysis and decisions making.

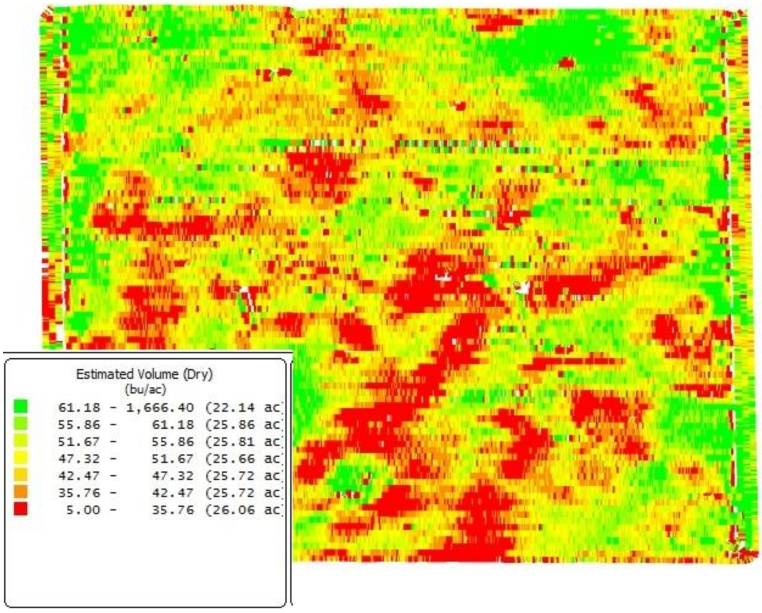

Figure 4.4 Example of a yield map of the field (ISUcyGrain, 2013)

4.2.2 **Market Status**

Even though the concept of on-combine NIR measurement was proved roughly twenty years ago, no commercial products are out on the Swedish market as of today (Wågstam, 2020). The main use for NIR measurement on farm site today is not for measuring grain quality, but to measure the content of manure or grass. For this purpose, some farmers have a stationary NIR measurement device at the farm. It would be possible to measure grains in these devices if calibrated, however since the equipment is stationary, on-line measurement is not possible.

There are some uncertainties around why it has taken such a long time for the on-combine application to get to market, but except for a lack in demand it could be due to technological difficulties (Eriksson, 2020). It has taken time to make the equipment accurate enough in the very rough environment on the combine. The hot and dusty environment is far away from a clean laboratory environment where most NIR measurements are done today.

One of the first commercial products for on-combine NIR measurement, AccuHarvest, was released in the early 2000s by the company Zeltex and measured the quality by sampling grain 4-5 times per minute (Zeltex, n.d). A picture of the product implemented on a combine can be viewed in Figure 4.5. The American company Zeltex was acquired by the Italian company Dinamarca Generale at the end of 2019, merging NIR technology for precision agriculture capabilities of Zeltex with digital and cloud competences of Dinamarca Generale, with the ambition to provide system-wide integrations (Dinamarca Generale, 2019). Furthermore, the Argentinian firm Tecno Cientifica also offers a system using NIR sensors to screen grain quality in the combine (Andrews, 2016). The Australian company Next Instruments offers CropScan 3300H, a stand-alone device measuring protein, oil and moisture which can be installed on combines from different brands (Next Instruments, n.d.). The price on the market for an on-combine NIR sensor is roughly 130-170 thousand SEK today (Wågstam, 2020; Eriksson, 2020).

Figure 4.5 NIR sensor placed on a combine (Farmer 21, 2019).

The country where on-combine quality measurement has been furthest commercialized is Australia where New Holland has successfully launched their on-combine NIR measurement device NIR-Exact (Eriksson, 2020). The solution is portable and can be placed in other New Holland machines than combines, though not in machines from other brands. The success in Australia is mainly due to two reasons according to Jonas Eriksson (2020), sales manager of combines in Sweden for New Holland. Firstly, since the climate is warm, the crop is dryer at harvest than in Sweden, eliminating the need for a drying process. Thus, the grain require less processing and is therefore sold to the buyers directly during harvest, making real time quality measurement relevant. In addition, while the Swedish market is dominated by a few grain buyers, the Australian market is more fragmented which increase the need for transparency. No on-combine NIR solution is distributed in Sweden today, although New Holland plans on releasing NIR-Exact on the Swedish market in the near future (Eriksson, 2020).

4.2.2.1 Substitutes

A competing solution for measurement of grain quality at farm site that is present on the Swedish market today is the handheld NIR device GrainSense (GrainSense, n.d.-a; Ryberg, 2020)). It is not placed on the combine, but is instead portable and handheld making it possible to take it out on the field. It was released by a Finnish company and is used by taking a sample of about a dozen kernels and scanning them inside the device. Sampling the kernels can be done both before and after the harvest, giving indications for when to harvest and also giving an indication of the quality in different locations on the field. However, it does not allow for real time measurement in the combine and thus does not generate a protein map of the field. A picture of a GrainSense device can be viewed in Figure 4.6.

Another competing solution is a beta version of protein forecasting for wheat based on satellite technology provided through the digital precision fertilization tool CropSAT (Birkebæk Jensen, 2019). The beta version was introduced in 2018, and estimates an exact protein percentage for a pixel of 10 x 10 meters of the field, though only showing the pixels in different colors relative to each other - high, medium or low protein percentages.

Figure 4.6 The handheld quality measurement device GrainSense. (GrainSense, n.d.-b)

4.3 Lantmännen

4.3.1 The Cooperative Company

Lantmännen was founded in 1880 as a cooperation for Swedish farmers (Lantmännen, 2019b). Today, Lantmännen is the biggest player on the Swedish agricultural market, owned by 25 000 Swedish farmers, which makes up around 40 % (Jordbruksverket, 2017) of the total number of farmers in Sweden. Except for being a cooperation, the main focus of Lantmännen is to be a business partner for the farmers and to support the agricultural sector through R&D concerning the future of food, bioenergy and farming (Lantmännen, 2019b). An outspoken goal is to be the main business partner for farmers.

The company operates mainly in northern Europe, has around 10 000 employees and a revenue of 45 billion SEK, where the majority of the revenue comes from the grain division of Lantmännen (Lantmännen, 2019b). Lantmännen is the dominant player within grain in the Baltic sea area, making it an interesting company to investigate when looking at the grain industry. On the Swedish market, Lantmännen is the biggest buyer of grain, as mentioned earlier (Björk, 2020). Further, Lantmännen operates the complete grain value chain from "field to fork", which gives the company knowledge and experience within each part of the chain (Lantmännen, 2019b).

4.3.2 Digital Technology Focus

Lantmännen has several ongoing projects within new technology and digital innovation, mainly coordinated through the corporate-wide digital business development unit (Åsman, 2020).

One important digital platform that is offered by Lantmännen is called LM2 and connects farmers and Lantmännen (Lantmännen, n.d.-b). The platform bundles the services from Lantmännen in a digital format and facilitates logistics and communication. On the platform, data can be shared and farmers can for example access current grain prices, book times for grain pickup or get up-to-date information about pick-up locations.

Lantmännen offers a program for environmentally sustainable crop farming called "Klimat & Natur", that includes a requirement for precision agriculture technologies (GPS and N-sensor) (Lantmännen, n.d.-c; Heiskala, 2020). The program also includes an indirect traceability for the end consumer that is made according to the mass balance approach. Hence the exact flour you buy in the store might not be produced through "Klimat & Natur" but Lantmännen assure that an equivalent amount of flour is being produced according to the program, similarly to green energy. Sustainability is one of the largest focus areas for Lantmännen (Lantmännen, 2019b). The largest environmental impact of Lantmännen is nitrogen that is released from the soil at farm site in the early steps of the grain value chain.

4.3.2.1 On-Combine NIR Technology Focus

A few research projects are ongoing about NIR-measurement on the combine (Dalemar, 2020; Wågstam, 2020). For example, a mini harvester with NIR is tested at a test facility in southern Sweden. Also, workshops with farmers are conducted, to try to get input on quality measurement at farm site (Dalemar, 2020).

Lantmännen could gain large value from quality measurement early in the value chain (Dalemar, 2020; Strömberg, 2020). Since Lantmännen operates the entire value chain, knowing the quality of the grain in an early stage would make it possible to optimize the rest of the chain. In addition, the whole value chain would be more rapid and sustainable due to that Lantmännen would know where to steer the grain directly, without taking unnecessary detours (so called "grain tourism") (Strömberg, 2020). It would therefore be of great interest for Lantmännen if more farmers measured quality at farm site, and in extension shared the data, preferably automatically.

4.3.2.2 Dataväxt and Digital Crop Management

As a step towards a more digital strategy, Lantmännen acquired the majority share of Dataväxt, the leading player on the Swedish market within digital crop management services, in 2016 (Jordbruksaktuellt, 2016). Dataväxt aims at providing farmers with new technology, independently of certain machine brands, thus they offer technologies that are not constrained to a certain machine brand (Martinsson, 2020; Dataväxt, n.d). They offer both hardware, software and services (including calibration), and a part of the offering is to help farmers make their technologies more compatible. Dataväxt sell all their hardware today (thus no leasing). Johan Martinsson (2020), head of market and business development at Dataväxt, points out that service is especially important for them since new agricultural technologies are not always "farmer friendly".

Dataväxt is the exclusive distributor of the N-sensor in the nordics (Martinsson, 2020). Moreover, Dataväxt use GrainSense to measure protein in the drying facility for advising. Furthermore, they participate in the CropSAT project to forecast protein content on the fields through satellite pictures. Lastly, Dataväxt has also looked into selling an on-combine NIR solution, but consider the price being too high for it to be realized.

The largest competitor for Dataväxt is the Danish company Datalogisk (Martinsson, 2020). They both offer various services, including planning, documentation, analysis and steering machines (through assignment files) with the help of farm site data (Dataväxt, n.d.; Datalogisk, n.d.). Hence, digital crop management programs enables the farmers to store, sort and gain insights from the data collected at farm site, simplifying precision agriculture.

5 Results

This chapter contains a synthesis of the farmer interviews. The answers are grouped in several aspects that are presented without further analysis. The empirical findings in this chapter is discussed and analyzed in the next chapter.

5.1 Overview

The results can be structured around six main aspects: characteristics of the technology, farmer and farm characteristics, grain market and business, grain logistics, farm data and the cooperative stakeholder (Lantmännen). The dynamic between these categories can be viewed below in Figure 5.1. The double ended arrows show it is not a one-way relationship, but that the different aspects are affecting each other in a dynamic way. Farm data touch upon all other aspects.

