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PRECISION AGRICULTURE AND ACCESS TO AGRI-FINANCE
How precision technology can make farmers better loan applicants

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Abstract

The World Bank has estimated that an additional \$80 billion in financing are needed annually to achieve the 70 % increase in food supply required to feed the world in 2050. One of the cornerstones in achieving this increase in production is expected to be improved agricultural technology, where one of the latest additions is precision agriculture. It is believed that the money for investing in this technology must come from the private sector, but financial institutions are hesitant in lending money to farmers. This, in part, comes down to a high perceived riskiness in agricultural lending stemming from the risk composition in agriculture compared to other industries as well as from weak collaterals provided by farmers.

This thesis aims to find what factors are most prominent in banks' risk assessment of agricultural firms during the lending process and look at how precision agriculture could help mitigate these risks. We have gathered aggregated quantitative data from FAOSTAT and the Swedish Board of Agriculture on farm income and hectare yield (productivity) at Swedish farms. These variables were found to be two of the most important factors in agricultural lending. In addition to this data, further information on e.g. weather, ecological farming and expenditure related to pesticides, fertilizer, and machinery were collected to further the analysis.

Precision agriculture is made up from a myriad of different technologies. We have opted to not separate the technologies in this study as the adoption of each technology included in the term is currently not sufficiently well understood. This aggregation of technologies allowed for us to use the dynamic AAGE-model to estimate the adoption based on the minimum hectare size where precision agriculture should be profitable at each point in time.

The study finds that precision agriculture does have a positive impact on farm productivity and income volatility. Hence, precision agriculture should reduce the risk of agricultural financing given to adopting farmer which would increase the access to credit and, in continuation, lead to an increase in aggregated food production. In addition, we conclude that financial institutions should gain a better knowledge of precision agriculture technologies and use this information to improve the credit evaluation process in agricultural lending. Lastly, banks should understand how the risks related to information asymmetry and moral hazard could be reduced by utilizing the data available through farmers use of precision agriculture technology.

Keywords: Precision agriculture, agricultural finance, food supply, credit risk, income volatility, farm productivity, production risk, Sweden, adoption, banks

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Definitions (anna)

Important definitions for the reader are explained below. These are the main definitions which the authors use throughout the research. It should be noted that additional definitions will be presented throughout the text for them to be in closer association to where a specific definition is necessary to understand

Precision agriculture (PA) is a farm management practice which uses ICT, sensors, satellite positioning, and data gathering. The purpose of the technology is to optimize the returns of inputs and make farming more sustainable (JCR, 2014, p. 1). It is used to observe, measure, and respond to crop yields and other farm activities. Precision farming is mostly used and furthest advanced among arable farms in Europe, Australia and the US (JCR, 2014, p. 9). While precision agriculture is the practice, the technology itself is referred to as precision agricultural technology (PAT)

One of the technologies pivotal to the functionality and development of PA is GPS which came into the markets in the early 90s. Since then, farms have implemented new technologies regularly. Recently, new technological developments in the drone market has opened for agricultural drone applications. The purpose of these drones is to make agriculture more productive by enabling farmers to frequently, and with precision, understand issues that is about to arise in the fields and take proactive measures to counteract this development before serious damage occurs (Yun et al., 2017).

Agri-finance refers to providing credit for agricultural companies (van der Kamp, 2017, p. 212) and it relates to managing risks within agri-lending (Skees, 2003, p. 1). Throughout the study, the authors will refer to agri-finance when discussing about the issues related to the lending processes and farms' access to credit.

Agricultural productivity describes the transformation of farm inputs into farm outputs which is affected by technological changes and efficiency (Mechri et al., 2017, p. 11). It is often measured using some measure which looks at the relationship between farm inputs and outputs. In this study, we will measure productivity as the hectare yield which is the relation between the input-factor land and the output-factor harvested crops. This will be further discussed in chapter 5

Ecological farming as a concept is widely used across the world. The term "ecological" includes several other concepts such as organic farming. One of the basic principle of ecological farming is that the farm process, from beginning to end, is sustainable (European Comission, 2018). For instance, farms should produce output free from genetically modified organisms (GMO) and take the nature and the wellbeing of animals into consideration (European Comission, 2018). Ecological farming in Sweden started back in 1993 as will be shown in section 6.3.2

Farm inputs and outputs are factors that are put into the farms to produce products or services e.g. crops. Common inputs are labor, fertilizer, pesticides, machinery, and seeds whereas outputs relate to the yield of different types of crops and are measured as yield/hectare in this thesis.

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1. Introduction

The aim of this chapter is to introduce the reader to the topic and prepare them for subsequent chapters by providing background information, an explanation of the research gap, and the purpose of the thesis as well as stating the research question. Further, the reader will be given the contributions which this thesis aims to provide in the light of certain delimitations outlining the scope of the thesis. The chapter will end with a collection of important definitions.

1.1 Problem background (everything related to banking and finance – anna)

The world is facing a massive challenge until the mid-point of this century and this challenge is related to the supply of food. The world bank has estimated that the food supply in the world needs to increase by roughly 70 percent until the year 2050 to continue to feed the growing population of the world and satisfy their changing dietary requirements (The World Bank, 2018). Therefore, the current level of the agricultural products produced is not enough. One solution would be to increase the amount of farmland. However, it seems as if the world has already reached what is known as “peak farmland”, meaning that the total acres¹ of farmland cannot increase in the future (Ausubel et al., 2013, p. 236). Increasing the farmland would also inhibit the growth of cities and create further problems with deforestation. At the same time as agriculture needs to become more productive, additional financing is needed to meet the increasing demand for food. To reach the estimated food production required, the agricultural productivity (TFP) must increase by 1,75 percent annually until 2050 (Global Harvest Initiative, 2017, p. 12). An additional \$80 billion annually is required to meet this demand and it needs to come from the private sector rather than from governments or organizations (The World Bank, 2018).

The problem is that agriculture firms are seen as unfavorable prospects for banks and therefore farms face a lack of financing compared to corporate firms. From the banks’ perspective, there are several factors which affect lending ratios for agricultural companies. Agriculture is perceived as high risk due to low profitability and high variability of output (Maurer, 2014, p. 139). Agriculture is also vulnerable to external factors such as weather conditions and pests to a high degree (Jainzik & Pospielovsky, 2014, p. 118), which makes forecasting future cash flows difficult. In addition, long production cycles and seasonal changes impact yearly profitability of farms (Jainzik & Pospielovsky, 2014, p. 118).

Another difference between corporate firms and farms comes down to collaterals. The main collateral provided by farms is the land they cultivate (Florenta & Georg, 2008, p. 831). Since land does not have a life expectancy or depreciation, one might picture it as being suitable collateral and something which should improve farmers access to the credit market (Zhengfei & Oude Lansink, 2006, p. 647). However, a lack of marketable collateral resulting in higher write-offs compared to other sectors might put farmers at a disadvantage when it comes to finding financing (Jainzik & Pospielovsky, 2014, p. 119). Furthermore, in many countries, land is not formally registered, which creates insecurities surrounding who the rightful owner of the land is and subsequently makes for unstable property rights (Maurer, 2014; p. 147). Factors related to the collaterals, volatility of production, income, and cash flows, make agricultural lending being perceived as riskier from the perspective of the banks (OCC, 2014, p. 2). This does not only decrease the overall supply of loans, but also drives the prices up.

¹ 1 acre = ~ 0,405 hectare

One of the most prominent characteristic of agriculture is the variety in farm size. Large number of farms are held by individual families whose only source of income is farming (Zhengfei & Oude Lansink, 2006, p. 646) whereas large farms are not faced with the same constraints as small farms as they are more profitable and stable (Castle, 2016; Schimmelpfennig, 2016). Because of the larger farm area of larger farms which divides between different fields or where parts of the fields experience different conditions, these farms are somewhat robust to the impact of agricultural specific risks². These risks include such things as pests and weather abnormalities. It is seldom that many different crops planted on different fields with different characteristics are all going to suffer from the same abnormality at the same time³. It would thus be reasonable to assume that large farms have lower volatility and more stable cash flows and should therefore be more likely to receive financing compared to smaller farms. Small farms are instead somewhat similar to micro enterprises because of the high credit risks (Maurer, 2014, p. 141). However, since the life style of small farmers is depending on the performance of their farms, these farmers could be seen as more risk averse and having a different decision-making processes (Zhengfei & Oude Lansink, 2006, p. 646). In addition, the agency costs associated with capital structure are lower in small farms since the interests of the small borrowers and the lender are somewhat aligned due to the full liability of the agent (Zhengfei & Oude Lansink, 2006, p. 647).

Decreasing food production is a worldwide multidimensional issue since many internal and external factors are correlated with each other. For instance, financing could be seen as a factor affecting the amount of fertilizers and technology used, which further might have an impact on the amount and quality of crops. The price of agricultural commodities which ultimately affect farm income, is affected by shifts in supply and demand (Madre & Devuyst, 2016) as well as many additional factors such as political decisions (Florenta & Georg, 2008). Hence, further examination of different factors that affect the overall outcomes such as farm output is needed. Besides financing problems, food production is pressured by a decrease in farmland. According to Schrijver et al. (2016, p. 5), the cultivated area in the EU is decreasing as a consequence of increased foresting and urbanization and has fallen by 0.7 percent between the years 2005-2013. Not only does the total amount of farmland drop, given the increase in population, the farmland per capita has on average been cut in half with e.g. Africa showing a reduction by more than 75 percent (Roser & Ritchie, 2017). Another notable development is the decrease in the number of farmers in large parts of the world. In a report by the European Parliament, it is stated that between the years 2010-2013 alone, EU lost 11,5 percent of their total amount of farmers (Schrijver et al., 2016, p. 6) and from the 1990s to today, Sweden lost 35 percent of their total number of farmers (Jordbruksverket, 2017).

This development is nothing new. In Sweden, yearly reports have been showing a declining trend in the cultivated area since the 1970s, with harvested land has decreased by 9,3 percent since the 1990s (Jordbruksverket, 2017, p. 4). At the same time as these developments, the average size of the remaining farms has increased. While the number of Swedish farmers holding more than 100 hectares of land has increased by only 2 percent from 2005 to 2017, their land holdings increased by 25 percent, and the holdings for those with more than 500 hectares have increased by 62 percent (Jordbruksverket, 2017). In his paper, Stafford (2000) found that the increase in farm size makes it harder for farmers to utilize their farmland effectively and that significant technological advancement would be required to maintain the continued increase in agricultural holdings per farm in the future.

² Agricultural specific risks are often related to production and market risks

³ Even temperature can vary significantly based on elevation differences and aspect

This is also one of the main factors brought up by the The World Bank (2018) as to where the additional financing to agriculture should go: technological advancements aimed at improving commercialization of smaller farmers in order to allow for them to grow. In this way, the output of farms will increase without increasing the total area of farm land.

One of the biggest technological leaps in later years in the field of agriculture has come with the introduction of what is known as precision agriculture. It utilizes ICT (information and communications technology) and GPS to optimize the input and maximize the outputs in agriculture and thus produce more with less (Schrijver et al., 2016). With a decrease in the total amount of farmers and farmland, the remainder simply need to take up the slack left behind.