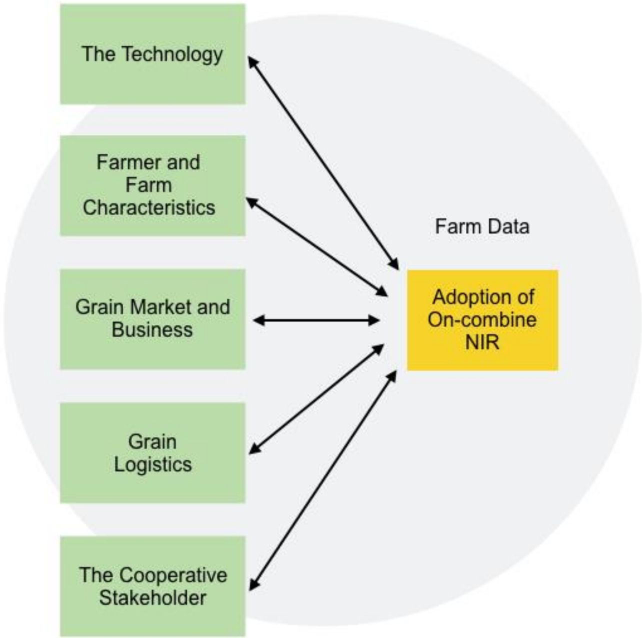

Figure 5.1 Overview of aspects affecting the adoption of on-combine NIR.

5.2 The Technology

5.2.1 On-Combine NIR Technology

The majority of the interviewees were familiar with NIR quality measurement as a general method while a third were familiar with the specific on-combine application of NIR. No farmers used on-combine NIR technology today. Around half seemed interested in trying this application, although with some hesitancy.

5.2.1.1 Values

The farmers identified mainly two values with the on-combine NIR-measurement technology: grain sorting and separation for increased revenues, and insights through detailed data on grain output. Some farmers also mentioned they see a value in using the quality data in combination with other farm data for future farming decisions.

The most important quality parameter was pinpointed to be protein. The most important grain type to measure was barley, followed by wheat, given that the classification of these crops and thus the price received is based on protein levels. A few farmers already managed to separate their grain by other methods than on-combine NIR, such as external tests or by measuring with the handheld device GrainSense.

5.2.1.2 Obstacles

The main hinders for the technology was considered being uncertainty about the return of the investment and logistical issues regarding separation of grain on farm site. Another big concern addressed doubts about reliability of the product. Some had experienced struggles with other new technology and expressed a wish for the product to be fully developed before going to market, to avoid interruptions in the already time pressured harvest period. A perceived lack of agricultural knowledge among technology developers was expressed, and that new technologies aren't always developed with the farmer utility ("bondenytta") in mind. It was mentioned that most obstacles could be overcome if the technology was profitable enough.

Since the on-combine NIR sensor cannot affect the quality itself, but just provide a confirmation of the quality, several farmers brought up how other technologies that affect earlier stages of the crop production are more highly prioritized.

Unavailability of the hardware on the Swedish market was not generally seen as an obstacle since it could be bought from abroad, though service and support, preferably from Sweden, was stressed to be important.

- *If I could defend the cost I would buy it immediately in order to understand how I can become a better cultivator.*

Farmer 4

- *The technology really has to work well if I am to skip my farmer intuition and trust a monitor, otherwise it is likely to be put away on the shelf.*

Farmer 10

Table 5.1 Summary of insights about on-combine NIR measurement.

Main values	1. Grain sorting 2. Data insight
Main obstacles	1. Uncertainty about return on investment 2. Logistical issues
Other concerns	Reliability of technology
Main relevance	Protein measurement for barley and wheat

5.2.2 Current Adoption of Precision Agriculture Technologies

The level of adoption of PA technologies (apart from on-combine NIR) varied between the farmers interviewed. So did their view on agricultural digital technology in general, as well as their view whether or not they were conducting precision agriculture at their farms. The majority had positive attitudes towards new agricultural technology in general. Roughly half pointed out some potential problems, mainly regarding cost and payback times for investments needed and compatibility with other technologies.

Roughly half of the famers in the study considered that they were pursuing some kind of precision agriculture on their farm. Many pointed out that it is a question of defining what precision agriculture actually means. All PA technologies described by the farmers where used in the cultivation step of the grain value chain, thus on the field. Worth noting is that not all farmers shared the same goals and ambitions with precision agriculture, aiming at optimizing different parameters such as volume and/or quality.

Some farmers spontaneously mentioned they had been considering investing in on-farm site quality measurement. For quality measurement of grain at farm site, two farmers, both classified as early adopters, were using GrainSense both for pre-harvest and post-harvest measurements.

5.2.2.1 GPS Auto Steering

All farmers (with two exceptions) had adopted GPS auto steering on their machines, and they expressed the value to be primarily improved working environment, and also increased efficiency on the field. Some mention they were hesitant towards the solution before, but were satisfied after trying it. One farmer pinpointed that GPS is the fundamental prerequisite for all precision agriculture technologies given that PA is location-based.

5.2.2.2 Precision Fertilization

A clear majority of the farmers used some solution for precision fertilization. The most common solution was satellite analysis through CropSAT. A few used satellite analysis through SOYL. Around 40 % used the N-sensor, and it was mentioned by several that they shared the device with neighboring farms. The reasons for adopting these technologies were mentioned being a more homogenous field quality at harvest and more control over the field quality, and thus increased profitability.

5.2.2.3 Participation in Research Projects

Two farmers had previously participated in early development phases of new precision agriculture technologies. One farmer had participated in development as an early user of yield mapping, the N-sensor, and was also early using positioning of equipment with signals from the Swedish shipping agency, before GPS technology was in place. This farmer had also participated in a research project using an on-combine NIR-sensor for quality measurement, and stressed that standardization is needed for this technology to spread in the future. The other farmer had been a part of the development of CropSAT and stressed that this technology did not matured until a full network of more precise satellite images was in place.

Table 5.2 Overview of the usage of PA technologies among farmers in the sample.

PA Technology	***Adoption among sample***	***Value perceived by farmers***
GPS auto steering	90 %	Improved working environment Efficiency on the field
Satellite analysis (CropSAT, SOYL)	50 %	Homogeneous field quality
N-sensor	40 %	Homogeneous field quality Real-time insights
GrainSense	10 %	Harvesting timing Grain sorting

On-combine NIR measurement	0 %	Grain sorting Data insight

5.3 Farmer and Farm Characteristics

5.3.1 Case Study Sample

The sample of the case study consisted of 22 farmers, who were all members of Lantmännen. The farmers were all based in south or central Sweden; operating in Skåne, Östergötland, Västergötland, Närke, Västmanland and Södermanland as seen in Figure 5.2. Most farmers operated mid-sized farms of between 300-600 hectares (ha). Three farmers operated farms of a thousand hectares and above, while four farmers operated less than 200 ha. The aged ranged from 33-75 years, the median being 51 years and the average 39 years. The distribution between gender was 21 men and 1 woman. All farmers had gone through some sort of agricultural education (with two exceptions) but the type of education varied largely, making it impractical to generalize.

Figure 5.2 Illustration of location in Sweden of the farmers in the sample.

5.3.2 The Farmer

5.3.2.1 Adoption Types

The farmers in the study were categorized as a certain adoption type based on the framework below in Table 5.3. The inclusion of PA technologies were based on the Swedish context and include: technologies for positioning and auto steering (GPS), for optimizing fertilization (N-sensor and CropSAT/SOYL) and mapping of the fields (soil and yield mapping).

Table 5.3 Criteria for farmer adoption types.

Adoption Type	***Characteristics identified from interviews***
Innovator	Extensive use of PA technologies. First with PA technologies. Expresses a will towards "being first". Have implemented on-combine NIR.
Early adopter	Extensive use of PA technologies. Early with PA technologies. Expresses a will towards "being first".
Early majority	Extensive use of PA technologies. Expresses hesitancy towards "being first".
Late majority	Moderate use of PA technologies. Expresses resistance towards "being first".
Laggard	No or little use of PA technologies. Expresses resistance towards "being first".

The distribution of adoption types in the sample, as distinguished by the authors on the basis of diffusion theory (Rogers, 1995), is presented in Figure 5.2. Thus, all adoption types were represented in this study but the distribution was weighted towards early majority.

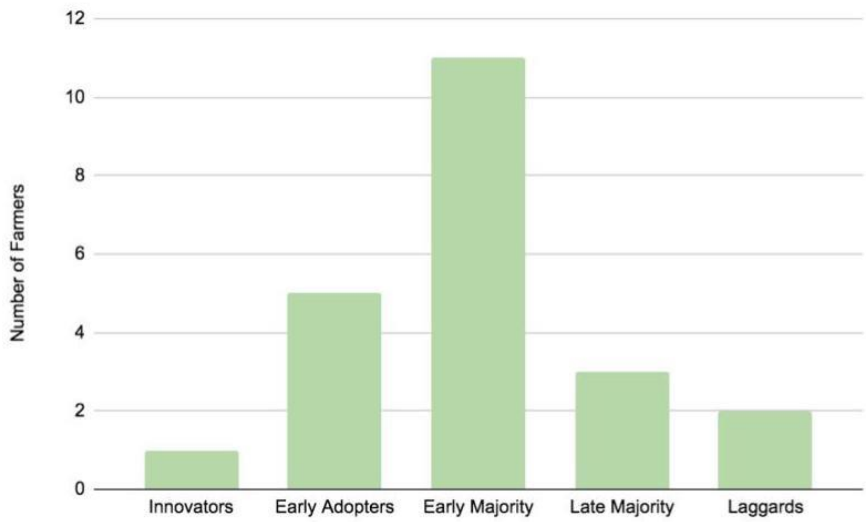

Figure 5.3 Overview of the adoption types in the sample of the study.

5.3.2.2 Technological Interest

Most of the farmers in the sample were positive towards new technological innovation, around a third stating that they had a clear interest in technology. It was pointed out that a technological interest could be the single most important factor for adoption of new agricultural technology.

5.3.2.3 Experience and Intuition

Most farmers brought up experience and sense of intuition as important when determining when to harvest and how to sort the grain according to quality. However, the trust in one's predictions varied. It was mentioned that most farmers can assure a good quality on their own fields by using experience, however that it has to be double checked through using technology and quality tests. Even though most farmers partially relied on their experience, there seemed to be consensus that new digital technology could make it easier, through making the work more comfortable, more efficient or requiring less to memorize. Another way in which PA technologies could help is by minimizing the need for experience. One farmer brought up that farms increasingly hire external workforce, creating an increased need for technology since the new personnel cannot rely on experience.

5.3.2.4 Age

Concerning age, many farmers speculated that younger farmers could be more rapid in the adoption of new digital technology and more positive towards data sharing, since they are more used to technology in general. However several pointed out that age is not an important factor and that it is risky to draw conclusions based on it.

- *Most farmers can steer inputs manually just as well as technology can, through experience on the fields, but technology lessens the need to always stay on top of things.*

Farmer 6

5.3.3 **The Farm**

5.3.3.1 Farm Size

According to most farmers, a larger farm could have more possibilities to implement new technology due to a better possibility to get back the investment. A few farmers expressed that very large farms might be less likely to try on-combine NIR measurement due to the risk of disturbing the efficiency in the logistics of the production. A farmer in the study operating 1500 ha said that they did not have time for subtlety. It was also mentioned that rather small farms could see a value in NIR-measurement on the combine if they are specialized in producing high quality crops.

5.3.3.2 Field Heterogeneity

The farmers mentioned that heterogeneity of grain quality could vary between farms, years and fields. Most farmers considered it hard to predict the grain quality from year to year, however there were different opinions whether the quality differed much within the same field.

- *You probably have to operate a farm of at least a thousand hectares for on-combine NIR to be relevant.*

Farmer 11

5.4 Grain Market and Business

5.4.1 **Technological Investments**

5.4.1.1 Investment Capital

Most farmers pointed out that the profit margins in the agricultural sector are small, and that profitability is the main concern of a farmer. The small margins have resulted in scarce investment capital and most farmers agreed that all new technology that is implemented needs to have a proven economical pay-back that is clear and easy to understand. Around a third of the farmers asked considered the price of on-combine NIR measurement to be too expensive. However, most farmers said that it depends on how long the pay-back is.

5.4.1.2 Bundling

Most farmers did not adopt technology individually, but in bundles when replacing something old. Many pointed out that they would not install on-combine NIR measurement on an old combine, but would consider it if it was an option when buying a new one.

5.4.1.3 Co-Ownership

A suggestion from one farmer on how to increase the possibility to invest in new technology within farming was to co-own the technology. In fact, several farmers in the study already leased other PA technologies such as the N-sensor. Co-ownership was pointed out as especially interesting for technology not needed each year, which was mentioned to be the case for on-combine NIR measurement.

5.4.2 **Grain Pricing**

The price levels of grain today was understood from the farmers to be controlled by the market, though there was a general feeling that they got paid too poorly and that larger margins lie in later stages of the grain value chain. The most essential aspect of the pricing appeared not to be the price itself but the price difference for varying qualities, especially between animal feed and grain for human consumption. It was pointed out that grain for animal feed pays less, and that it is important to ensure protein levels to avoid downgrading. It was pointed out that the pricing is different year to year and thus one cannot know how to get the most paid for the grain beforehand.

5.4.3 **Grain Business**

5.4.3.1 Location and End Product

What end product the farmer produced for, affected the relevance of on-combine NIR measurement. Several farmers did not intend to optimize protein. These were mostly producers of grain for ethanol production located closely to these facilities. However, most farmers in the sample produced high quality grain, mostly for flour and beer production.

5.4.3.2 Distance from Consumer

Several farmers expressed a gap of knowledge between the farmer and the consumer which in turn could affect the possibility to invest in on-combine NIR measurement. According to the farmers, the market does not always recognize and value grain quality, which prevents the buyers from paying for increased quality. They expressed that the money invested in new technology needs to be derived from a consumer demand. A couple of farmers also requested a traceability between the farmer and the consumer, so it is more clear for the consumer what quality they pay for.

5.4.3.3 Weather

Almost all farmers in the study mentioned weather as a factor affecting grain quality; several pointed out that it is the single most important factor within grain farming. Firstly, a feeling of being powerless was expressed by some farmers. They stated that no matter how much technology they used to assure a good harvest, in the end they had no control over how much it rains or how much the sun shines, making the possibility to affect grain quality with smart technology limited. Secondly, several farmers mentioned that it could be especially interesting to get a receipt on protein levels for years with extreme weather, to be able to optimize the sales of the lower yield.

- *Since the profitability is so low in farming, if we were to implement on-combine NIR to create a better product, it is important that the buyer transfers the profitability from increased revenues to the farmer that does the real work.*

Farmer 22

- *We need to make the consumer understand that there is a difference between grain and grain, today they lack that knowledge.*

Farmer 13

5.5 Grain Logistics

5.5.1 Internal Logistics

The farmers pointed out they would need to adjust their internal logistics processes in order for grain sorting based on on-combine NIR-measurement to be realized. Firstly, the farmers could not sort directly in the combine given it only has one pocket, though it was speculated that several pockets might be a reality in the future. However, it was mentioned that it could be possible to separate batches by harvesting the same field in several runs. Also, the carriages and the drying facilities were not generally adjusted to hold a large number of separated batches.

Storing capacity in the silos for separate batches was seen as another possible bottleneck, though many had capacity enough today and did some sorting. Having silos and thus storing possibilities could facilitate in optimizing sales timing, making sorting more profitable. One farmer pointed out that if he would know the quality already when harvesting, he could sell the low-protein grain immediately at harvest and store the high quality grain for when the price is optimal.

Several farmers viewed a NIR measurement device connected to the drying facility as a potentially better solution for quality sorting of the harvest, due to better sorting possibilities in the dryer.

5.5.2 **External Logistics**

Some doubts were raised regarding whether separation of grain could be retained in later stages of the value chain. A few farmers mentioned that the recipient stations do not have the capacity to accept highly separated batches of grain, which means sorting at farm site is not motivated.

- *The buyers are not willing to pay for the added value that I can deliver through quality sorting since they cannot receive it.*

Farmer 4

- *There needs to be serious profitability for me to lower the capacity in the whole logistical chain on the farm in order to keep batches separate.*

Farmer 18

5.6 Farm Data

5.6.1 **Data Usage**

5.6.1.1 Current Usage

Most farmers in the study did not analyze the data collected through their PA technologies over time, but rather observed it in real time and then stored it on a local computer or through a crop management service. Around half of the requested farmers used Dataväxt in some form (using it as a database or through the crop management program), and a couple used Datalogisk. Most farmers wished to gain more insight from their farm data, and especially sought to gain an understanding of what parameters affect the turnout of the yield, in order to make better decisions and become a better cultivator.

Some described data handling as a “hustle” because of difficulties in transferring data between various machines and systems that do not communicate with each other. A need for standards and compatibility was expressed.

5.6.1.2 Potential of Quality Data Usage

Concerning the quality data generated by on-combine NIR measurement, most farmers mainly saw a practical use of the data since it enables sorting. However, some also saw that the data could be combined with other farm data (such as yield mapping) to gain deeper insights, although it was mentioned that it has to be easy.

5.6.1.3 Data Security

Most farmers did not express any concerns at all regarding security issues when collecting quality data at farm site. Several explained that they did not see quality data on farm site as sensitive, while others were confused about the question of security issues in this context. Few farmers expressed what a leakage of data from farm could result in, but rather expressed that they do not know. A few farmers were still hesitant and mentioned the importance of owning the data themselves and the freedom to decide who they want to share it with.

5.6.1.4 Quality Data and Sustainability

It was also mentioned that using data from on-combine NIR measurement could have a sustainability role. One farmer explained that when comparing the added amount of nitrogen to the field with the protein content in the finished grain, it would be possible to calculate how much nitrogen is left in the soil. It was suggested that since excess nitrogen can cause environmental problems, minimizing nitrogen levels in the soil could be basis for some kind of environmental certification.

5.6.2 **Data Sharing**

A clear majority of the farmers were generally positive towards sharing quality data, a third being solely positive while several pointed out they would be positive if there was a clear purpose of sharing. Generally, most farmers in the study thought other farmers were more negative towards data sharing than themselves. Worth noting is also that a few early adopters in the study spoke for the data to be completely open, stating that the agricultural sector moves forward only when learning from each other.

5.6.2.1 Sharing with Neighbors

Most farmers were positive towards sharing quality data with their neighbors. They pointed it out as an opportunity to learn from each other, and since the quality data is site-specific for each individual farm, it is hard to take advantage of. Around a third of the farmers, that were negative, viewed their neighbors as competitors and the data as business secrets.

5.6.2.2 Sharing with Technology Providers

Most farmers were positive towards sharing quality data with technology suppliers. A few pinpointed the importance of contracts to prevent the technology supplier to take commercial advantage of it. Some also mentioned it depends on which tech supplier it is.

5.6.2.3 Sharing with Crop Advisors

The one external party that all farmers agreed on sharing data with was the crop advisor. In fact, it was viewed as absolutely necessary that the advisor gets access to the quality data to be able to give accurate advice.

5.6.2.4 Sharing with the State

Around half of the farmers were positive towards sharing data with the state or region, however a few stated it depended on the purpose. Almost as many were skeptical. The reasons were mainly a lack of understanding of the purpose of sharing, or a concern that the data could be used in regulating grain prices or through legal regulation.

- *I am happy to share my data with everyone if that increases knowledge about how to best produce grain. Data sharing is needed to gain new insights, and this aspect clearly outweighs the risk that the data could be used against me.*

Farmer 18

5.7 The Cooperative Stakeholder: Lantmännen

5.7.1 **Relationship with Lantmännen**

The farmers interviewed described their relationship with Lantmännen differently, though most saw Lantmännen as a major business partner and were neutral towards their ownership of Lantmännen. Some, mostly farmers elected for positions at Lantmännen local associations, expressed the ownership to be important and clearly valuable. Some expressed dissatisfaction with the membership since they considered their influence and benefits to be limited.

5.7.2 **Actions to Facilitate Adoption**

Regarding what role Lantmännen could play in increasing the value of on-combine NIR technology, the farmers brought up five ways:

1. Prove value through R&D
2. Make the technology available
3. Adjust pricing
4. Assure traceability of grain quality
5. Adjust logistics

Firstly, several farmers stressed the importance of proving the value of on-combine NIR measurement for the farmer ("bondenyttan") since it is not as obvious as the value for Lantmännen. Several mentioned that Lantmännen should ensure the reliability and functionality by pilot testing the use case before the solution reaches the farmers. Further, a request for Lantmännen to prove the complete business case, including extended values, was expressed.

Secondly, some called for Lantmännen to provide the technology. Dataväxt and Lantmännen Maskin were mentioned in this regard. Thirdly, higher payment for quality sorting and/or a more homogenous product was called for. Fourthly, enabling traceability of grain quality from field to fork was mentioned by one farmer as valuable for all stakeholders. Lastly, a few mentioned that Lantmännen could make logistical adjustments of the value chain; "It would be great if Lantmännen was automatically noticed [about our delivery and its quality] when we are on our way to Malmö" said one farmer.

5.7.3 **Data Sharing with Lantmännen**

Regarding sharing of quality data to Lantmännen, the farmers could be divided into two main groups: those who were completely positive and those who stated that it depends on the forms of such an agreement. Roughly half were completely positive, while only a couple were completely negative. Many wanted to share the data given certain conditions, for example if it would be safe enough, if there were contracts for selling grain to Lantmännen in place, or if the data sharing would generate value back to the farmer (such as payment). One farmer mentioned that he would only be positive towards sharing data if Lantmännen remains a cooperative. There was no clear connection between those that were negative towards data sharing with Lantmännen and their relationship with Lantmännen. It was mentioned that some farmers worry about that Lantmännen (as a buyer of grain) receives farm data through Dataväxt already today.

- *I don’t know where Swedish farming would be if we didn’t have a large cooperative company to rely on, it creates safety and they offer good services.*

Farmer 16

- *I see Lantmännen mainly as just a business partner, and I don’t see a real worth in being a member since I don’t get much better prices anyways.*

Farmer 11

6 Discussion

In this chapter, the result is discussed and analyzed. Firstly, an overview of found aspects and factors affecting adoption is presented. Each aspect is then discussed in individual segments, connecting it to the research questions and theory. Lastly, two scenarios for the adoption of on-combine NIR are presented.

6.1 Overview

There are several important factors found under each aspect in the result, affecting the adoption among farmers. Based on the results, the factors can be categorized as having a negative, positive or ambiguous influence on the adoption of on-combine NIR technology. In Table 6.1, the main factors, divided by aspects can be found. The colors indicate if the factors have a mainly positive (green), negative (red) or neutral/ambiguous (black) effect on adoption. Additionally, when looking at the adoption of other PA technologies, insights about adoption among Swedish grain farmers can be generated. The findings are discussed further in the segments below.