Precision agriculture has been around for a long time but did not gain real momentum before the invention of GPS became publicly available in the 1970s, allowing farmers to better understand their movement across the field (Stafford, 2000, p. 267). These systems were at the beginning plagued with problems related to a lack of satellites on which the position of the machinery could be decided upon. This meant that the GPS-system had problems relating the actual position with the accuracy needed for it to effectively be used in today's precision agriculture (Stafford, 2000, p. 267-269). The modern precision agriculture started in the 1990s and gained momentum throughout the decade (Stafford, 2000, p. 267).

However, even by the year 2000, the vast majority of farmers were not using any parts of this new set of systems (Stafford, 2000, p. 267). In his paper on the progression of precision agriculture during the 21st century, Stafford (2000) concluded that the main drivers of progression in precision agriculture would be environmental legislations, traceability, public concern about farming practices, and a worry about genetically modified crops.

By 2010, Stafford (2000) predicted that we would see most farmers picking up the concept of precision agriculture on a "whole-farm" basis. However, it was found that in 2010, only around 25 percent of US corn farmers had adopted at least one aspect of precision agriculture with similar adoption rates among farmers of other crops (Schimmelpfennig, 2016). The study, however, found a big difference between smaller and bigger farmers when it came to the adoption rates. While farms smaller than 600 acres had an adoption rate of 12 percent across all of the technologies used within precision agriculture, those above 3800 acres hovered at or above 80 percent for all technologies except VRT⁴ (Schimmelpfennig, 2016, p.12). Similar results are found in studies conducted in Europe (Paustian & Theuvsen, 2017).

Since agricultural output is a highly standardized commodity where prices have consistently dropped for more than 100 years (Roser & Ritchie, 2017), the importance of staying up to date on current technology becomes increasingly important to stay competitive. Since the adoption of precision agriculture, it has been thought that it might bring benefits for farmers of all sizes (Schimmelpfennig, 2016, p. 16-17). If properly implemented, it could decrease the cost of inputs such as fertilizer and pesticides and increase operating profit (Schimmelpfennig, 2016, p. 16-17). Thus, opting out of PA is not a long-term solution. One of the main reasons given for the lower adoption rate among smaller farmers is the up-front cost associated with converting to precision agriculture (Paustian & Theuvsen, 2017, p. 713-714). Studies carried out in New Zealand points towards an up-front cost of around

⁴ VRT = Variable rate technology, the aim of which is to disperse fertilizer, water, or pesticides at different rates at different parts of the field based an analysis of field conditions. An in-depth explanation outlining the different aspects of precision agriculture technology is to follow in chapter 5.

\$100,000 (Knight & Malcolm, 2009, p. 20-21). Even with dropping prices on technology and signs of return on investment of 8 percent per year (Knight & Malcolm, 2009, p. 28) it still is a substantial amount of money to be paid up-front for smaller farmers. An investment of this sort might be hard to carry out without external financing, especially considering the weakening financial situation for many farmers (LRF, 2015, p. 14)

Paustian & Theuvsen (2017) find that the main determinants for adopting precision agriculture are either being a newly cooked tech savvy farmer or a highly experienced farmer with large holdings. The authors boil this finding down to these groups having a longer term commercial outlook on farming and thus they see the cost of precision agriculture as being off-set by long term gains (Paustian & Theuvsen, 2017, p. 713). As precision agricultural equipment is highly specialized, and to be considered a sunk cost if the farmer decides to discontinue their farm, this further demotes smaller farmers from investing in the technology (Paustian & Theuvsen, 2017). With the decrease in small scale agriculture mentioned earlier, it is apparent that many farmers are thinking about leaving the agricultural business and thus the low adoption rate is not surprising. The risk that we are facing is that more farmers discontinue their farms than what the production increase of larger commercial farmers can offset, something which makes it even harder to reach the necessary production increase needed according to the The World Bank (2018).

As can be noticed, several different aspects are intertwined making for a complex problem to solve. The world needs more food production in the future and agriculture is the one providing it. With the current system, agricultural companies are underfinanced and cannot provide higher outputs. Also, the area of land is limited which leaves increased efficiency as the only solution. However, due to the structural differences between corporate firms and agriculture which makes risk default estimations difficult, the risks perceived by banks are high. Agricultural business is more volatile and less profitable due to agricultural specific risks⁵ which causes less lending to agricultural companies. To ensure a sufficient level of food production, the The World Bank (2018) states that the agricultural sector must modernize and, to do so, it needs financing which allows it to invest in becoming more productive. Precision agriculture might be a potential solution to this issue since it holds the potential of making farms more efficient, profitable, and, subsequently, more financially stable. If this holds true, it should make the farms better loan applicants from the banks' perspective and provide increased financing to agriculture.

1.2 Research gap (lowe)

Numerous papers have in recent years studied the effects of precision farming (Abdullahi et al., 2015; Ali, 2012; Balafoutis et al., 2017; Baráth & Fertó, 2017; Castle, 2016; Daberkow & McBride, 2003; Far & Rezaei-Moghaddam, 2017; Gupta et al., 2017; Jensen et al., 2012; Knight & Malcolm, 2009; Paustian & Theuvsen, 2017; Reinecke & Prinsloo, 2017; Schimmelpfennig, 2016; Stafford, 2000; Takacs-György et al., 2013; Yun, et al., 2017). Most of these studies are discussing the adoption of precision agriculture and its impacts on the financial positioning of farms as well as its effects on productivity. However, several of these papers have only looked at a niche area such as cotton producers (Gupta et al., 2017). Others yet have carried out case studies which do not provide the possibility to aggregate the results to a larger population (Knight & Malcolm, 2009). The capital structure of farms and its effects have been studied (Zhengfei & Oude Lansink, 2006; Wu et al., 2014) as well as how banks make decisions regarding lending and selection as to minimize risk (Betubiza & Leatham, 1995; Jainzik & Pospelovsky, 2014). While these papers can be helpful to understand different aspects of precision agriculture, the studies mentioned do

⁵ Especially production risk (Maurer, 2014, p. 142)

not provide in-depth information related to agri-finance or agricultural banking. As far as we know, no study yet has tried to isolate the effects of precision agriculture on banks' lending behavior within the agricultural industry. Even though there are many studies dealing with precision agriculture and how precision agriculture influences productivity and profitability, there is a lack of studies on how this structural change in the industry affects the farms' risk ratings and the risks banks are exposed to. In addition, it is unknown whether the adoption of new technology in agriculture makes a farm a better loan applicant or not.

Also, there are few studies which take into consideration the effects of external factors which could have a negative effect on productivity such as the structural change related to ecological production⁶. Given that an increase in ecological production could offset productivity improvements by reducing yield, it is important to take this effect into consideration. Crop prices and their effect on farming could also play an integral part in the equation. Big farms, in particular, have large portions of their production devoted to cash crops⁷ compared to smaller farmers (Fafchamps, 1992, p. 90). Seeing that price fluctuations create a shift in production from certain crops to others, it is important to take this into consideration when conducting research as it could lead to income volatility (OCC, 2014, pp. 2–3) given the difference in growing techniques and setup time required.

In summary, we see the following problems with previous studies:

1. Focused on a limited area of precision agriculture
2. Case studies not possible to aggregate to a larger population
3. No deeper understanding of agricultural finance
4. Lack inclusion of external factors in the analysis

We thus feel relatively certain that, if able to answer our research question, we will be capable of making a novel contribution to both the scientific understanding in the field and bring practical implications to the sector.

1.3 Thesis purpose (anna)

The purpose of this thesis is to study the effects of precision agriculture in a Swedish context to better understand how precision agriculture affect the ability of farmers to access external financing by making them better loan candidates. We aim to examine this from the banks' perspective and study the connection between precision agriculture and banks' lending criteria. Our goal is to create an understanding of what is being factored into the lending decision of banks and how these factors are being affected by the practice of precision agriculture. We will investigate this by looking at previous literature to find the most prominent factors affecting agricultural lending and then find how these factors in turn are affected by precision agriculture adoption by collecting and analyzing quantitative data. Through the understanding this gives us, we should be able to better explain how the adoption of precision agriculture affects factors that influence the lending ratios and access to external finance by making farmers more attractive as loan applicants. Thus, we should help increase the knowledge within the banking sector of how to properly calculate and factor in the benefits of agricultural technology investments and how to judge loan requests from farmers aimed at investing in precision agriculture. In helping financial institutions to correctly judge these investments, we should aid in the creation of a sounder financial market surrounding agriculture which we hope can lead to higher overall investments and

⁶ Ecological farming has the potential to profoundly offset some of the productivity increases which has been spurred by the use of fertilizers and pesticides rejected when farming ecologically.

⁷ Crops grown for the sole purpose of being sold rather than consumed by the farming family

subsequently more food production going forward. The factors we have found to be most influential in the banks' agricultural lending process are income volatility and productivity⁸

1.4 Research question (both)

How does precision agriculture affect banks' willingness of agricultural lending by improving productivity and lowering income volatility among farmers?

1.5 Social and business contribution (both)

The aim of this research is to provide an in-depth understanding of the factors affecting lending ratios and access to external finance in the agricultural sector. In Sweden, reports are showing that a large portion of today's farmers are going to retire within the coming 10-15 years (LRF, 2015). This translates to a need for financing amounting to 10-15 billion SEK in Sweden alone just to maintain the current agricultural land. Additional financing is then needed on top of this to modernize these farms (LRF, 2015).

Agriculture is one of the primary sources of income and employment in many parts of the world and makes up about 40 percent of worldwide employment (IFC, 2018). Employment, coupled with uncertain overall food supply, makes this an important topic on all societal levels as a situation where a large number of farms discontinue their agricultural production would be problematic. It should be mentioned that the drivers for not continuing (either by taking over after retired parents or by buying up a farm sold by a farmer retiring) differs (LRF, 2015). In poorer regions of the world, agriculture is more about feeding the family rather than building a profitable agri-business which is the predominant motivation in developed countries where most farms are run as business and where the decisions made must make economic sense. However, in either case, having access to modern techniques and equipment has historically benefitted farmers of all sizes as the gains oftentimes trickle down.

As with any company, including farms, the principle of going concern is important. Companies must be able to operate in a long-term basis and stay competitive in the future. While lenders oftentimes are required to present information proving their financial status, credit institutions are often using information found from the company's financials to make assumptions of the current financial stage of the company themselves. While this information gives an understanding of how the company has performed in previous years, it entails nothing about the future. Therefore, it could be assumed that not all investment opportunities are taken advantage of as some companies are bound to be misjudged. By gaining an increased understanding of how technological adoption influence the productivity of farmers, financial institutions should be able to make better estimations of whether loans aimed at long-term investments in precision agriculture are going to improve the financial situation of the farmer to the point where it should alter the risk analysis conducted by the bank for that farmer.