Table 6.1 Aspects and factors affecting the adoption of on-combine NIR measurement.

Aspects affecting adoption of on-combine NIR technology					
The technology	***Farmer and farm***	***Grain market and business***	***Grain logistics***	***The cooperative stakeholder***	***Farm data***
Clear perceived value (relative advantage)	Farmer interest in technology	Production for high quality end products	Difficulty for separation of grain on farm site	Possibility to increase value across the value chain	Difficulty to gain value through data handling and usage
Uncertain extended value	Farmer experience	Lack of price differentiation	Adoption of NIR application on the drying facility		Lack of security concerns
Unclear ROI	Farmer age	Scarcity of investment capital	Storing capacity on farm (silos)		Positive attitude towards data sharing
Availability of substitutes	Large farm size	Bundling of investments	Reduced need for lab tests		
Unavailability on Swedish market	Field heterogeneity	Lack of consumer demand for quality differentiation	Recipients inability to receive separate batches		
Doubts about reliability		Increased weather deviations			
Lack of observability					
No trialability					
Usage of other PA technologies					

6.2 The Technology

6.2.1 **On-Combine NIR Technology**

6.2.1.1 Values and Obstacles

Regarding the farmers' view on on-combine NIR technology, there is yet no general knowledge about the application among all respondents, which could affect the adoption rate at least in the short term.

The value for the farmers is twofold. Firstly, sorting the grain is seen as a way to gain better control of their commodity and potentially generate higher returns. Secondly, gaining insights and thus potentially improving as a plant cultivator is pointed out and can in the long run achieve higher returns as well. These benefits confirm the purpose of the technology earlier described, and shows that the farmer generally understands the values of the technology. Thus, lack of understanding of the values is not a hinder for the adoption of on-combine NIR technology.

The main concern is instead that it is not possible to realize the values. Though the farmers can clearly see the immediate value of the technology, the economic and extended values are viewed as uncertain. In particular, concerns about the return on the investment seem to hinder adoption. In addition to economic concerns, the extended values of the on-combine NIR application such as quality payment and decision support, are not viewed as practically possible today. The immediate and extended values, including the farmers uncertainty, can be viewed in Figure 6.1. The extended values will need to be proved, through for example specifications of payback-times and demonstration of use cases, for the farmers to embrace the solution and the adoption rate to increase.

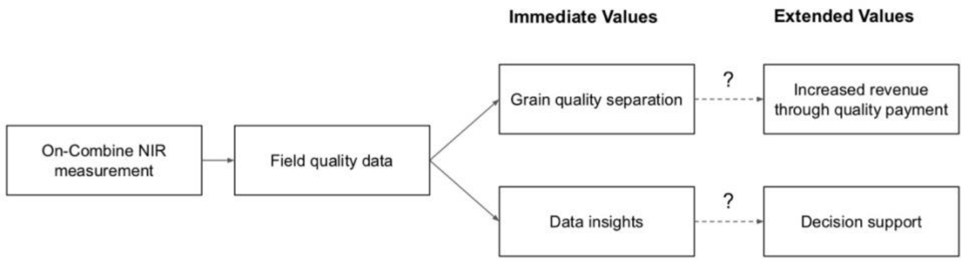

Figure 6.1 Overview of immediate and extended values for adoption of on-combine NIR, including question marks where the farmers finds uncertainty.

In addition to this, for on-combine NIR to give added value for farmers, other PA technologies need to be in place. The fact that quality measurement during harvest cannot affect the quality itself, but is just a receipt of the quality, means that it needs to be combined with other PA technologies that can affect input in the crop cultivation to retain maximum value. Thus, the innovation might be most relevant for farmers using other PA technologies. On the other hand, as PA technologies generally work towards homogeneity of fields, high level of PA adoption at a farm could reduce the perceived relevance of on-combine NIR-measurement. At the same time, many farmers conducting precision agriculture on a high level express they see a value in gaining insights through the quality measurement even though they have a homogenous quality level of the field.

Further, one can ask how much better opportunities for separation of the harvest the on-combine NIR measurement actually provides since several farmers already anticipate separation by lab-tests and/or tests by GrainSense. On the other hand, many farmers are not satisfied with the current possibilities to measure and sort, calling for more reliability and simplicity. In addition, since there are ongoing projects to predict protein content with satellite images, it can be assumed that new innovations to measure quality on farm site can emerge. If a forecast like that would become available, it would be seen as a substitute for the on-combine NIR measurement and thus affect the adoption rate negatively.

As for which quality parameters that are important to include in a sensor like this, protein is the most important factor since payment for the grain product largely is based on protein level. For a measurement solution to appeal to the farmers, protein data will thus need to be prominent and easy to handle and access. There seems to be a general request for tech developers to have the farmer utility ("bondenytta") more in mind. Some farmers perceive that the developers of PA technologies lack agricultural knowledge and that it results in a user experience that is not farm adjusted or easy-to-use, creating frustration. There is a vast need for tech developers to involve the farmer in creating better user experience for new PA technologies, to make the technologies more attractive.

The unavailability of the on-combine NIR hardware on the Swedish market is not necessarily an obstacle too large to overcome, as farmers already buy technology abroad today. However, it can be assumed that this mostly is the case for innovators and early adopters where the interest in new technology is big. Since there still seems to be a large dependency on local resellers, due to service and maintenance needs and importance of personal contact, it is important to offer the technology on the Swedish market to increase the adoption on a broad scale.

6.2.1.2 Five Characteristics of Innovations

Looking at on-combine NIR measurement through Rogers five characteristics of innovations, the characteristics indicate differently for the speed of adoption. The evaluation has been made through limiting the on-combine NIR solution to the hardware and software that enable quality sorting and simple data analysis such as generating protein maps at farm site, hence extended values across the value chain are not included. While relative advantage would have a positive impact on the adoption, the impact of compatibility and complexity is more ambiguous. The aspects which appear to slow down the adoption of the innovation are observability and trialability. A summary can be viewed in Table 6.2.

As reliability is crucial to many farmers, it is important that technology is not malfunctioning when launched. Previously, technologies lacking standards or not even being fully developed have been acquired by several farmers which has been expensive and complicated. Many farmers do not want to be a part of experiments.

The view of the reliability of the on-combine NIR application will remain unclear until adoption takes off on the Swedish market. If the technology is viewed as reliable, the willingness to adopt it could increase, since reliability is found to be such a crucial aspect. The five characteristics of innovations, presented by Rogers, lack the perspective of reliability and therefore it has been added to the analysis in Table 6.2 below.

Table 6.2 Rogers five characteristics of innovations applied to on-combine NIR-measurement, complemented with reliability.

Aspect	*Context and Interpretation*	*Effect on Adoption*
Relative advantage	No other solution allows for on-line, real time, highly detailed quality measurement. Therefore it has relative advantage compared to other quality measurement solutions at farm site such as lab tests, GrainSense, stationary NIR devices, relying on experience or no measurement at all.	Positive
Compatibility	The technology itself is compatible with current routines and other technologies currently used in the combine. However, necessary extended actions, such as quality sorting and increased data handling require logistical and behavioral changes.	Ambiguous
Complexity	The solution is not hard to grasp technically, however the usage can be considered complex due to logistical and data competence needed to gain value from it. A good user experience is needed.	Ambiguous
Observability	Low visibility due to the difficulty in observing the results from the technology. The use is in a closed environment on farm site, and the benefits requires advocacy from the farmer to be visible.	Negative
Trialability	Not possible to experiment with the technology on a limited basis today.	Negative
Reliability	Viewed as crucial by the farmers. High reliability could have a positive impact on adoption.	Unclear

6.2.1.3 Product Innovation Categories

When looking at product innovation categories (Gourville, 2006) several conclusions can be drawn. Depending on how on-combine NIR technology is used, it can require more or less behavioral changes. If the technology is limited to the hardware and software that is installed in the combine, the behavioral changes needed for the farmer are low since the farmer already use technologies in the combine today. The on-combine NIR technology does not require any certain process or maintenance but rather passively provides the farmer with numbers. However, when extending the solution to include quality sorting and data analysis, the behavioral changes are big. Quality sorting and data analysis are not in the general farmers routines today and would require additional investments, new routines and new knowledge. Therefore, to be able to gain the complete value from the technology, behavioral changes are big.

The degree of product change is high. There is no other technology that allows real-time on-combine quality measurement of grain. Therefore it is a unique application of existing technology. The combination of a high degree of product change and behavioral change makes the innovation a long haul. Being a long haul could mean a slow but steady adoption rate and in accordance with Gourville (2006) stakeholders such as tech providers should brace for slow adoption.

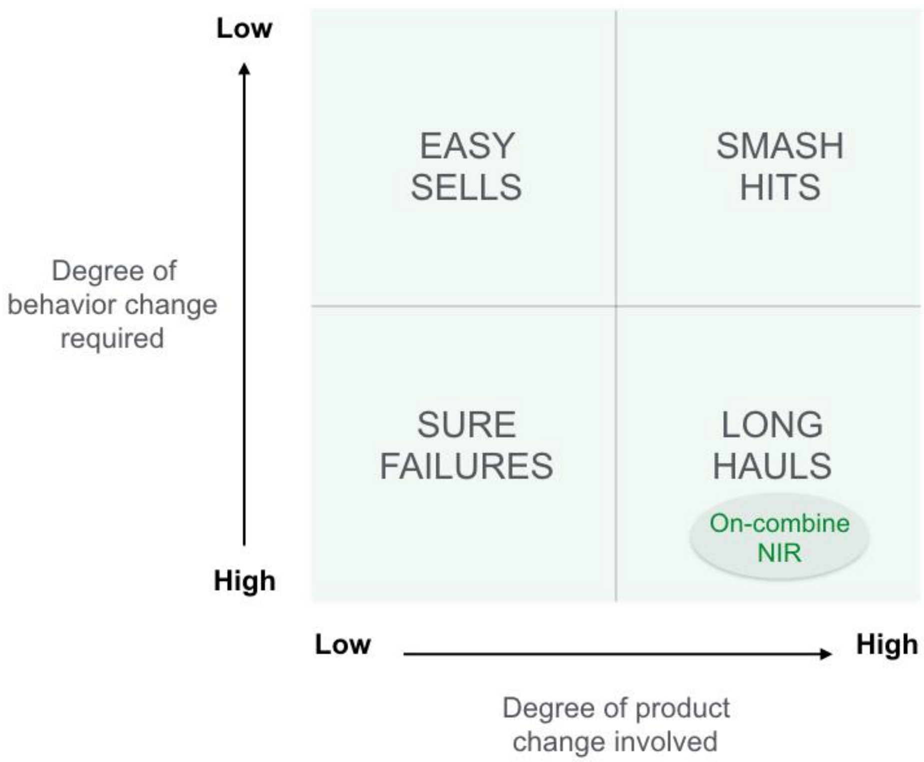

Figure 6.2 On-combine NIR placed in Product Innovation Categories (Gourville, 2006).

6.2.2 **Current Adoption of Precision Agriculture Technology**

Concerning the farmers use of PA technologies in general, the farmers show some confusion about the meaning of precision agriculture. Despite this, PA technologies seem to be widely used among Swedish farmers. Studying the adoption of PA technologies used by the farmers today gives an indication on the potential adoption of on-combine NIR technology. The adoption of the PA technologies used by farmers in the study seem to follow Rogers' adoption curve. The technologies can be placed in the process and be connected to certain Swedish grain market adoption characteristics, as seen in Figure 6.3.

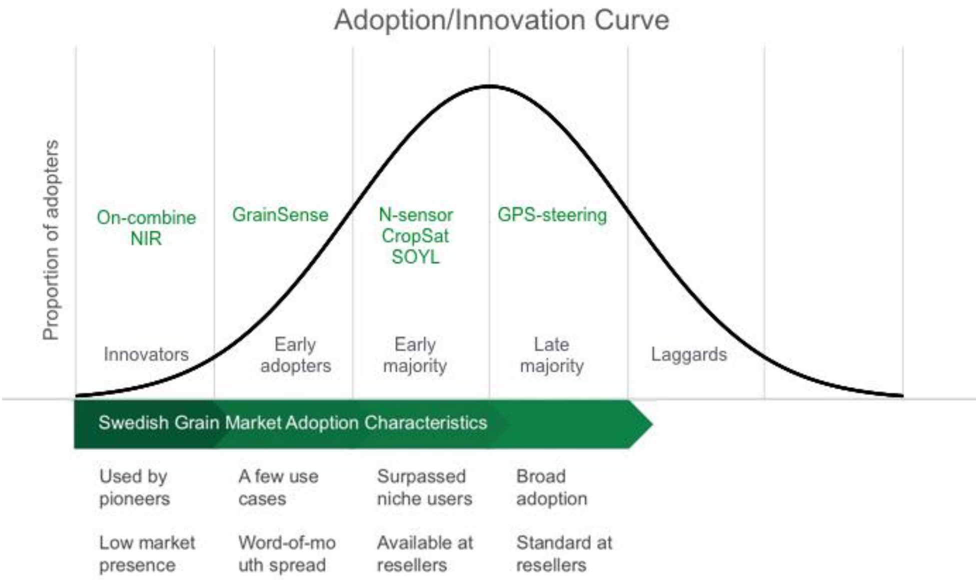

Figure 6.3 PA technologies placed in the Adoption Curve, including characteristics for the Swedish grain market.

6.2.2.1 GrainSense

GrainSense enables insight for finding the right timing to harvest and measure grain quality post-harvest. The product has been on the market for some time and is at the early adoption stage where concrete use cases are in place and is spread by word-of-mouth effects. Furthermore, using GrainSense can be viewed as a substitute to on-combine NIR measurement with an added value that it is possible to measure grain quality on the field before harvest for the perfect timing. The adoption rate of GrainSense may thus affect the adoption rate of on-combine NIR measurement since it provides similar values.

6.2.2.2 GPS Auto Steering

For GPS auto steering, the value lies in both the improved working environment and gained efficiency on the field - saving the farmer time and money. These clear and tangible values are the reason this innovation has managed to achieve broad spread rapidly among farmers in Sweden. The success of the GPS auto steering solution was not completely obvious when launched, but took off after pioneers that had tried the innovation spread the word through word-of-of mouth to neighboring farms. GPS auto steering has thus gone from being a niche product to being integrated in many new vehicles. This shows the importance of references from innovators, observability as well as trialability for a new innovation to succeed.

6.2.2.3 Precision Fertilization

Regarding the N-sensor, it enables real-time screening of the crops and thus up to date input for precision fertilization for generating a more homogenous field and in extension higher profitability. It has bridged the early adopter phase and is today available at resellers. As shown in earlier research, the N-sensor has a less direct and tangible value compared to for example GPS auto steering, causing the adoption process to be slower. The on-combine NIR application has similar characteristics, which could mean that it will have a similar slow adoption pattern. Since the N-sensor has managed to bridge the innovator and early adoption stages, this could also be the case for on-combine NIR measurement.

Satellite analysis tools like CropSAT and SOYL also enable precision fertilization, with similar values like the N-sensor, but lack real-time screening. The adoption process for these tools has seen a higher intensity of diffusion compared to the N-sensor which could be due to lower cost and ease-of-use (e.g. it does not require a screening with tractor).

6.2.2.4 Adoption Patterns

It is important to note that on-combine NIR measurement does not necessarily need to follow the exact adoption patterns as other PA technologies in order to be successful. It could spread among a smaller target market, for example large or niched high grain quality producers, meaning a spread with a smaller magnitude of the adoption curve. Moreover, both the N-sensor and GPS auto steering were associated with risks and doubts among farmers before being implemented by innovators. This could be the case for on-combine NIR measurement as well.

6.3 Farmer and Farm Characteristics

Concerning farmer and farm characteristics, our study confirm what has been found in previous research; it simply matters who you are and what kind of farm you operate for the adoption behavior. Moreover, the farmers current adoption of PA technologies show the general adoption patterns on the Swedish grain market.

6.3.1 **The Farmer**

6.3.1.1 Technological Interest

Interesting for this study is the importance of an interest in technology, which is pointed out by several farmers as the most important factor. The adoption of new agricultural innovations in Sweden seems to be catalyzed by a few farmers that have a big general interest in technology and become innovators. These then act as advocates for the new technologies they adopt. Since Swedish farmers are relatively few, these innovators play a big and important part in spreading new agricultural technology. Some of the early adopters in the study did not even specify the reasoning behind them wanting to adopt on-combine NIR measurement, but simply stated that they were interested because they wanted to "know it all", which emphasizes the importance of interest. This is in line with other European research, that points out the importance of optimism for adoption (Barnes et al., 2019). However, interest can be dependent on other variables, such as age or education, making it hard to measure, and more research is therefore needed within this area.

6.3.1.2 Experience and Intuition

Another interesting finding is the importance of intuition and experience, and the linkage to technology. It seems like most farmers still largely rely on the feeling they get when harvesting, but what parameters they look at is unclear, even if they vaguely mention color of the crops or how heavy the combine feels. One noticeable finding is that even though most farmers agree on that PA technologies lessen the need for experience, it does not seem like the farmers who considered themselves very well at estimating grain quality through experience are less interested in on-combine NIR measurement. It would be easy to assume that farmers trusting their experience would feel less of a need to implement PA technologies, but this does not seem to be the case. However, the adoption of PA technologies could decrease the need for experience. It was mentioned that farmers increasingly hire external labor, which might lead to that someone with little or no experience operate the fields in the future. If this trend continues, the need for PA technologies could increase, due to a necessity to minimize the need for experience.

6.3.1.3 Age

When looking at age, the findings in this study supports former research (Borges et al., 2019). This means that one should be careful when drawing conclusions between age and adoption of new technology, since it doesn't seem to be clearly related. Important to note is that this research does not statistically investigate this issue but rather take the perspective of the farmers view of age.

6.3.2 **The Farm**

6.3.2.1 Farm Size

The farm size could have a negative curvilinear relationship with adoption of new technology as see in Figure 6.4. Thus, the larger the farm is the easier it is to invest in new technology, but if the farm is too big the farmer might be less likely to try new innovation due to that the farm is run like an industrial production company and therefore more risk averse. This relationship needs to be tested through further research, since this thesis cannot statistically prove it.

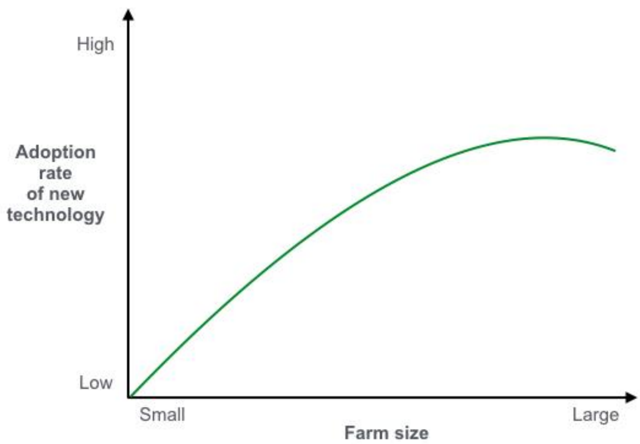

Figure 6.4 A schematic illustration of the relationship between farm size and adoption of new technology.

6.3.2.2 Field Heterogeneity

Each farm has different conditions regarding field heterogeneity. It can for example depend on farm location or farming inputs. It could be assumed that farms with large field heterogeneity could benefit from on-combine NIR measurement since it gives them a receipt on how it varies. Further, if a farm has homogeneous fields that do not vary much between years and fields, the general need for PA technologies could be lower. However, since no farmers measure quality on the combine today, full insights of field quality and heterogeneity remains unclear. Thus, how much this aspect affects the adoption of on-combine NIR is indistinct.

6.4 Grain Market and Business

6.4.1 Technological Investments

6.4.1.1 Investment Capital

It is clear that running a business within agriculture is unlike many other industries. The expressed economic scarcity within grain farming in Sweden could be a large hinder for new technologies to be adopted, simply because the farmers cannot afford to take economic risks with investing in something that is not fully developed. This emphasized the need to always prove the economical feasibility when introducing new technologies to grain farmers. The investment of on-combine NIR measurement might be hard to defend in a low-margin industry. Before there is a clear, understandable and tangible economical value realized by adopting the technology, the adoption will be slow among the majority of the grain farmers.

6.4.1.2 Bundling

The farmers seem to invest in bundles. This could be due to that the investment in on-combine NIR technology feels less weighty when bundled together with other technologies, or that a discount is expected when making a large investment. Hence, what innovations are adopted seem to depend largely on what technologies the tech providers put on the tractor or combine. This could mean that there is a possibility to make a technology push for on-combine NIR measurement by targeting farmers that invest in a new combine.

6.4.1.3 Co-Ownership

Co-ownership or leasing different technologies could be a way to make the investment burden lower. Several famers mentioned that they lease or share equipment today, which reflects the business model focus on leasing within agriculture. NIR measurement might not be needed each year for instance. However, it is likely to be needed during years with extreme weather for most farmers, which might make it difficult to co-own since there is a risk that the needs overlap for several farmers. Co-ownership and leasing is still an option that can facilitate adoption due to a lower requirement of investment capital.

6.4.2 Grain Pricing

As mentioned before, the farmers express clear understanding that the technology enables grain sorting, however they do not consider the grain price justifying the investment. When looking at on-combine NIR measurement, it is rather the differentiation of the pricing than the absolute price that does not support the adoption. Although the pricing is differentiated today, a more detailed classification could make it more valuable for the farmer to sort their grain and further to invest in on-combine NIR measurement. Another large obstacle is that even though it might be possible that the buyers pay extra for sorted grains, what will the price premium be based on? An option could be to not only base grain pricing on the average of the grain batches, but also consider deviation in the samples when pricing.

6.4.3 **Grain Business**

6.4.3.1 Location and End Product

The result showing that on-combine NIR technology is mostly relevant for farms producing malting barley and milling wheat has a clear connection to protein precision. This indicates that new PA technologies can have more or less relevance depending on what end product is aimed at producing, something that in extension could affect the adoption.