As discussed earlier, from the banks' perspective, agri-lending is considered unfavorable due to perceived low profitability and high volatility (Maurer, 2014, p. 139). However, by using precision agriculture technology, the data from farms could become easier and faster to gather and banks could keep better track of the farms' activities. Together with a possible production increase, precision agriculture should, in theory, reduce the perceived portfolio risk overall for banks which would make agri-lending more favorable in the long run. This could create new opportunities for banks and other financial institutions by allowing for, e.g. new financial instruments tailor made for the agricultural sector. Previous studies have

⁸ The underlying literature explaining why these factors are the most prominent is given in chapter 4

shown that financial institutions which are actively working on improving their agricultural lending can improve their agricultural lending. An example is provided by Accessbank situated in Azerbaijan. In early 2007, the bank had an agricultural portfolio constituting about 1,3 percent of their total portfolio as a result of non-structural and inadequate means of evaluating agricultural businesses (Jainzik & Pospelovsky, 2014, p. 117). During that same year, the bank decided to take conscious strides towards establishing itself in the agricultural sector and, by teaming up with KfW (Kreditanstalt für Wiederaufbau), the bank successfully developed an agricultural lending product which took into consideration the specific risk conditions present in agriculture (Jainzik & Pospelovsky, 2014, p. 119-122). Only four (4) years later, the bank had reached an agricultural portfolio which made up 15 percent of their total portfolio and this was done without increasing their Value at Risk or their write-offs (Jainzik & Pospelovsky, 2014, p. 123). This goes to show that by actively trying to understand the conditions in agriculture and developing financial products aimed at farmers, lending to agriculture can be increased.

In this research, we concentrate on the objectives that are important from the banks' perspective. These objectives are for example, credit worthiness, income volatility, profitability as well as predictability (Florenta & Georg, 2008; Katchova & Barry, 2005; Maurer, 2014; Madre & Devuyst, 2016) as they are linked to the farm production. Furthermore, with this research we hope to provide another piece of the puzzle which is being laid out and, when completed, hopefully can reveal a solution to the problems we are faced with today when it comes to providing employment and food for the growing global population.

1.6 Delimitations (anna)

We have chosen to limit our study to the Swedish market. This has been done for several reasons. When dealing with a complex topic where several factors are likely to influence the result, by only focusing on a single geographical area, we can cut down on the number of potential sources of error. Sweden has a very long, accurate, and comprehensive time series of agricultural and meteorological data which enable us to understand possible changes more in depth. Additionally, the Swedish banking sector is considered to have been stable in the past and likely to continue to be stable in the future (Lundberg & Marion, 2017) which somewhat mitigates issues in the data related to an instable banking sector.

We have chosen our time frame to be from 1961 to 2016, in order to see the pattern of farms' productivity rates before and after implementing new technology. Research has also shown that agricultural data spanning 30 years or more is related to a reduced risk and impact of heteroskedasticity (Fischer et al., 2014, p. 36). Our base group is large farms since it is normally the large farms that are adopting the technology first. It is also likely that they also have better access to financing which helps them for further investment processes (Pierpaoli et al., 2013, p. 66). We have excluded some other activities surrounding agriculture such as forestry and animal production. This has been done to concentrate on crop production as we want to keep our study within a narrow and well-defined area where the results are easier to observe.

1.7 Structure of the thesis (anna)

Chapter 1: Introduction	<ul style="list-style-type: none">• <i>Introduction to the topic and to the research gap. Further, The research question is stated, and the purpose of the thesis discussed</i>
Chapter 2: Theoretical Method	<ul style="list-style-type: none">• <i>Presentation of the research approach and discussion about quality assessments and research methods</i>
Chapter 3: Theoretical framework	<ul style="list-style-type: none">• <i>Presents, discusses, and analyzes the central theories related to the study in detail</i>
Chapter 4: Review of agricultural finance literature	<ul style="list-style-type: none">• <i>Analyzes previous literature from banks' perspective based on the theories presented in previous chapter. Additionally, agri-finance is discussed in more detail</i>
Chapter 5: Review of precision agriculture literature	<ul style="list-style-type: none">• <i>Explains historical, current, and future agricultural development with focus on PAT. Describes effects of PAT adoption and its relation to farm economy and production</i>
Chapter 6: Practical method	<ul style="list-style-type: none">• <i>Introducing the methodology for collecting and analyzing the data as well as the ethical and societal implications of the study</i>
Chapter 7: Results	<ul style="list-style-type: none">• <i>Presents the results of the study together with some initial discussion</i>
Chapter 8: Discussion	<ul style="list-style-type: none">• <i>Further discussion of the results and the importance of the results with respect to previous studies and the theoretical framework</i>
Chapter 9: Conclusions	<ul style="list-style-type: none">• <i>Final, concluding words about the topic, results, and contributions are provided together with ideas for further research</i>

2. Theoretical Methodology

This chapter covers information regarding the researchers' background and research philosophy such as ontology, epistemology, and axiology. Additionally, it will present the research approach and research methods used based on the research philosophy. Lastly, quality assessments, such as reliability and validity will be discussed in detail.

2.1 Pre-understanding (anna)

Our thoughts, values, and beliefs are influenced by the social world surrounding us and these individual perspectives might seem so natural so that we cannot see that they are subjective and influence our every-day decisions (Quinlan, 2011, p. 12). This means that our background might be influencing the approaches and methodology chosen during the research project. Since the research approach chosen is quantitative⁹, to maintain objective during the research project is essential (Long et al., 2000, p. 190) and therefore it is important to explore our motivations (Quinlan, 2011, p. 12) and keep our personal thoughts under control.

Preconceptions

We have taken the possible impacts of preconceptions into consideration. Even though we have no personal interest in the topic but rather study it based on interest, we acknowledge the possibility of preconceptions and their impacts. Thus, we have tried to reduce the influence of subjectivity as much as possible. Due to the research philosophy of the authors, the purpose is to critically argue and examine the data collected and show the results without any preconceptions. This will be done by carefully identifying the possible preconceptions and consciously avoiding the influence of these preconceptions during the project.

Background of the Researchers

Both authors have a background in Finance and write this thesis as a part of their two-year master's program in finance at Umeå University (Sweden). In addition, one of the authors also studies a double degree program in finance and therefore the thesis will also be presented at the University of Vaasa (Finland). Neither of the authors have a background in agriculture and have selected the topic based on finding it interesting and socially important. However, considering that agriculture is big within the Nordics and having lived in a farm-rich environment, both authors are familiar with agriculture and agricultural concepts. This has, combined with a strong interest in technological advancements and their applications in a wider context, contributed to our choice of topic. Since both authors have a strong interest for finance and banking, it was natural to combine our interests and take on the challenge of studying the effects of precision farming to access on financing from the banks' perspective. Hopefully our background will help form a novel practical and theoretical contribution with minimal ethical implications.

2.4 Research philosophy (lowe)

This section will deal with fundamental questions regarding our view of the world, what is acceptable knowledge, and how values might affect the interpretations of the findings made. As such, the understanding among readers of these things will be of importance for the continuance of this paper. It has been argued that methodological choice and the adequacy thereof is determined by the fundamental assumptions a researcher has with regards to the nature of the underlying subject of study (Long et al., 2000, p. 190). Hence, we will in the

⁹ We will discuss and motivate the selection of either a qualitative or quantitative approach further in section 2.6

subsequent sections go through our ontological, epistemological, and axiological standpoints to be used in this thesis.

However, the paradigm that guides the researcher through their work is somewhat vague without specifying what is perceived by the researcher as being included in a paradigm. It has been questioned whether it is reasonable to assume that a certain paradigm can and should be inclusive to the point where it encompass all that which a person thinks or believes (Morgan, 2007, p. 52). In addition, according to Morgan (2007, p. 52), it is important to clearly define and specify what is incorporated in ones' view of a paradigm. This should be done with a primary focus on the ideas held about what is the nature of research to the author.

If a paradigm is not consistent with the researchers entire worldview, then it could instead be seen as only the view held on what is acceptable knowledge (Morgan, 2007, p. 52). While not incorporating values held by the researcher in non-research context, this stance on paradigms is still fairly including in that it would refer to a paradigm as something which would, in all research situations, steer the researcher towards either a qualitative or quantitative methodology. While there is an longstanding argumentation regarding whether the research methods should be viewed as extremes on a continuum with no spectra of combination existing in between, or as possible to combine, it should be noted that venturing into such territory should be done carefully as ad hoc mixing could result in a threat to the validity of the research (Tashakkori & Teddlie, 2003, p. 19).

A less incorporating view on paradigm is presented by Morgan (2007, p. 53), as paradigms being the shared beliefs among the members of a specialty area. This steers the discussion away from a more philosophical room to one more pragmatic in nature. While this would naturally entail a deeper philosophical root for the entire research area, which on some level every researcher subscribes to, the decision of the individual researcher would rather come from a standpoint of best practice than from a philosophical argumentation with oneself. This might come from the fact that practitioners in the same field are absorbed in the same literature and thus, similar conclusions are drawn regarding the suitability of a specific research method within that field (Morgan, 2007, p. 53).

Our view is that a paradigm does not encompass all that a researcher stands for, nor does it encompass all that a researcher believes in a research setting. Instead, we opt for subscribing to paradigms as being pragmatic choices made in accordance with what can be considered best practice within a field. By following the methodology used by previous researchers, the results of which has provided generally accepted and valid results, the research we will be conducting in this thesis gain both credibility and allow for comparison to be made with preceding research.

2.4.1 Ontology

According to Long et al., (2000, p. 190), ontology is defined as "the assumptions held about the nature of social reality" and discusses the matter of whether reality can be seen as objective and external to the individual or not. Regardless of whether this is the case or if it is bound to being subjective and individually constructed, it has an impact on the epistemological standpoint. Thus, it is important to discuss these matters as it will impact to the choice of research methods used to investigate the topic at hand (Long et al., 2000, p. 191).

As discussed previously, our view is that the ontological choices come down to the research field in which the researcher partakes. It has been seen, and will be expanded upon in chapter

5, that research in agriculture is mainly either focused on understanding what impact different agricultural methods have in terms of some measure of output or look at the reasoning and rationale behind adopting or not adopting these methods.

Given that our goal is to measure productivity and income volatility following the methodology of past researchers, the work of which focuses on generating results external to the researcher and that are objective, we are going to adopt a positivistic view on ontology in this thesis. While unable us to connect our findings directly to a social phenomena, the nature of this thesis is such that we have no ambition to make such connections. As such, this limiting factor is considered minor in this thesis. We instead focus our attention on separating the individual from the context they are in as to be able to deduct and interpret findings from our dataset.

2.4.2 Epistemology

When deciding the epistemological standpoint to be used in a research, it is often an implicit choice to adhere to the corresponding position to the ontological position used (Long et al., 2000, p. 191). The underlying rationale for this would be the assumption that the elemental supposition leading to a certain ontological stance would subsequently also steer the researcher towards a certain epistemological position (Long et al., 2000, p. 191). While this partly apply to this thesis since we take a positivistic approach to epistemology which correspond to our positivistic view on ontology, we do so not because of our underlying assumptions regarding human nature but to be in line with previous studies. However, the assumption that statistical information collected regarding harvest is to be considered unbiased by human nature is likely not far from reality.

2.4.3 Axiology

Values are something which is of great importance when it comes to the practices of conducting research. Even though the practical methodology in itself is designed to minimize the effect of biases generated from the values of the researcher, the very topic and method itself is created based on the values of the researcher (Saunders et al., 2012, p. 137-138). By selecting a method which does not involve any human interaction, we implicitly state that the human element will not be of importance in finding the answer to our research question. Additionally, by deciding upon the topic of agricultural finance, we as researchers make it clear that we value this topic above other topics which could have been selected instead.

2.5 Research approach (lowe)

The approach to research usually comes in three forms: Deductive, inductive, and abductive. The choice between them has an effect on the logics used, the level of generalizability it allows for, how data is used, and how one relates the results to theory (Saunders et al., 2012, p. 144). In deductive reasoning, the researcher attempts a mental process of making logical inferences based on the idea that if the premises are true, then the conclusion drawn must also be true (Johnson-Laird, 2010, p. 8). If a car requires petrol to run and there is no petrol in the car, then deductive reasoning would conclude that the car would not run. The logic applied in this thesis depends on the premises that if precision agriculture is shown to positively impact factors affecting productivity and volatility, and if productivity and volatility are positively affecting access to financial capital, then we would assume that the adoption of precision agriculture would also affect the access to financing positively. Based on this, one could conclude that we are applying a deductive approach to our research. This would subsequently allow us to draw specific conclusions based on general data (Saunders et al., 2012, p. 144), meaning that we will be able to make use of data collected from statistical information and, through logical assumptions, turn this data into information

regarding the sought after variables. It will also allow us to evaluate our research question in relation to existing theory (Saunders et al., 2012, p. 144). The choice of research approach also has implications on the theoretical contribution possible.

2.6 Research method (both)

As discussed in the previous section, we attempt to answer our research question through the collection and testing of quantitative data, by which we hope to further the current knowledge in the area. The ability to make a theoretical contribution is central when conducting any type of research (Crane et al., 2016, p. 783). The reason for this is that being able to contribute to theory is the watershed between making a scientific contribution which furthers the field by explaining phenomena rather than merely conducting descriptive work which can only state phenomena as they are (Crane et al., 2016, p. 784). In order to come to this theoretical contribution, it is important that the work has internal consistency through all the parts stretching from the research question through to the design of the research with specific emphasis on the decision between qualitative and quantitative research (Edmondson & Mcmanus, 2007a)

According to Edmondson & Mcmanus (2007, p. 1155), this internal consistency among the individual research elements is better known as a methodological fit and by maintaining this fit, the researcher can provide the foundation for high quality research. In their paper, Edmondson & Mcmanus (2007) find that the less that is known within a specific field, the more appropriate qualitative research methods are as these would enable the construction of suggestive theory upon which future research can be built. This type of research enable the researcher to identify patterns through the use of open ended questions that can be interpreted in order to understand the lay of the land within the field (Edmondson & Mcmanus, 2007, p. 1160). For example, if agricultural finance was a highly nascent field and if it was not known whether farmers even used precision agriculture, then studies trying to isolate the effects of this phenomena would not be suitable.

When conducting research in a highly mature and heavily researched field, the work of previous researchers has already paved the way for studies to come. According to Edmondson & Mcmanus (2007) the most suitable type of study in the environment of a quantitative nature aims to answer focused questions related to existing constructs. These studies should rely heavily on existing constructs and measures which are analyzed using standard statistical analysis as to draw statistical inferences (Edmondson & Mcmanus, 2007a). The outcomes of studies like these are ideally supported theories which could cause existing theories to become more specific or uncover new mechanisms or boundaries (Edmondson & Mcmanus, 2007).

Given the extensive literature related to precision agriculture and agricultural finance, we consider the field in which we operate to be mature to the point where the most suitable type of study would be a quantitative longitudinal study. This type of study would not only be consistent with our research philosophy since it uses methods derived from natural science (Robson, 2002, p. 17-22), but also has strength to allow the detection of change and development over time (Saunders et al., 2012, p. 190-191). This will enable us to detect changes in patterns that span the period of time prior large-scale adoption to present day and thus provide us data on if and when a change in behavior have occurred.

2.7 Quality assessment (anna)

2.7.1 Reliability

The reliability of research relates to whether or not the techniques and methods used in data collection and analysis would produce results which would stay consistent if a replication

attempt was to be carried out at a later date by other researchers (Saunders et al., 2012, p. 192). This view is shared by Ihantola & Kihn (2011, p. 42-43), who state that reliable measures should stay consistent if multiple measures are taken, stating that low levels of reliability have a negative effect on the ability to test hypothesis and draw inferences from the data. Some even go as far as to state that results which are not reliable simply cannot be seen as valid (Robson, 2002, p. 101). Of course, it should be noted that simply because a method produces reliable results, does not make it inherently good. This comes down to the fact that there might be errors or biases built into the way one measure or source data (Robson, 2002, p. 101-103) which takes the shape of random errors (Ihantola & Kihn, 2011, p. 43).

The reliability of research is often divided into four (4) subcategories (Robson, 2002, p. 102; Saunders et al., 2012, p. 192-194) while (Ihantola and Kihn, 2011) lump these categories together. To clarify how our research method will stay robust towards issues related to reliability, we will go through these and the steps we have taken to avoid these to the best of our abilities. It should be noted that both Robson (2002) and Saunders et al., (2012) describe these issues from a standpoint of either qualitative studies or quantitative studies using questionnaires. While the intent is still highly applicable as is shown by Ihantola & Kihn (2011b), we will alter the phrasing as to aid the readers understanding based on our context while at the same time keeping the intent of the authors.

Measurement error (subject error)

This threat to reliability comes down to factors which causes the information that comes from the data source to be altered in some way (Saunders et al., 2012, p. 192). An example could be that a participant has been part of another study during the same day causing the person to be tired and answer differently compared to if the person was well rested. Another example is a database in which the information changes between the points in time at which the data is collected from the database.

The databases used in this study belongs to the Swedish Board of Agriculture and the Food and Agriculture Organization (FAO). These databases are updated regularly and also holds the advantage of being under governmental supervision which should reduce the risk of subject errors. It should be noted though that we cannot have full knowledge of how the farms have provided the information to the two organizations and the situation at the time. However, since the data is aggregated and collected using a standardized approach, the individual farm level biases are minimized. Additionally, given the linkage between the two databases¹⁰, the risk for conflicting data is reduced. Overall, we do not perceive any major issues related to measurement errors present in our methodology.

Measurement bias (subject bias)

This type of bias spawns from a situation where the information or data becomes flawed due to subjective acts during, for instance, an interview where the interviewee seeks to please the interviewer (Robson, 1993, p. 67). The design of our data collection method should minimize the risk of subjective errors since we have gathered data from sources where subjective behavior is highly improbable. Although we cannot fully control the reliability of the databases, the fact that they constitute the backbone of Swedish and EU statistics makes it highly unlikely that the databases would be biased. Therefore, we perceive this risk as being negligible.

¹⁰ The connection between the SBA and the FAO database will be further outlined in section 6.3.1

Sourcing error (observer error)

Sourcing errors are related to errors made by the researchers when working with the data. Examples includes, but are not limited to, misunderstanding data or labels or faulty handling of data. This could be due to the researchers e.g. being tired or incapable of using statistical software. To combat this, we have made sure to always work with the data while fully rested, taking frequent breaks and using software with which we are highly familiar. Additionally, both researchers have been present during the data collection and analysis as to reduce the risk of errors being made.

Sourcing bias (observer bias)

Whenever collecting or working with data, the perceptions and biases of the researchers should be taken into consideration. The data is gathered at an aggregated level from the Swedish Board of Agriculture and FAO based on farm size which should eliminate bias in the selection of data since the authors cannot subjectively affect the data through the collection methods used in the thesis. However, the dataset has been partly altered to enable testing of the data and, through this alteration, it is possible for the biases of the researchers to influence the data used in the study. It should however be noted that the authors, to the furthest extent possible, have tried to use the data in its originally form when possible. For in depth information regarding this, please refer to section 6.3.2.

2.7.2 Replicability

Replicability corresponds to a situation where a study, if repeated afterwards with the same methodology, yield the same results. If this holds true, then the validity and reliability of the first study is ensured (Robson, 1993, p. 73). Given that the data used in the study belongs to the official statistics of Sweden and the EU and thus is readily available together with using known statistical software (STATA) for analysis, the replicability should be sufficient.

The authors have used STATA for their empirical study which enables later replication of the research as it is a commonly used statistical software and readily available. The fact that the number of farmers who are using PAT is hard to observe directly has led us to utilize the methods of previous studies which has been compared to the few research findings of adoption in existence for comparison. Replicability attempts by future researchers should be easily carried out by consulting the outline of our methodology. Additionally, the fact that we have used aggregated data means that the same farms should make up the sample going into the aggregated total harvest per hectare and thus, even if individual farm data becomes unavailable, the aggregated data should remain and make replication attempts possible. This also gives the additional benefit of allowing for comparison studies as the methodology is not reliant upon the inclusion of the exact same farmers.

2.7.3 Transferability

Transferability corresponds to the concepts of external validity and generalizability and relates to the possibility of transferring the results of research to another context e.g. another sample group (Robson, 1993, p. 405). Thus, it measures how well a study could be applied to another situation. The data collected in this study is publicly available and, even though the study is conducted in Sweden where this data is easy to find, similar data is available for many other countries as well. The database of FAO provides nationwide farm information from many of the different countries in the world. Therefore, applying a similar study in other market areas should be relatively simple. In addition, the basic principles of agriculture and the existing financing issues within agriculture are somewhat similar globally which makes it reasonable to measure the effects of PA on access to credit across different regions using our methodology.

2.7.4 Validity

A reader is typically expected to be skeptic of the information he or she receive since assuring the validity of the information is an ever pressing issue (Robson, 1993, p. 67). Low levels of reliability are problematic as the quality of findings are lowered if they cannot be re-enacted or duplicated with a high level of consistency by other researchers (Saunders, Lewis and Thornhill, 2012, p. 156). Robson (2002, p. 101) even go as far as to say that if a result is not reliable, it is not valid under the premises that the test is in itself not biased. In his book, Robson (2002, p. 101-103) mentions four threats to reliability in a study which we will now investigate more in depth.

Construct validity

The critical reader would naturally be concerned with the construct validity of a study as the odds of the findings being the result of spurious relations rather than actual relations increase if noise exist in either the measurements or variables (Abernethy et al., 1999, p. 8). Hence the question becomes whether the measurements being used in this thesis are able to sufficiently cover the objects they intend to measure. In this study, we have measured productivity and income volatility using aggregated data in line with researchers who have successfully used similar dataset to measure related things. We have thus concluded that using aggregated data to measure productivity and volatility will suffice in terms of enabling adequate construct validity. However, it should be noted that we cannot remove the risks related to construct validity completely as the quality of the data can never be guaranteed with absolute certainty.

Internal validity

According to Ihantola & Kihn (2011, p. 41-46), internal validity is concerned with the ability to draw valid conclusions from the data gathered with respect to the research design and controls utilized throughout the research process. This basically comes down to whether the variations in the dependent variable can be attributed to changes to the independent variable (Ihantola & Kihn, 2011, p. 41). Naturally, if this does not hold, then the variation might come from other influencing factors. If these are not properly identified and dealt with, the researcher might come to the wrong conclusion. Since aggregated data is used in this thesis, the authors cannot fully remove the issues related to internal validity as some of the factors affecting the results of the secondary data are unavailable. For instance, we cannot completely know if the measurement principles of the two databases have remained the same throughout¹¹. However, the fact that the data is collected by large supervised organizations makes us more confident in the internal validity of the study.