It was found that the geographical position can affect what innovations are relevant and how they are adopted, due to the various demands for different grain qualities across Sweden. In some places it is more profitable to produce bulk while high quality grain is rewarded in other places, which affect what technologies are relevant. This could mean that the strategies for tech providers or other stakeholders, such as Lantmännen, should vary depending on location when introducing certain technologies on the market.

6.4.3.2 Distance from Consumer

It is expressed that the communication between the farmer and the end consumer is poor. The demand from the end consumer affects the demand from the grain buyers, which in turn affects what the farmers produce and what technologies they need. Some farmers believe that if the end consumers would be more informed, they would value grain quality and be ready to pay more. Today, no direct traceability is possible although indirect tracing through the mass balance approach (like through the Lantmännen program Klimat & Natur) is made. A direct traceability might be possible in the future through solutions like blockchain, however if this would result in a better communication between the farmer and the end consumer, and in turn lead to the consumer making more conscious decisions, is yet to be studied.

6.4.3.3 Weather

The one factor that overshadows all else within grain farming is the weather. No matter how much technology is implemented at the farm, the unpredictability of the weather cannot be changed (yet). This uncertainty can make the adoption rate within agriculture unpredictable. Extreme weather can act as a catalyst for adoption of new technology. As seen in the adoption of the N-sensor, it can be easier to understand the value of a new technology when the benefits are pushed to the extreme or if farmers without the technology suffers loss. Like the N-sensor, that got a boost after a year of extreme weather, the key to large adoption of on-combine NIR measurement might be surprising weather conditions that makes it easier to understand the value of the technology. Farmers experiencing such extreme weather might be more likely to adopt innovations that facilitate forecasting and steady quality levels. Although, in short term, deviating weather such as the drought of 2018 can result in lower adoption rate due to limited investment possibilities caused by economic loss. Furthermore, climate change might lead to less predictability in the weather and more extreme conditions, which can increase the importance of PA technologies that stabilize and evaluate grain quality and yield.

6.5 Grain Logistics

6.5.1 **Internal Logistics**

Regarding internal logistics, there are adjustments needed for the on-combine NIR technology to be valuable to the farmers through sorting. These logistical setups are largely unavailable for the farmers today. Sorting in the combine tank is not possible, and while separation is possible in later stages, it demands large investments for most farmers. This implies that the technology will have to provide even larger returns to cover also for the logistical investments apart from the initial technology investment. This is an obstacle for adoption. Measurement at the drying facility might therefore be a more attractive option, given it could be logistically more easy to sort. If a solution like this is to be developed, a large portion of farmers would view it as the preferred option, which would naturally affect the adoption of the on-combine NIR application negatively. Whether NIR measurement in the dryer is a viable alternative remains unknown, thus further research is needed to this field.

Moreover, farms that sell grain directly during harvest could have more value of on-combine NIR measurement than the ones who mainly store in silos to sell later. This is because the detailed quality data generated from the field can be used to optimize the selling during the time pressured harvest. When storing the grain in silos, several batches have to be mixed in order to fill up the silos, which hinders grain separation and thus makes the on-line measurement unnecessarily detailed. On the other hand, farmers with storing capacity are enabled to sell certain qualities of grain when the supply and demand balance generates a favorable price, perhaps making it easier to justify investments in separation of grain qualities. It is important to note that separate storing of grain needs to be weighed against desired level of storing capacity and utilization to avoid suboptimization. Overall, the silo system does not support detailed quality separation due to inability to contain separation.

Quality measurement at farm site could make the value chain more efficient, through reducing the need to send samples from farm to laboratory tests. However, since the need to get a correct falling number through lab analysis remains for wheat and rye, and that it is done in the same facilities as the lab NIR measurement, these improvements would be limited.

6.5.2 **External Logistics**

As for external logistics, some farmers view that separation of grain needs to be retained even after the farm (hence in later stages of the value chain), in order for the separation to be valuable. The farmers view that the buyers do not have capacity to contain separation in the recipient stations, making it pointless to sort at farm site and thus affecting the relevance of on-combine NIR measurement negatively. On the other hand, the purpose of separating grain later in the chain can be questioned in terms of who actually needs the separation. Farmers do get paid premium for higher quality already today, even though batches with differing qualities are mixed later on anyhow. The end consumer does not demand separation of quality, as of today. Hence, the main value of measurement and separation can be realized in middle stages of the value chain where players (such as Lantmännen) could improve their control, precision, and optimization. Therefore, it could be argued that the demand for the technology should be derived from the stakeholders getting the main value, being the intermediaries rather than the farmers or the end consumers.

6.6 Farm Data

6.6.1 **Data Usage**

There seems to be a large wish to get insights from data among Swedish grain farmers in the study. Much farm data is already collected, but old routines and a lack of knowledge on how to handle the data stands in the way. Data handling is seen as troublesome, especially when different data sources are to be combined, which can hinder the farmers from getting maximal value out of the PA technologies they possess or will invest in. The view of data handling as complicated could be a hinder for adoption of data heavy PA technologies such as on-combine NIR technology. Increased data competence among the farmers and clear standards for agricultural technology could however reduce this obstacle. It could therefore be important for agricultural stakeholder to not only provide or inform about the hardware and software but also provide extended knowledge about the usage and potential of data analysis. Long-term, industry standards to make sure the technologies on the market are compatible with each will have to be in place to facilitate data handling. As noted by earlier scholars (Wolfert et al., 2017), partnerships across the whole value chain concerning data has to be created to facilitate data handling and usage.

6.6.1.1 Data Security

The security aspect of collecting quality data at farm site is not a main issue for farmers. However, some farmers were concerned with the privacy of the data and who owned and accessed it, which supports earlier research on the subject (Castle, Lubben, & Luck, 2016). If the farmer's view that data collection at farm site is safe is because of a lack of knowledge or that they view quality data as non-sensitive is unclear. It can be concluded that the security issue is taken lightly by farmers today, thus it should not hinder adoption of data heavy PA technologies. It does not necessarily mean that the security issue can be ignored or that it will remain unimportant for the farmers in the future.

6.6.1.2 Quality Data and Sustainability

Specifically for on-combine NIR data, potential environmental benefits needs to be further investigated. Given that it is possible to gain insight from the collected data about how much nitrogen from the fertilization that is left in the ground, it could be a good tool for environmental improvements. If a certification of how well a farmer manages the nitrogen at farm site would be established, it could increase the value of on-combine NIR measurement for the farmer. Such a certification could be a part of the traceability towards the end consumer, for example through being a requirement for different environmental programs such as GPS and N-sensor is for "Klimat & Natur".

6.6.2 **Data Sharing**

Attitudes towards sharing of PA data can affect the collective value that can be realized across the value chain, and thus the adoption of the PA technologies. When looking at data sharing it becomes clear that it is not possible to generalize the farmers' attitudes towards it. It all depends on what type of data is involved, who the receiver is, what the purpose of sharing is and if the farmer gains value from the sharing. The farmers generally want control over their data, which could be an obstacle for automated data transfer.

Regarding data sharing with the tech supplier, trust seems to be most important, which could be a result of the still important personal contacts and relations within the Swedish agricultural market. It might be easier to share data with a tech provider that one know personally and trust, than with a stranger. Many are hesitant towards sharing data with the state, mostly not seeing the purpose with it, but also because a concern that it might be used for regulation. The general attitude that it is necessary to share data with the crop advisor, could most easily be explained with that the farmer gets a clear value out of it, through advise, and that the advisor is generally highly trusted. In addition, most farmers already share data with their advisor today, making the behavioral changes for also sharing data from on-combine NIR measurement low. In conclusion, most farmers are positive towards sharing quality data, which has not been found in other studies. The positive view however comes with three conditions: that they share the data to someone they trust, own the data and get a clear purpose of sharing (such as an added value that can be used on the farm).

It is important to note that the farmer can gain value from on-combine NIR measurement without data sharing across the value chain in place. Thus, a lack of data sharing itself does not necessarily hinder the adoption of on-combine NIR measurement for the farmers. However, a negative attitude towards data sharing can hinder the value quality measurement can give for other actors of the value chain such as Lantmännen.

6.7 The Cooperative Stakeholder: Lantmännen

6.7.1 **Relationship with Lantmännen**

Most farmers viewed Lantmännen as any business partner (however an important one, which is one of the goals of Lantmännen) and did not view the ownership as a central aspect of their relationship with Lantmännen. The sense of ownership might affect how the farmers view the success of Lantmännen. Since there are clear benefits for Lantmännen if farmers would measure grain quality at farm site, farmers with a sense of ownership could be more likely to be keen on doing so. The sense of ownership might increase the perceived total value of on-combine NIR measurement since the farmer then has a more holistic perspective and this could therefore increase the adoption rate.

6.7.2 **Actions to Facilitate Adoption**

Former research suggest that membership of producer organizations (such as Lantmännen) can have a positive impact on adoption rate (Knowler and Bradshaw, 2007). Proving the value and assuring reliability through R&D activities are seen as the primary tasks for Lantmännen in order to enable a shift in quality measurement more towards farm site. Pinpointing the value of on-combine NIR technology through R&D could thus fasten the adoption of the technology.

6.7.3 Data Sharing with Lantmännen

It is of central importance that data sharing gets in place for Lantmännen to realize the full potential value the technology can provide them, and in extension the farmers. Although many were positive, farmers do not generally want to share data unconditionally, but request a value in return. Thus, Lantmännen needs to offer specific conditions that give value back to the farmer, either financially or through a service. Moreover, data sharing can be a potential business opportunity for both Lantmännen and the farmer through including it in the business agreement. Although it could be questioned how detailed the data has to be to be valuable for Lantmännen when forecasting. Perhaps a rough value of the grain quality could be enough, rather than sharing detailed, location-specific quality data from the fields (e.g. the complete protein map). This could make the data less sensitive and thus easier to share for the farmer. In addition, this would make the data sharing balanced, since Lantmännen today only give the farmer a rounded mean value when giving feedback to the farmer on their delivered grain, and thus does not give the farmer detailed quality data.

6.8 Adoption Scenarios

No former studies have investigated the on-combine NIR application through an adoption perspective, and many new findings have therefore been made. There is a large number of factors affecting the adoption and many perspectives to take on. If on-combine NIR will be generally adopted is still unclear, although it seems to have similarities with the N-sensor which indicates a slow adoption. If on-combine NIR measurement is adopted, there seems to be two future scenarios based on the indications of this report:

1. The sensor becomes a niche product for farmers that aim at producing grain with especially high quality precision.
2. The sensor becomes standard in new combines through a technology push from tech providers and other stakeholders and therefore becomes generally adopted.

Both of the scenarios could occur, however at different timing.

7 Conclusion

In this chapter, the conclusions of the study are presented. The research questions are answered followed by practical implications (including recommendations to Lantmännen), generalizability, suggestions for future research, limitations and validation.

7.1 Answers to Research Questions

What aspects affect the adoption of precision agriculture technology among farmers?

1.1: What positive and negative factors affect adoption of on-combine NIR technology among Swedish grain farmers?