External validity

External validity deals with the ability to transfer the results of a study across space and time (Ihantola & Kihn, 2011, p. 42). Problems regarding external validity would thus exist if, e.g., the sample is very different from what is found in other geographical and time settings. For instance, if farming is being carried out differently in other countries or over time. As described earlier, we have chosen Sweden based on its technologically advanced position and its relatively stable banking environment. It could be the case that, if the study were to be carried out in a different setting which does not hold these properties, the results may differ from the ones found in this thesis. However, as banks operate in similar fashion around the world and farming in principle is fundamentally the same, the level of external validity should not pose a major problem.

¹¹ For more information, please refer to section 6.3.1

3. Theoretical framework (anna)

In this chapter, the theoretical foundation related to technological usage in agriculture and agricultural lending is presented. Asymmetric information, moral hazard and adverse selection are introduced together with the theory of lemons, diffusion of innovations and its sub theory, the rate of adoption. This chapter will also serve to build a theoretical understanding which aids the reader during the discussion of determinants and predictors of new innovations and technology adaptation to follow.

3.1 Asymmetric information

Asymmetric information, which includes adverse selection and moral hazard, is a well-known issue present in any lender-borrower relationships with agri-lending not being an exception (Florenta & Georg, 2008, p. 830). It occurs between two or more market participants during, for example, a lending or insurance process. An example of asymmetric information comes in the form of a car dealing process where the seller usually have a natural information advantage regarding the condition of the car compared to the buyer (Akerlof, 1970). This problem is also present in a lending situation between a bank and an individual or company. Normally, the borrower has more information about its financial situation and other relevant conditions while the institution lending the money has only whatever limited information that has been given by the borrower and some additional information gathered from other sources. This means that banks have difficulties finding sufficient information regarding the financial situation of the borrower for them to adequately judge their credit worthiness and set a correct price on the loan. Banks thus often make their lending decisions based on the financial statements and the previous lending history of a borrower. The problem is that borrowers whose financials and history are such that handing them over to the bank could result in their loan application being turned down or the terms of the loan could be worsened have an incentive to not disclose this information¹².

Asymmetric information comes in other forms as well. According to Fama (1985), bank debt is inside debt for companies meaning that the lending institution gets access to the decision making process of an organization that would not otherwise be publicly available (Fama, 1985, p. 36). Sometimes the lender even have the possibility to participate in the company's decision making process (Fama, 1985, p. 36). When a company and a bank create a relationship where the company is a customer and the bank is a debtholder, the market participants get to know each other better and share inside information. This leads to a situation with reduced information asymmetry between the bank and the borrowing party. However, as other market participants do not possess this information, it creates asymmetries on an aggregated level in the market (Sharpe, 1990, p. 1069).

Not only does the asymmetric information affect loan decisions, but loan maturities as well. Berger et al., (2005) find that asymmetric information is an important factor when it comes to loan maturities which is the reason why companies often take short-term debt to finance their long-term projects. Berger et al., (2005) observed over 6,000 newly issued loans to small businesses to determine whether risky businesses have more short-term debt compared to intermediate risk businesses. The results show that there are no differences in loan maturities between high risk firms and intermediate risk firms. Therefore, the risk ratio of a firm does not affect the loan maturities, as long as the firm have high- or intermediate risk, in the case of asymmetric information. Berger et al., (2005) also state that banks have a comparative advantage in relation to public debt markets when gathering data and information about the loan applicant. This has an impact on, among other things, collaterals,

¹² This way of acting is closely related to moral hazard which will be covered in section 3.1.3.

and covenants. As stated by Fama (1985, p.36), banks have access to organizations' decision making processes which implies that more information is shared between the borrower and the bank compared to what is shared publicly.

3.1.1. Adverse selection

Adverse selection is closely related to the concept of asymmetry of information between two or more market participants. As described by Wilson (1979, p. 313), “A *common characteristic of a large class of markets is that one side of the market is more informed than the other about the properties of one of the goods being traded*”. In a general sense, this means that people will take advantage of the information asymmetry by participating only in transactions which benefit them more than the other party. In the banking world, this can be interpreted as a situation where the borrower has more information about their ability to keep up with loan repayments and interest than the lender has. For instance, a farm with poor productivity and high variability in income (high risk) would be more likely to take a loan which is being offered to a more credit-worthy farmer (low risk) on the same terms and for the same interest rate. The reason being that, as the bank cannot distinguish between the two, the loan-terms would have to be set to somewhere between the two cases and thus the terms would be considered discounted for the less credit-worthy farmer.

Sometimes, a situation where one market participant has information the other does not, will only have a marginal effect on the market (Wilson, 1979, p. 313). An example of this is trading in goods, such as fruits, where the quality of a specific fruit is somewhat similar between different suppliers. In a case like this, the agents that have more information do not gain a competitive advantage from using the additional information held (Wilson, 1979, p. 313). Therefore, this does not cause significant inefficiency within the markets. In some cases, a third party, such as specialists (i.e. credit rating agencies), can provide the information needed with low costs and thus help alleviate some of the problem with adverse selection (Wilson, 1979, p. 313).

3.1.2. Market for Lemons

Definition and the use of the theory

The concept of lemons is often used when discussing adverse selection. In the article, *Market for “Lemons”*: *Quality Uncertainty and the Market mechanism*, Akerlof (1970) pioneered the concept by giving examples from the car market. The car market described consists of two main components: new cars and used cars. Used cars can then in turn be divided between those of high quality and those of low quality known as lemons¹³. According to Akerlof (1970, p. 489), sellers of used cars have superior knowledge, after owning the car for a while, regarding whether the car is to be considered a lemon or not. However, since the buyer find it difficult to know if the car is good or bad in the timespan available prior to purchase, they are going to offer the same price regardless of whether the car is a lemon or not.

The price regarded as fair by the buyer will thus stand in relation to the probability¹⁴ of a certain car in the aggregated market being a lemon (Akerlof, 1970, p. 489) As the seller knows the quality of the own car, this would make a seller whose car is of high quality hesitant to sell at what is a discounted price being offered by the buyer. However, the seller of a lemon would be happy to sell at this price given that the person will receive a higher price than the car is worth. This creates a situation where the sellers of poor quality products

¹³ A lemon is common slang for a car of inferior quality

¹⁴ A specific car will with probability (q) be a quality car and with probability (q-1) be a lemon

may have an incentive to take advantage of being in the same group as high quality cars since the returns are accrued to the entire group (Akerlof, 1970, p. 487).

Since the owners of quality cars will be underpaid, it could be assumed they are less likely to put their cars up for sale leading to an aggregated quality degradation throughout the entire market causing the probability of buying a lemon to increase. This is commonly referred to as Gresham's law which states that poor quality assets are bound to drive out quality assets given that they are accepted at the same face value (Aiyagari, 1989, p. 694). The situation can however also act in reverse. In some cases, it might be the buyer who has more information and who could then have incentives to take advantage of the situation. This concept can be used in most instances regardless of the industry or social situation.

The issue of lemons can likely also be observed in the banking industry and within lending processes. It could be assumed that within the aggregated pool of loan applicants, there are always some bad loan applicants among the others. The banks do not always have the resources to thoroughly screen applicants with the degree of precision needed to single out the lemons. Additionally, the necessary information required to do so is not always available. Because of the presence of lemons among bank customers, and the difficulties of dividing between them, a majority of loan applicants are likely to be offered sub-optimal lending terms and conditions compared to their inherent worth. The lemons will however benefit from the higher credit-worthiness of the others within the group and thus achieve better terms compared to a situation where applicants are measured and judged individually. At the same time, the good loan applicants are not getting their optimal loan terms because the lemons pull the cost of capital and collateral requirements higher.

Costs of dishonesty

The concept of the market of lemons also takes into consideration the costs of possible dishonesty where the seller can either sell the good honestly (correctly represent the quality of good for sale) or chose to sell the good dishonestly (misrepresent the quality of the good for sale) (Akerlof, 1970, p. 495). This would not be an issue if it was not for the fact that the buyer has issues separating the two from one another. Thus dishonest offerings have a tendency to drive honest offerings from the market (Akerlof, 1970, p. 495). This drives cost in two ways. The first is through the actual amount paid for the good above its market value and the second is through the cost of driving honest business out of the market (Akerlof, 1970, p. 495). This problem is expected to be exacerbated in developing economies given the assumption made by Akerlof (1970, p. 496) stating that quality variation is larger in developing economies than in developed ones as a result of less granular regulatory quality control and inspection.

If central regulation regarding quality is lower in developing countries, it would be likely to assume a greater responsibility being placed on the inspection by the buyer (which, as stated above, can be difficult without proper knowledge). If the buyer is not sufficiently knowledgeable regarding the intricacies of that good, then the buyer is more susceptible to the cost of dishonesty in developing economies. An example could be the market for pharmaceutical drugs. If a country has a well-regulated pharmaceutical industry, a buyer can, without any medical skills, be relatively certain that a drug will be of a certain quality if purchased through an official outlet. If the market however is under-developed, the buyer faces a much larger uncertainty connected to the purchase. As most buyers of pharmaceuticals are likely to not have any medical training, they are unlikely to be able to discern between a high-quality drug and one of lower quality. Since sellers of inferior drugs could offer lower prices, they are effectively out-competing honest sellers. This leads to a cost of dishonesty both related to the sub-optimal competition and to the increased cost for

the buyer from either having to re-purchase high-quality drugs or falling ill from the low-quality drugs.

3.1.3. Moral Hazard

Definition and implications

Moral hazard is another concept related to the issues of asymmetric information and adverse selection. In short, moral hazard relates to a situation where one or more of the market participants are not acting in good faith by changing their actions after an agreement have come into place. Moral hazard can be seen more as a behavioral and psychological issue rather than a pure situation created by circumstances in the market. While market circumstances affect the possibilities of moral hazard, it originates from the individuals' behavioral norms.

The insurance industry, and health insurance industry in particular, is especially affected by the problem of moral hazard (see Einav et al., 2013; Shavell, 1979). When an individual or a company takes an insurance, it is common that the behavior of the insured agent changes to where they make more risky decisions. For instance, if an individual takes an insurance for sport activities, the individual might start to act riskier because he or she knows they are insured against accidents. Studies also show that moral hazard is a problem with car insurances (Cummins & Tennyson, 1996).

The issue of moral hazard cannot be avoided in the banking industry either. Banks are often thought to act in ways through which moral hazard issues arises and there have been several scandals where banks have been acting unethically. This can be illustrated by Lehman Brothers during the latest financial crisis which led to governmental bailout. Another example is the questionable conduct by HSBC. Moral hazard can also be observed from the perspective of the loan taker. An example of this comes from the behavior of individuals leading up to the subprime mortgage crisis which partly caused the financial crisis of 2007-2008. Since the loan terms for getting mortgages were relaxed, individuals took advantage of the situation. This was done by knowingly entering mortgages which the individual was partly sure they would not be able to repay or act in such a way that the risk for the lender were increased after granting the loan.

The industries suffering the most from moral hazard have developed techniques to decrease the exposure to the problem. One solution is monitoring techniques (Einav et al., 2013, p. 179) which not only have positive impact on the issue of moral hazard but also on adverse selection. Insurance companies and banks can use monitoring to track the behavior and credit history of their clients and thus reduce risk. Also, bank regulations, such as the Basel Accords and additional country regulations, have an impact on banks' behavior (Smelt, 2010, p. 236). For instance, the capital requirements have affected how banks are evaluating applicants. An example from agricultural financing could be farmers who leverage their investment in new machinery using bank loans. The loans are granted based on previous behavior, but once the loan is granted, the farmer might start taking higher risk to pursuit higher profits which, if certain factors do not align, might cause losses sufficient to bankrupt the farmer. In this case, the farmer reaps the benefits if the risk pays off, but the bank would have to cover the cost of the losses if the gamble does not work.

3.2 Diffusion of Innovations

New innovations enter the markets constantly. Some of the new innovations manage to survive entering the market while others are forgotten. While some innovations are of minor significance, others are such that they change or shape the world (e.g. the invention of the galvanic cell and mobile phones).

Nowadays, many innovations are related to technology and making things more efficient. Diffusion and the rate of adoption have been widely discussed and applies to a wide range of situations. One of the milestones was “*Diffusion of Innovations*” by Rogers (1982)¹⁵. However one could consider the study made by Ryan & Gross (1943) of rural sociology to have created the basis for the modern diffusion theory. These studies, among others from the rural field, have successfully been integrated in previous research regarding the adoption of PAT (Lamb et al., 2008).

Diffusion can be understood as a process during which a new idea is communicated widely to society (Rogers, 1995, p. 5). The time dimension is an important part of diffusion and the rate of adoption is one way to perceive this relation between the time dimension and diffusion process. (Rogers, 1982, p. 23). According to (Rogers, 1982, p. 23), “*The rate of adoption is the relative speed with which an innovation is adopted by members of a social system*” and it is normally measured as the number of individuals who adopt a new idea in a specific time period. Rogers (1995) argues that the adoption curve is s-shaped and upward sloping. What this means is that adoption is slow until the diffusion phase is reached. During this phase, adoption increases rapidly until only late adopters are left and the adoption rate slows down.

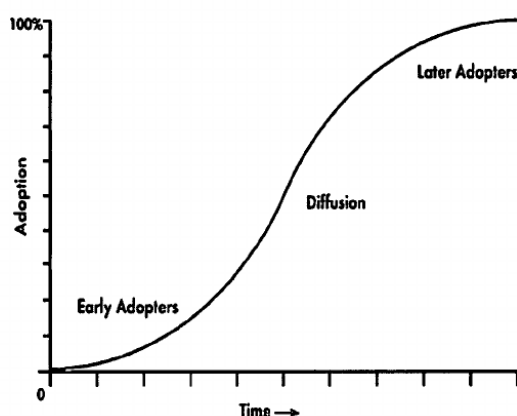


Figure 1 S-shaped diffusion curve (Rogers, 1995, p. 106)

In his book, Rogers (1995), discusses what attributes of new innovations that makes them spread. He recognizes five attributes related to innovations which explains from 49 to 89 percent of the variance in rate of adoptions (Rogers, 1995, p. 206). These attributes are: relative advantage, compatibility, complexity, trialability and observability (Rogers, 1995, p. 208). Next these attributes are discussed closer.

Relative advantage

“*Relative advantage is the degree to which an innovation is perceived as being better than the idea it supersedes* “ (Rogers, 1995, p. 212). Better in this regard refers to either giving an economic advantage, social prestige, or other social benefits.

Oftentimes, a new product is not an instant success, directly generating a relative advantage. Rather, this advantage emerges through several iterations and gradual improvements. Through this process, the cost of production is lowered as the technology become increasingly known by the producers. Eventually, this process will lead to a reduced selling

¹⁵ The first edition of the book was published already in 1962

price which facilitate a more rapid adoption; a process known as “learning by doing” (Rogers, 1995, p. 213-215).

We can see this happening in many modern technologies such as mobile phones, computers, and televisions. Mobile phones used to be very expensive but when the technology became increasingly understood by producers, prices dropped, and adoption increased. This in turn changed the whole industry and created further new innovations. According to Rogers (1995, p. 216), relative advantage is one of the best predictors of the innovation’s rate of adoption.

Thus, new farming technology which offers a relative advantage over the technology that it supersedes should have a higher adoption rate compared to such technology which does not offer the same relative advantage or where the advantage is not as well recognized.

Compatibility

Compatibility refers to how compatible a new innovation is with the existing values and previous experiences of individuals (Rogers, 1982, p. 223). The more compatible an idea is with existing values or experiences, the more likely it is that the idea will generate a high degree of adoption (Rogers, 1982, p. 223).

Rogers (1995, p. 235) also notes that some innovations should be introduced in packages rather than separately as this will increase the rate of adoption. For instance, a package of agricultural innovations was recommended to be used when being introduced to Indian and Asian farmers. The adoption rate of such things as chemical fertilizers and rice varieties developed by the International Rice Research Institute (IRRI) would probably not have been as high among these farmers if they had not been introduced as part of a package but rather introduced separately (Rogers, 1995, p. 235). If PAT are compatible with current machinery, or if the usage of PAT does not significantly alter the core working mechanics of farming, then the adoption of this technology should go faster and have greater reach.

Complexity

Complexity refers to how difficult it is for a person to understand a new innovation (Rogers, 1995, p. 230). Since there exist a negative correlation between the complexity and the rate of adoption, (Rogers, 1995, p. 250) there is a direct relation between these two factors. Technological innovations are often seen complex at the first and individuals, as well as companies, may be hesitant to start using more complex innovations. For example, in developing countries, farmers may not have the required knowledge to use the latest farm technology which then negatively affect the adoption rates. Furthermore, Ali (2012) finds that proper education has a positive impact to the adoption rates. Because of this, PAT which require advanced computer knowledge to operate or which offer benefits which are hard to grasp at a glance should suffer in terms of adoption rate.

Trialability

According to Rogers (1995, p. 243), “*trialability is the degree to which an innovation may be experimented with on a limited basis*”. Trialability is also positively correlated with the rate of adoption. Trialability is generally more important for early adopters than for laggards as the laggards have the possibility to base their decision on the experience of the early adopters and thus gain an understanding of the innovation prior to their purchase decision (Rogers, 1995, p. 231). Thus, precision agricultural innovations which are easy to retro-fit should have a higher adoption rate among early adopters as they possess a higher degree of trialability. This does however not limit itself to the compatibility with current machinery or operations. If the cost of adoption is sufficiently low to the point that the financial harm

in case of a miss buy is limited, then this could also be considered to increase the trialability of a product or technology.

Observability

Observability is the last factor which affects the spread of new technology. According to Rogers (1995, p. 244), observability is described as the degree to which the outcomes of a new innovation are visible to others. Of course, with some innovations, the results are easily observed whereas with others, it may be more difficult to see the actual results and whether they are good or bad. Observability is positively correlated with the rate of adoption (Rogers, 1995, 251). For instance, if new technology is implemented in agriculture and the results can be easily observed, this should affect further adoption positively (given positive results).

3.2.1 Timing of adoption

Bass (1969) was another pioneer in the diffusion and rate of adoption discussion. He created the Bass Model which explains the process through which the new ideas are adopted in a society. He emphasized the importance of timing of the adoption. Bass (1969), classifies the adopters into five different groups based on the time of adoption. The adopter groups are as follows: 1) Innovators 2) Early adopters 3) Early Majority 4) Late Majority and 5) Laggards. Innovators are an adopter group not very influenced by timing as they are the forerunners who like new ideas and are not persuaded by social pressure or opinions. The other groups are affected by social factors and timing to a higher degree. Bass (1969, p. 216) describes these groups as being imitators. Imitators learn from innovators and make their decisions based on the experiences of others. According to both Rogers (1995) and Bass (1969), innovators adopt new innovations earlier than the imitators and make their decisions based on their interactions with other innovators. Laggards, on the other hand, hesitate to adopt new innovations until the late stage of the diffusion process (Bass, 1969; Rogers, 1995).



Figure 2 Steps of the adoption process
Source: based on Rogers (1995, p.262)

The figure above based on Rogers (1995, p.262) shows the rate of adoption during the diffusion process. From the figure, innovators represent a very small portion of the entire population, while early adopters and laggards, though small in comparison to the majority, are still vastly more populous than the innovators. The two biggest groups, early and late majority are adopting the innovation at the top of the curve, after early adopters have adopted the technology and when the trend starts to decline.

3.2.2 Adoption rates in Agriculture

Agriculture and agricultural technologies have been widely studied for a long time (Ryan and Gross, 1943) and studies from the rural field have laid the foundation for the theories

of diffusion and adoption rate discussed by Rogers (1995) and Bass (1969). Many of the earlier theoretical studies of diffusion emphasize the importance of farm size and credit constraints in the agricultural field (i.e. Feder, 1980; Feder, Just & Zilberman, 1985). According to Marra et al. (2003, p. 215), the main features of a new innovation affecting farms' adoption rates are risk, uncertainty and learning while Abdulai & Huffman (2005) argue that the location of a farmer matters when studying the adoption rates. The fact that location is influencing the adoption causes farms closer to local markets to be more likely to adopt new innovations faster compared to ones further away (Abdulai and Huffman, 2005). The reason behind this is believed to be that farms closer to markets are more likely to receive credit. Additionally, farmers closer to population centers are easier to monitor and should thus suffer less from the issues discussed previously in this chapter. Because of their improved access to credit, they are more likely to adopt new agricultural technology.

Furthermore, from the farmers' perspective, the adoption rate depends on the perceived utility received from adoption. Given that farmers' utility can be expected to be derived from the amount of output, and the efficiency with which they can produce this output, and the fact that most studies hold farmland as a fixed variable, the utility received by a farmer should result from the productivity of the land they currently hold (Feder et al., 1985, p. 258).

Trialability is another important factor for farmers. They often evaluate the possible utility gained from adopting a new technology by seeking experiences from other farmers who have already adopted the technology (Feder et al., 1985, p. 264). Social learning, which relates to Bayesian theory, explains that the probability of an event, based on previous information, is one of the most important factors affecting the adoption rates in agriculture together with geographical location (Abdulai & Huffman, 2005).

As can be seen, there are many factors in play when it comes to lending to farmers and farmers adoption of new technology. Many of the concepts discussed in this chapter are going to help explain the adoption of precision agriculture among farmers and help explain some of the problems faced by both banks and loan applicants. Going forward we are presenting a thorough review of existing literature regarding banking and agricultural technology to give the reader a deeper understanding of the theoretical foundation upon which we build the thesis.

4 Review of agricultural finance literature (anna)

The literature review section is divided into two separate sections. This first section will introduce previous literature and studies related to banking and agriculture. It starts by looking at the objectives and risks that concern banks when making lending decisions to agricultural companies. Risk types, such as, production risk, market risk, credit risk and political risks are discussed as well as farm volatility. Lastly, different aspects of asymmetric information within agriculture are introduced and possible solutions to the agricultural risks are brought up.