The factors affecting the perceived value of on-combine NIR technology, and thus the adoption, can be divided into six aspects and a number of factors, as seen in Table 6.1. Firstly, the technology itself both has positive and negative factors, for example it has a clear perceived value by the farmers, though uncertain extended values, such as how to assure ROI and decision support. Secondly, within farmer and farm characteristics, the most important positive factors are a high interest in technology and a big enough farm. Other factors in this area such as experience, age and field heterogeneity are more ambiguous and harder to generalize. Thirdly, regarding the grain market and business, production of grain for high quality end products, as well as increased weather deviations are positive factors for adoption while lack of consumer demand for quality differentiation, lack of price differentiation and scarcity of investment capital are negative factors. Fourthly, grain logistics include negative factors such as difficulties to separate grain on farm site, potential adoption of NIR measurement on the drying facility, and recipients inability to receive separate batches. One positive aspect within grain logistics is the potential to reduce the need for laboratory tests.

The attitudes and concerns towards farm data generated by PA technologies in general and on-combine NIR measurement in particular seem to have an effect on adoption. The increased value that can be realized across the value chain if data is used and shared could make farmers and agricultural stakeholders see more benefits with PA technologies and thus have a positive impact on adoption. However, data handling is seen as troublesome today and ease of use is requested for it to be more widely implemented. The willingness to share data among farmers is largely context dependent and require a clear purpose. To enable future sharing of quality data, more detailed purposes and conditions between the involved parties are needed, and the farmer value of data sharing needs to be considered.

Cooperative companies have a unique possibility to realize the value of PA technologies across the entire grain value chain and thus increase adoption. Several ways in which Lantmännen can affect the adoption is found, where the main contribution would be to prove the value of on-combine NIR through R&D projects and pilot testing. In addition, Lantmännen could contribute by adjusting the pricing to better reward quality and enable changed logistics through creating separation possibilities in the recipient stations. Also, making the technology available through selling or leasing is a possible way to facilitate adoption. Lastly, Lantmännen could assure traceability across the value chain, for consumers to get informed about grain quality and therefore demand an increased quality precision, which in turn could increase the demand for on-combine NIR measurement.

1.2: What can be learned from previous adoption of precision agriculture technologies in Swedish grain farming?

Through gaining the farmers view of their usage of PA technologies on the field, adoption characteristics of the Swedish grain market were identified, and similarities in adoption patterns between the N-sensor and on-combine NIR technology were found.

Firstly, the adoption pattern of PA technologies on the Swedish grain market seems to be in line with the adoption curve created by Rogers (1995), and a mapping can be seen in Figure 6.3. Several characteristics of adoption on the Swedish market were identified, showing the importance of innovators that adopt new technologies early despite initial uncertainty and risk. The early stages of adoption seem to be driven by use cases and word-of-mouth. When surpassing niche users, the PA technologies become available at reseller and eventually becomes standard equipment with a broad spread.

Secondly, both on-combine NIR technology and the N-sensor have an unclear and intangible extended value, indicating that they could have similar slow adoption patterns. Given this, it is likely that on-combine NIR becomes a long haul with a slow adoption rate.

7.2 Academic Contribution

The adoption of innovation within agriculture clearly has many perspectives. Much of the findings in this thesis are similar to former research, however several new context dependent findings have extended the current knowledge. The study adds an agricultural context to diffusion theory and contributes to innovation adoption research in several ways. Firstly, the qualitative approach of in-depth interviews have given the perspective of farmers, which has been requested by former studies. Secondly, this thesis has contributed with a Swedish grain context which is relevant due to that former findings have been largely context dependent. Lastly, a new application of NIR has been studied, the on-combine application of the technology.

7.3 Practical Implications

Since the study aims at investigating adoption of new PA technology, the findings can be practically used by any party that aims to gain understanding about this subject. In particular, the insights can be used to form adequate strategies for technology pushes in agriculture. The insights can also be used in trying to reduce the hinders of new PA technologies, and especially the hinders of the on-combine NIR application in order to increase adoption. The findings can further be used when considering how to form data sharing cooperatives or agreements between agricultural stakeholders. Also, these insights could be used in understanding the adoption patterns of new PA technologies with similar characteristics as on-combine NIR measurement, in order to evaluate attractiveness.

7.3.1 **Recommendation to Lantmännen**

On the basis that Lantmännen finds it valuable to play an active role in the adoption of on-combine NIR measurement, the following recommendations have been identified.

Quantify the value of adoption of on-combine NIR for Lantmännen

The potential value for Lantmännen if on-combine NIR is to be adopted have been declared by representatives from the company to be related to improved logistics, more detailed insights and possible future forecasting of grain qualities. However, the potential financial effect of these values are unclear. How valuable the shift of quality measurement towards farm site would be to Lantmännen needs to be quantified more specifically before engaging in activities to increase the adoption. If the solution becomes a niche product adopted by few farmers, the benefits for

Lantmännen might not be substantial enough compared to the resources allocated to facilitate adoption.

Share the added value with the farmers

If there is potential added value to gain in receiving more detailed sorted grain to the recipient stations, this value needs to be shared with the farmers providing the sorting and investing in the technology. Even though increased homogeneity would not generate a higher price from the end consumer, Lantmännen should consider paying the farmer for increased precision, control and optimization of grain handling.

Prove the use case and business case for on-combine NIR measurement

Lantmännen should consider conducting R&D activities as brought up by several farmers to prove the case of on-combine NIR measurement. Increased revenues through quality payment and decision support through data insights especially need to be proved, since these extended values are harder to grasp than the immediate values. Technological reliability should also be ensured through testing before encouraging adoption. In other words, the full business case of acquiring on-combine NIR technology needs to be clarified with the farmer utility ("bondenytta") in mind.

Since many farmers expressed an unwillingness to be "experimental rabbits", it is important to clearly separate pilot testing with commercial launching. It is further important to note that Lantmännen is not a technological developer and thus do not have technical capabilities to develop the full solution themselves. However, as a cooperative company, Lantmännen is a unique player on the market affecting the whole value chain and could conduct pilot projects investigating the full value of on-combine NIR measurement (including adjusted logistics and data handling) together with farmers. The value needs to be investigated from a holistic perspective, rather than focusing on separate steps of the value chain, in order to avoid suboptimization.

Identify and target innovators and early adopters

During the early stages of adoption, Lantmännen should identify relevant farmers for potential pilot projects. Midsize and large farms should be prioritized, as should farms producing high quality wheat and barley rather than bulk. Furthermore, farms utilizing other PA technologies that generate data are the most interesting in order to prove the value of combining farm data for insights. As for who is a target farmer, a high technological interest is the most important characteristic.

Prepare for slow adoption

Given the large behavioral change required for the farmers to realise the full value of on-combine NIR measurement, Lantmännen (as well as other stakeholders) should brace for slow adoption and not jump on this specific solution. Since the adoption pattern remains uncertain, and several scenarios are possible, it is important to be prepared for a slow adoption and avoid an aggressive push to ensure the right type of solution at the right time.

Innovate the business model across the grain value chain

Adjustments of the business model will be needed if farmers start measuring quality at farm site, given that this will increase knowledge and shift the power balance in the value chain. Lantmännen should play a role in enabling logistical adjustments internally and for the farmers. For example, Lantmännen could reshape their role as an intermediary and become a broker of grain, distributing the farmers specific grain qualitiy to the optimal buyer. Lantmännen could be a mediating party between the farmer and buyers of certain qualities, reducing the need for Lantmännen to physically receive the grain before reselling while at the same time increasing the incentives for the farmer to share their quality data.

Regarding payment, a more detailed price differentiation rewarding high and homogenous quality should be considered. This could further include quality deviation of a grain batch as basis for payment. Lantmännen could play a part in mediating the importance of uniform quality towards buying parties later in the value chain, such as mills. To further encourage farmers to measure and provide high quality grain, including protein as a basis for payment for animal feed is an option worth considering.

Be a reseller of the technology

A clear way to facilitate for the adoption of on-combine NIR on a broader scale is to make the technology available on the Swedish market. Dataväxt could be an appropriate provider of both the hardware, software and services such as calibration and data analysis. Lantmännen Maskin could also offer the technology as an option on their combines. To lower the threshold even further, the ability for the farmers to try the technology before fully committing to a purchase should be an option, as well as offering extensive service and support to increase ease of use.

Keep a close eye on the technology providers

The adoption of technologies among farmers depend largely on the technology pushes made by technology providers, such as New Holland or John Deere. It is therefore crucial to follow their moves in launching new technologies to be able to forecast what innovations will be important and influential. An evaluation of the 2020 launch of New Hollands NIR solution should be made.

Declare clear purposes for data sharing and bring back value to the farmer

It is important to give value back to the farmers, when requesting them to share data. The purpose of the data sharing has to be clear to create a positive attitude towards sharing. Even though pure monetary payment for data could be far-fetched, the sharing of farm data could be included in grain price premiums or beneficial payment terms. Lantmännen could also provide value through ensuring smooth logistics, such as automated pricing or time booking for pickup through LM2. Further, the farmer could be offered data analysis when providing their farm data. These arrangements could also be a way to build loyalty. The fact that the farmers also are owners of Lantmännen should be stressed since the ownership could be a part of the purpose for data sharing.

No matter how Lantmännen decides to bring value back to the farmer, it is crucial that the data sharing is made in a safe way with clear contracts and smooth data transfers. Even though a long-term goal of more automated transfers of data could be beneficial, it is important to acknowledge that some farmers prefer manual transfers today. In addition, accessing data through Dataväxt can be a good way to acquire farm data in an indirect way, however it is important to acknowledge that farmers have concerns about this and Lantmännen must therefore ensure transparency in data transfers.

Additionally, Lantmännen should assure that the farmers (rather than the tech providers) have ownership of the farm data and in extension advocate for this across the industry. Lastly, Lantmännen needs to be prepared to compromise with the level of detail of the quality data received from the farmers, and recognize that an average might be sufficient enough.

Support the farmers to make data driven decisions through PA technologies

The R&D efforts of Lantmännen should include ambitions to make it easier for the farmer to become a better cultivator. How to interpret the vast amount of farm data generated by PA technologies to be able to understand the connection between inputs and outputs in farming, still needs to be further explored. Creating and providing user-friendly decision support based on farm data would be a way to realize the full value of on-combine NIR measurement. This service could combine PA technology data from different sources (such as CropSAT or the N-sensor) to identify root-causes for turnout of the harvests. This would be a suitable service to be implemented by Dataväxt. Integrating these data sources would be a way for the farmer to fully utilize their network of PA technology and generated data. The decision support could for example be provided in exchange for the farmers sharing their quality data, or be offered as a separate service.

Lobby for standards and compatibility to be established between PA technologies

To be able to facilitate for adoption of data heavy PA technologies, standards have to be established. Lantmännen can lobby for this through evaluating suitable options to make technologies and data handling within agricultural technology more compatible.

Further work towards traceability between the consumer and the farmer

To bridge the knowledge gap between the consumer and the farmer, and facilitate for the consumer to make conscious decisions about grain quality (which could increase the incentives for quality sorting), traceability should be established. Since Lantmännen operate across the entire value chain, they have a unique possibility to explore how traceability could be done. For example, the traceability done today through Klimat och Natur could be extended to include more quality parameters and new technologies (such as the on-combine NIR application). Another option is to investigate blockchain as an option for traceability of quality (which could be a scope for a future master thesis).