4.1 History of agricultural banking

Agriculture is one of the oldest industries in the world and people have used agriculture to make a living for themselves and feed their families since the very beginning. Therefore, it is no wonder that the agriculture credit system is old as well. Credit systems within agriculture were recognized early and Europe has long been at the forefront when it comes to agricultural credit (Farm Credit Bank of Texas, 2017). Before agricultural bank lending, credit cooperatives were common (Farm Credit Bank of Texas, 2017). According to FCA (2014), credit cooperatives across the world should be: 1) open to everyone with voluntary involvement, 2) democratic organizations controlled by their members, 3) operated such that members contribute equally to the capital of the cooperative, 4) independent and autonomous, 5) providing necessary training and education to their members and to others linked to the operations of the cooperative, 6) working together with other cooperatives across the world, and 7) working for the greater good, i.e. for sustainable communities.

The first cooperative system was established in New London, Connecticut already in 1732 (FCA, 2016), but the beginning of 1800 century was the big starting point for the agricultural credit cooperatives. In the 1850s, Germany started agricultural credit cooperatives and, by world war I, these were large financial institutions within the German market (Guinnane, 2001, p. 366). The idea of credit cooperatives spread across Europe and the United States (FCA, 2016). Credit cooperatives were more common than bank loans at this time among farmers and it is argued that the credit cooperatives had an efficiency advantage over banks because the cooperatives knew their customers better than traditional banks and were able to use sanctions not available to banks at the time (Guinnane, 2001, p. 367). This implies that there were more information asymmetries between farms and banks than between farms and credit cooperatives.

The Federal Farm Loan Act was passed by congress in 1916 (FCA, 2016). The purpose of the act was to make sure that farmers had access to the credit market and to find new ways to enable this. This was done by improving how loans were granted, reducing the, at this time, large administrative costs and commission charges and stipulating uniform interest rates on land-mortgage loans (Putnam, 1916, p. 780). Alongside agricultural credit cooperatives, specialized agricultural banks have existed from the beginning of 1800s, despite cooperatives offering seemingly better credit systems. The national banks were, for instance, able to offer loans to farmers in the US (Kemmerer, 1912, p. 853). However, during that time, the interest rates for farmers were high and it was difficult for them to get long-term credit compared to short-term credit (FCA, 2016). Even though the banking system did develop in the US, it should be noted that the development of the agricultural credit system was minimal compared to other areas and also compared to more progressive countries (Kemmerer, 1912, p. 852).

Not all banks have neglected agriculture. Many big banks, such as French Credit Agricole, started their operations as a pure agricultural bank and only later expanded their operations to the consumer and investment bank sector (Credit Agricole, 2018). Agricultural banks

have deep knowledge of industry specific issues and are well versed in the objectives of agriculture. In addition to credit cooperatives and agricultural banks, regular consumer banks such as Nordea and Swedbank in Sweden, offer their services to agriculture as well (Nordea, 2018; Swedbank, 2018).

4.2 Agricultural risks

Commercial banks have been an important part of agri-lending for a long time (Betubiza & Leatham, 1995, p. 112). Agricultural loans distinct themselves from other commercial and retail loans due to the special characteristics of the agricultural industry (Barry, 2001, p. 115). Agriculture is cyclical and vulnerable to extreme weather conditions as well as diseases and pests (OCC, 2014, pp. 3–6). Also, politics and other macroeconomic changes across the world affect the industry since it is a key industry in many countries and thus a politically debated topic. When discussing risks in this context, it is important to note the difference between two concepts: risks in agriculture and risks in agricultural finance (Maurer, 2014, p. 140).

While the risks in agriculture is concerned with the risks farmers are exposed to, risk in agricultural finance relates to the risk of lending to farmers from the perspective of financial institutions. These risks are made up from the following components: 1) credit risk, 2) agricultural specific risk (Production risk and market risk), and 3) political risks (Köhn, 2014, p. 141-145). Even though some of these concepts can be hard to separate, the risks in agricultural finance differ from those in agriculture.

As these risks will be central to the thesis, we will go through them more in depth while also explaining volatility and asymmetric information in agriculture. While market risk and political risks are important in agri-lending (Deutsche Bank, 2009; Maurer, 2014), the fact that the farmer cannot influence these factors to the same degree as they can with credit risk and production risk means that less emphasis will be given to these risks.

4.2.1 Production risk

Production risks are industry specific and thus, what constitute a production risk differ between industries. According to Hardaker et al. (2004, p. 6), production risk in agriculture arises from unpredictable weather conditions and the uncertainty of crop performance. As farmers cannot fully control the extent to which they are exposed to production risk, it can be hard to mitigate. At the same time, production risk is one of the most important risks in agriculture (Schaffnit-Chatterjee, 2010) and one which farmers are likely to be increasingly exposed to in the future (Meuwissen et al., 2001, p. 343; Schaffnit-Chatterjee, 2010). This makes understanding production risks even more important. One of the reasons for this increased exposure is the more pronounced specialization in farming as more farmers rely on monoculture cropping where a farm produces only a single crop at a time (Schimmelpfennig, 2016). Through this strategy, a farmer can increase yields but, at the same time, it could make the crops more sensitive to diseases and harvesting at the right time becomes more difficult (Maurer, 2014, p. 142). Implementing this on a large scale could lead to higher earnings but could also increase the risk of something going wrong which would leave the farmer unable to cover the loan expenses. While this risk is related to the production at the farm, it is clearly also a financial risk for the bank. By relying on only one crop, the farmer is left more vulnerable to crop damage related to pests affecting this particular crop (Schimmelpfennig, 2016). Meuwissen et al. (2001, p. 344) argue that through the regulation of pesticides and herbicides, and the discontinuation of the catastrophe loss compensation previously provided by many governments, the need for finding new solutions to this problem is becoming increasingly pressing.

Even though farmers can take preventive actions against pests and diseases, the risk cannot be alleviated fully. It is also difficult to provide accurate long-time weather forecasts and because of the exposure to the elements, future earnings forecasts are more difficult to generate compared to other industries. For instance, a Canadian study revealed that as many as 78 percent of farmers have had financial loss from weather related factors during the three-year period investigated (Khan et al., 2010, p. 170).

The financial risk for banks related to production risk can somewhat be mitigated if farmers purchase insurances which enable them to recoup some of the amount lost due to adverse weather conditions. However, studies have shown that such insurances often only partially cover the loss with 50 percent of farmers being forced to add additional instruments to be sufficiently protected (Khan et al., 2010, p. 173). One of the reasons for this is that low frequency/high severity events are often not included and must be hedged against using weather derivatives or similar instruments which pay out related to the deviation from normal conditions rather than based on the amount of loss sustained (Geysler, 2004, p. 445-446). However, banks cannot fully rely on this to mitigate risk either as studies have shown that around half of US farmers are unaware of the existence of such instruments and only 10 percent of US farmers actually use them (Khan et al., 2010, p. 174). Similar studies from Europe show that the current insurance level in EU is still insufficient to smooth farm income changes in poor years (Schaffnit-Chatterjee, 2010, p. 1).

Production risk is thus a somewhat uncontrollable factor from the banks' perspective as they cannot reduce it by themselves and including production related risks into their credit rating models is getting increasingly complex. This problem becomes aggravated when looking at small farms. These farms are more vulnerable to production risks since they cannot diversify their production as well as large farms can due to the lack of capital, labor force and land, which makes small farm loans being perceived as particularly risky and unprofitable for banks (Carter, 1988, p. 102). According to the World Bank (2005), improved risk management tools for production risks are important in order to increase the amount of credit in agriculture and new technology in agriculture plays an important role in this. These new technologies will be further explained in the upcoming section devoted to agriculture, but generally it can be said new technology which capture more data could be beneficial when it comes to risk analysis.

Ever since Basel II was introduced in 2004, quantitative risk management has become increasingly important for financial institutions (Castro & Garcia, 2014, p. 2). This also means that understanding the risks involved when lending to agriculture receives additional focus from the banks. (Castro & Garcia, 2014, p. 2). Especially rural banks, whose portfolios are heavily weighted towards agricultural loans, must carefully assess the impact of production risks since their portfolios cannot be diversified in a similar way as loan portfolios of commercial banks. As production risks within agriculture affect the creditworthiness of the farms, it thus also directly affects the risk of default and subsequently credit risk which is introduced next.

4.2.2 Credit risk

Credit risk is the primary risk group for financial institutions (Barry, 2001, p. 104). Credit risk, or default risk, is the risk of losses or foregone profits due to the default of the borrowing party. Banks are naturally concerned with the creditworthiness of agricultural businesses and the likelihood of default. They are also required to disclose information about credit risks in their trading and banking books. Creditworthiness is evaluated based on the information of farms' ability to meet the terms of the loan contract and on how well the farm can assure that the risks of lending are minimized (Barry et al., 1981, p. 217).

Credit risks are, unlike production risks, not as industry specific and can thus more easily be observed and compared to other businesses. The similarities between normal business corporations and farms when it comes to credit risk means that the basic principles of credit risk are the same. For instance, large agricultural loans are likely to be treated in a similar way to commercial loans, whereas small farm loans are similar to retail loans (Barry, 2001, p. 115) where net cash flows are important drivers.

According to Barry et al. (1981, p. 217), identifying forces that effect the supply of credit and farm risks is difficult due to the complexity of credit determinants. These determinants originate from financial markets and agriculture itself. For instance, macro-conditions attributed to monetary and fiscal policies and structural characteristics of financial markets might have an influence on the costs and availability of agri-loans (Barry et al., 1981, p. 217).

Banks capital adequacy requirements

Credit risk is a factor in bank regulations and it is taken into consideration in the Basel Accords. Banks are required to have sufficient capital adequacy and therefore the Basel Committee developed the original Basel Capital Accord (Basel I) in 1988 (Harrison & Hoskin, 2011, p. 5). The idea behind Basel I was to implement global capital adequacy requirements for banks which provided a sufficient link between the credit risks associated with the assets held on banks' balance sheet and capital requirements (Harrison & Hoskin, 2011, p. 5-6). Agri-loans were placed in the same group as commercial loans and the risk weight of this group was set at 100 percent (Harrison & Hoskin, 2011, p. 6). Basel II was established in 2004 and introduced the three-pillar model where pillar I stipulated the minimal capital requirements for the three main sources of risks faced by banks (credit risk, operational risk and market risk) (Magnus et al., 2017, p. 3). Pillar II and III instead regulated supervisory review and market discipline (Magnus et al., 2017, p. 3). One of the major changes between Basel I and Basel II was the increase of risk sensitivity of the credit risk capital requirements (Harrison & Hoskin, 2011, p. 6).

Under Basel II, the risk weighted assets (RWA) are calculated in relation to certain group types of loans by using specific weighting (Harrison & Hoskin, 2011, p. 6). This means that the banks use specific weights for agri-loans when estimating the RWA. The risk weights should not work as a determinant for prioritizing different types of lending but rather to get the riskiness of different types of lending right to ensure that the banks hold an appropriate level of capital in reserve (Harrison & Hoskin, 2011, p. 6). Basel III, which was introduced in 2013 increased the existing capital requirements further but the basic principles remained the same with capital requirements staying at eight (8) percent (Magnus et al., 2017, p. 3). Banks under Basel regulations are also required to disclose information about the RWA and credit value at risk (VaR) (Magnus et al., 2017).