Include quality measurement at farm site in an environmental certification

Given that on-combine protein measurement can be interpreted as a receipt of how much nitrogen has been removed from the soil, Lantmännen should aim to incentivize the farmers to quality measure by creating a low nitrogen leakage certification. This could be implemented under the current scope of the "Klimat och Natur" certification. It would also be a way to more closely connect Lantmännen to farmers for potential automated data sharing. An extended or new certification based on nitrogen measurement could be a way to reduce nitrogen leakage which is one of the largest sources of environmental impact of Lantmännen.

Be open for adoption of different solutions

On-combine NIR measurement is not the only option for quality sorting or in gaining insight of grain quality on farm site. In fact, many new technologies are up and coming. The adoption of substitutes such as GrainSense, NIR in the dryer or protein forecasting from CropSAT could take off and lessen the importance of the on-combine NIR application. It is therefore important to have a wide and open approach when looking at innovations to push for, in order to avoid getting locked into one certain solution. The quality data can come in many forms or be generated through different sources, and even though it is interesting to gain detailed data insights from on-combine measurement, less precise quality data from other technologies could bring value to Lantmännen.

7.4 Generalizability

One should be careful with generalizing the findings of this study. Since it is a case study, the findings can only be generalized within the set context. The results of this qualitative study of 22 farmers can hardly be translated as absolute truths applicable to the whole population of grain farmers in Sweden, but it is safe to conclude that it reflects some farmers view. By interpreting these points of view one can aim to understand what it means in a larger context.

The benefits and concerns with the on-combine NIR application will be weighed and perceived differently among farmers depending on their preconditions and affect how relevant the farmer views the innovation, making the result hard to generalize. However, the identified positive and negative factors for adoption of on-combine NIR could be applied in a larger context. The findings might be generalizable to some extent for other PA technologies that are introduced on the Swedish market, especially since the results showed similarities to the adoption of the N-sensor. Alternatively, some findings could be generalizable for on-combine NIR measurement in a geographical context similar to the Swedish one.

7.5 Future Research

It is evident that farm data is a central part of new PA technologies, including on-combine NIR measurement. However, the farmers' view of the data is complex and context dependent. There is a need to further research how the vast amount of data generated by new PA technologies should be handled and how it can be combined to generate maximum value for the farmers. The value of data insights and how to technically combine the data seems well established today, however how to turn the data into decision support and actions is still unclear and requires further exploration.

The questions regarding data sharing in the interviews were on a general level. Hence, the findings concerning data sharing in this study are on a conceptual level. To investigate if standardised quality data sharing could become a reality, further research more thoroughly examining data sharing purpose and conditions will be needed.

Lantmännen has been the focal stakeholder for this study. Lantmännen is a unique cooperative company on the Swedish market, and their role could therefore be risky to generalize for other players. To further understand how agricultural stakeholders can affect adoption among farmers, case studies involving other stakeholders should be done.

Further findings that needs to be confirmed in future research is the relationship between farm size and adoption, as well as the environmental benefits of on-combine NIR measurement. Also, the possibility to place NIR technology in the drying facility, needs further investigation.

This thesis has taken on the perspective of diffusion theory, however other theoretical lenses could be used to gain increased knowledge about how PA technologies spread. It would be interesting to investigate the adoption of on-combine NIR measurement through the theoretical lens of innovation translation (that look further into the context och network around the technology (Tatnall & Davey, 2001)), in order to confirm or contradict the findings of this study.

Lastly, qualitative case studies examining adoption other PA technologies and/or taking place in other geographical contexts could contribute in understanding adoption of PA technology.

7.6 Limitations

A number of limitations can be identified regarding the results of this thesis. This segment addresses the major limitations concerning uncertainty of adoption factors, comparability of adoption of other PA technologies and knowledge about farm data.

The factors identified in this study are derived from both former research as well as the interviews conducted. The factors can be dependent on each other and thus overlap. Further, the definitions can partially be vague and complex, which this study does not fully explore. Regarding education in farming, no conclusions could be drawn of how education level affects a farmer's view of the technology and thus the adoption rate. This was mainly due to the fact that the interviewees had undergone different educational programs at different places during different points in time, making it hard for this aspect to be comparable among the farmers. This uncertainty might have affected the conclusion drawn of the importance of experience due to a possible overlap with education. As for the sample of farmers, most seemed to be early majority and tech positive, which could affects the result, for example leading to a skewed focus on technological interest.

Regarding the comparison between adoption rates of PA technologies, the adoption patterns might not be completely comparable or generalizable, and thus they might be risky to compare. However, it is safe to say that adoption patterns identified for the other PA applications could hint about the future adoption rate of on-combine NIR technology.

The farmers generally did not express concerns towards security of data collection, though knowledge about this issue was relatively low, for example shown through a lack of understanding of what could pose a risk. The low level of knowledge thus could have affected the results of the study, simply because the farmers might not have understood the question. In addition, there seemed to be a lack of understanding about the purpose of sharing the quality data with an external party (except for with an advisor). If there had been more specific questions regarding the purpose of a data sharing agreement for the farmers in the study to consider, the results could have been more thorough and detailed.

7.7 Validation

Alongside the study, experts have been consulted, to validate the background, theory and case study setting. The finished results of the thesis has been validated through dialogue with experts and representatives from Lantmännen. The authors have mapped the findings against expert statements and comments, to ensure a relevant analysis. Lantmännen has contributed with validation from the perspective of the parties in the value chain, including the farmers. The report have been adjusted accordingly when needed, although no major adjustments were called for.

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Appendix A Interview Guide

Intervjuguide för lantbrukare - Adoption av innovation inom lantbruk

Semistrukturerad djupintervju, 45 min

Introduktion

Tack för att du tar dig tid att delta i vår undersökning. Intervjun kommer ta ungefär 45 min. Den kommer främst bestå av öppna frågor, där du får dela med dig av dina tankar.

Vi heter som sagt Julia och Ludvig och undersöker vi lantbrukare och ny digital teknik, genom vårt examensarbete på Lunds Tekniska Högskola tillsammans med Lantmännen. Särskilt tittar vi på kvalitetsmätning av spannmål direkt på gård, med hjälp av NIR-teknik som man fäster på tröskan.

Undersökningen är anonym. Är det okej om vi spelar in under intervjun? Det är bara för vårt eget minnes skull och kommer inte delas med någon annan.

Har du några frågor innan vi sätter igång?

Demografi och lantbruk - öppna frågor

- Berätta vad du bedriver för lantbruk!
    - Vad odlar du för spannmålstyp?
        - Är det något av det som är utsäde?
    - Vilket ändamål säljer ni oftast för?
    - Har du djur?
        - Odlar du foder till dem?
    - Hur stor är din gård?
    - Äger du eller arrenderar du marken? Om båda, hur stor andel av vad?
    - Har du tork på gården?
    - Kravbonde?
- Hur länge har du bedrivit lantbruk?
    - Hur länge har du haft gården? Har den funnits i familjen?

- Berätta om din väg till lantbruket?
    - Lantbruk i familjen? Intresse?
- Utbildning?
- Hur skulle du beskriva Lantmännens roll för ditt lantbruk?
    - Hur ser du på att vara delägare i Lantmännen?
    - Ser du dem som en affärspartner?

Tekniskt nuläge - öppna frågor

- Vad är dina generella tankar kring lantbruk och ny digital teknik?
    - Skulle du beskriva dig själv som teknikintresserad?
- Hur använder du nya teknologier i ditt lantbruk idag?
    - Vilken typ av teknik? Digital teknik?
    - Hur länge har du använt denna teknologi?
    - Vad ledde fram till beslutet att börja/att inte börja använda teknologin?
- Skulle du säga att du bedriver precisionsodling?
- Har du nyligen övervägt att börja använda några ytterligare nya teknologier? Vilka? Varför?
- Hur använder du datan som samlats in? För du över den till en dator? Analyserar du den?
    - Dataväxt?

NIR-teknik på tröskan - öppna frågor

- Gör du någon typ av kvalitetsmätning på gården idag? Vilken typ? Vad mäter du?
    - Om ja, vad använder du datan till?
- Kände du till NIR-teknik innan du kom i kontakt med den här undersökningen?
    - Om ja, vad kände du till?

NIR-teknik är en mätteknik som baseras på infrarött ljus som sänds ut. Genom att mäta vilka våglängder som absorberas av spannmålskornen kan man mäta innehållet av protein, stärkelse, aska, vatten, fett och fiber i realtid medan man skördar. En sensor monteras på en befintlig tröska där vattenhalten mäts idag. Detta gör att man kan göra en detaljerad kartering över kvaliteten på ett visst fält så att man vet vilken kvalitet spannmålet har uppnått.

- Hade kvalitetsmätning av spannmål direkt på tröskan givit dig ett värde? Vilket?

    - Har du övervägt att införa kvalitetsmätning på gård? Varför? Varför inte?
- Vad är det största hindret för införandet av en sån här teknik?
    - Interna hinder (personliga och på bondgården), externa hinder
- I vilken situation skulle du överväga införandet av NIR-teknik?
- Om du hade kunnat kvalitetsmäta, är det något typ av spannmål som det hade varit mer eller mindre intressant för?
    - Ifall utsäde - relevant för det?
- Är det någon särskild kvalitetsparameter som är mer intressant?
- Hade det varit praktiskt genomförbart att separera spannmålet?
    - Hur många silos?
- Varierar kvaliteten på spannmålet från år till år?
    - Inom fält?
    - Är det lätt att prognostisera kvalitet

Faktorer för adoption - flervalsalternativ

- Resonera kring följande aspekter som skulle kunna hindra införandet av NIR på tröskan:
    - Svårigheter att få tag på tekniken
    - Investeringskostnaden
    - Storleken på gården
    - Dagens prissättning på spannmål
    - Andra tekniker är högre prioriterade
    - Säkerhetsrisk i datainsamlingen
    - Tvivel på pålitlighet av tekniken
    - Brist på referenser
    - Övrigt *(här har lantbrukaren möjlighet att lägga till eget alternativ)*

Lantbruksdata - öppna frågor

- Om du hade kunnat mäta kvaliteten löpande på tröskan, hur hade du använd den datan?
- Hade du kombinerat datan med annan data du samlar in på gården?
- Hur känner du inför att dela datan med extern part?
    - Dina grannar?
    - Teknikleverantören?
    - Rådgivare?
    - Lantmännen?
    - Regionen eller staten?

Generella frågor - öppna frågor

- Vad tror du lantbrukare i allmänhet har för tankar kring att dela med sig av data som samlas in på gård till Lantmännen?
- Har du några generella tankar kring vad som gör att lantbrukare tar till sig vissa teknologier men inte andra?
- Är det något du saknar från Lantmännens sida som skulle kunna ge tekniken mer värde för dig?

Avslut

Slutligen, har du några frågor till oss?

Tack för att du deltagit. Undersökningen är anonym men om du samtycker så kan vi ha med ditt namn i urvalsgruppen, så att Lantmännen skulle kunna följa upp i efterhand, vad känner du kring det?