Credit rating systems of agri-loans

After the introduction of the Basel Accords, new credit rating systems have been developed among financial institutions to meet the new capital requirements (Katchova & Barry, 2005, p. 194). In practice, financial institutions sort farms into different credit groups based on, among other things, their default or survival probability ratios (Katchova & Barry, 2005, p. 194). There are two ways to calculate the historical default rates. The first way is to calculate the percent debt in default whereas the second is to calculate the percent farms in default (Katchova & Barry, 2005, p. 196). To calculate percent debt in default is the most common of the two given that it better reflects the impact on profitability and capital requirements (Katchova & Barry, 2005, p. 196). Shortfalls in cash flows often leads to a situation where

the farmer cannot fulfill his/her debt obligations and could ultimately end in default unless the farmer is still to be considered solvent¹⁶, in which case the loan can be refinanced and a default can be avoided (Katchova & Barry, 2005, p. 195).

If the exposure of farm debt in the portfolio is similar, the portfolio risk depends on the number of farms in the portfolio and the correlation of asset returns between farms (Katchova & Barry, 2005, p. 196). Financial institutions that lend money to farms often have their own internal credit risks models which are used to assess the risks. These models are normally using estimates of the probabilities of borrower defaults (PDs) and loss given default (LGD) to estimate credit risk (Pederson & Zech, 2009, p. 170). Traditionally, banks have been using subjective analysis methods or banker expert systems to calculate the credit risk. In practice, this means that a bank is relying on special expertise within the field in their internal credit rating systems where the borrower's characteristics and other factors are considered (Bandyopadhyay, 2008, p. 88). Often the characteristics included can be summarized as the so called "5 Cs" of credit: Character of the borrower, capital (leverage), capacity, collaterals, and conditions (Bandyopadhyay, 2008, p. 88). These are used in conjunction to make an overall estimation of the creditworthiness and default risk of a borrower. However, Pederson & Zech (2009) find that implementation of these models is difficult due to the seasonality in agriculture, the need for external financing as well as the high degree of inter-correlation among industry default rates which relates to the homogeneity of agri-loans.

With homogeneous loans, such as agri-loans, the use of credit quality classes has the advantage of precise estimation of default and loss given default (Katchova & Barry, 2005, p. 198). The CreditMetrics Model (developed by J.P Morgan) , used by Katchova & Barry (2005) is a credit rating system, which calculates the probability that a loan moves from its current credit quality class to the worst credit quality class (default). Another measure available is the KMV model (developed by Moody's KMV) which is also used by Katchova & Barry (2005). The model first measures the probability of default for every farm and then groups the borrowers into credit quality classes based on their probability of default (Katchova & Barry, 2005, p. 199). In their study, Katchova & Barry found that the historical default rate among US. farms is 0.785 percent and that the average LGD¹⁷ is 35.468 percent of the borrowed amount. (Katchova & Barry, 2005, p. 199). Because of the cost associated with borrowers defaulting on their loans, high quality credit risk models are essential for enabling banks to identify and remove borrowers that carry too high credit risk as well as to determine the amount of debt for eligible borrowers (Pederson & Zech, 2009). As agricultural lending is perceived as riskier compared to other industries, then the risk modelling should be of particular importance in agri-financing.

A step towards improving the risk models is the inclusion of non-financial factors when forming credit ratings and making loan decisions for farms to help banks to paint a more comprehensive picture of the creditworthiness of a farm (Olagunju & Ajiboye, 2010, p. 7). These non-financial factors are things not found on the balance sheet or income statement such as the characteristics of the farmer, future plans and development ideas. These factors could provide more information about the motivation of the farmer and the future growth plans as well as other things which might be interesting from the banks' perspective.

¹⁶ When the value of assets > the value of debt

¹⁷ Loss given default (LGD) is the percentage of a loan not recovered if the borrowing party were to default on their loan obligations

4.2.3 Market risk

Another important risk category is market risk, often known as price risk. Market risk arises from the uncertainty of output prices (e.g. crop) and price volatility. Commodity prices in agriculture are normally highly volatile in the short-term. This volatility is often caused by changes in input prices such as fuel and fertilizer (Deutsche Bank, 2009, p. 18). For instance, the agricultural sector was very volatile during 2008 partly because of the correlation with oil prices, a weakening US dollar, and biofuel demand for corn (Deutsche Bank, 2009).

Market risk and production risk are often positively correlated (Hartig et al., 2014, p. 174). Market risk can be caused by local factors but also by global changes. For instance, segmented agri-markets are normally influenced by local supply and demand whereas international production dynamics affect globally integrated markets more (Maurer, 2014, p. 143). Farmers cannot fully affect market risk by themselves, but they can protect against it e.g. by using derivatives such as futures and forwards.

As with other agriculture specific risks, it is difficult to manage market risk. Due to the myriad of factors affecting prices globally which makes it almost impossible to forecast short term future prices. Market risk is also not as affected by new technology with the exception of enabling lowering overall costs. However, given the volatility of exchange rates and oil prices, the effect of technology on price risk might be hard to measure. In other words, the actual effect of technology on price risk might be difficult to separate from the other influencing factors.

4.2.4 Political risk

Political risk is also often referred to in agri-finance discussions. According to Maurer (2014, p. 144), agriculture is an important and highly strategic industry for governments and organizations in both developing and developed countries. The reason is that agriculture is one of the major source of income for many people globally and it contributes heavily to GDP in many countries. The economic importance together with the insufficient food supply in parts of the world make agriculture a sensitive political topic (Maurer, 2014, p. 144). For instance, price interventions are popular within the agricultural sector because low food prices are normally in the interest of consumers (Florenta & Georg, 2008). However, the low income level of small farmers can cause heated feelings which sometimes leads to prices floors being set up by the governments to improve the economic situation of small farms (Florenta & Georg, 2008). Other legislations, such as the restriction on GMO-crops by the European Union are also affecting farm operations (European Commission, 2018).

4.2.5 Volatility

Volatility is also playing an important factor in agri-lending. For instance, volatility in cash flows affects loan repayments and are thus linked to credit risks (OCC, 2014, p. 2-5). Volatility has many sources but is generally caused by the variations in farm output combined with relatively inelasticity of demand/supply (Tangermann, 2011). According to Tangermann (2011), farm volatility globally has not systemically increased in the last fifty years with the exception of 2006-2008 and 2010-2011 when two major food price spikes occurred. A study by Hill & Bradley (2015) found that among the EU countries, 55 percent of large farms and 38 percent of small farms have experienced income volatility of ± 30 percent from the previous three year average when measured at the individual farm level. It is also notable that the volatility in prices and farm income is believed to increase in the future (Madre & Devuyst, 2016).

Betubiza & Leatham (1995) found that financial institutions are lending less money to agriculture compared to other investment opportunities in countries where the farm income

is more volatile compared to nonfarm income. Betubiza & Leatham (1995, p. 123), also found that a one percent increase in farm risk, measured as the ratio of the coefficient between farm income volatility and the total income volatility in each country, decreases agri-loan portfolios by 0.3 percent. Hence, it can be assumed that lenders in countries where the farm income volatility is higher than in other industries prefer loan portfolios with non-farm debt as these will have an impact on access to credit for farms. Moreover, rural insurance markets and informal rural institutions affect the income volatility either directly or indirectly and thus have an impact on farms' access to credit as well (Ciaian et al., 2012, p. 24).

The discussion about volatility requires tying several factors together. For instance, the law of supply and demand will determine a specific level of crop production. If the demand remains at the same level during times of low production, in other words, when the supply is low, the prices will increase. These price fluctuations will in turn affect the income volatility of farms (Madre & Devuyt, 2016). Fluctuations in income might have an impact on the ability to meet loan obligations. Subsequently, it can be assumed that high volatility in farm income increases the risks for banks and could lead to higher costs of capital.

Enjolras et al. (2014) studied the effect of risk management tools on farm income volatility in Italy and France and found risk management tools to reduce income volatility and also that an increase in input efficiency increases crop-related income. The high volatility in income and prices in agriculture globally during the past 10 years has increased the interest in risk management tools in agriculture (Hill & Bradley, 2015, p. 2). This could imply that new technologies which enable more efficient use of inputs and bring new solutions to risk management in agriculture in addition to decreasing farm income volatility and increasing farm productivity could become more widespread going forward.

4.2.6 Asymmetric information in agriculture

Asymmetric information in farm insurances have been frequently studied with many studies finding adverse selection being present in crop insurances (see e.g. Skees & Reed, 1986; Quiggin et al., 1993; Makki & Somwaru, 2001). Agricultural insurances are therefore, alongside health- and car insurances, a group where adverse selection is a problem. Even though the issue of asymmetric information is most prevalent with crop insurers, lenders, such as banks are also concerned about information asymmetries (Skees, 2003).

Asymmetric information has been studied extensively from several different angles. Goodhue and Simon (2016) studied adverse selection in farm contracts with focus on the effects of asymmetric information between the farm and the buyer of goods while Smith & Stutzer (1990) studied the connection between self-selection mechanisms and adverse selection as well as systemic risk in Farm Credit System (FCS). The findings in these studies support the prevalence of adverse selection and moral hazard in farm lending. For instance, Goodhue and Simon (2016, p. 20) state that asymmetric information may occur due to private information regarding farm's productivity allowing for some farms to collect information rents at the expense of the buyer.

The problem of asymmetric information is however two-fold. While moral hazard and adverse selection are often thought to occur among a group of borrowers, they can also occur in financial institutions. Adverse selection by financial institutions can take the shape of simply choosing more profitable borrowers (Jack et al., 2016). The study by Jack et al. (2016) looked at Kenyan farms and suggested that profit maximizing deposits will exceed the socially optimal deposit rates of farm loans when influenced by adverse selection. In other words, profit maximizing would in these instances be valued higher by the financial

institutions than the rates that would be socially optimal. This implies that from a social perspective, the presence of adverse selection among financial institutions is disruptive. Jack et al. (2016) also argue that adverse selection creates market failures leading to excessive borrowing requirements.

Interest rates play an important role within credit markets and are linked to adverse selection as interest rates are set based on the perceived ability of a borrower to repay their loan (Stiglitz & Weiss, 1981, p. 393). Furthermore, banks use different screening devices to separate the “good” borrowers from “bad borrowers” and interest rates can work as a screening device (Stiglitz & Weiss, 1981, p. 393). This screening process works as follows: In sound credit markets, interest rates are positively correlated with an increase in risk which suggest that companies being perceived as riskier will be offered a higher interest rate to compensate the lender for accepting higher risk. Stiglitz & Weiss (1981) state that changes in interest rates cause adverse selection because only the riskier borrowers will apply for loans with higher interest rates. In addition, this changes the behavior of borrowers. Stiglitz & Weiss (1981) argue that high interest rates will cause firms to undertake projects with lower probability of succeeding but with higher pay offs when succeeding. In other words, companies would prefer to make riskier investment choices when the cost of capital is high which implies moral hazard problems among borrowers. This in turn causes further adverse selection among lenders who raise interest rates further to compensate.

The lemon problem is related to the issue of adverse selection in agri-finance as well. As stated in the car example (Akerlof, 1970), sellers of poor quality products take advantage of being lumped together with sellers of high quality products. The same may occur within the credit market. For example, a group of small farms which operate at the same level and provide same products, are most likely belonging to the same credit category. Therefore, lenders might not be able to separate “lemons” from good borrowers. In a situation like this, the properly managed farms with low default risk will be evaluated as riskier than they really are whereas mismanaged farms presenting high default risk are evaluated as relatively less risky. Therefore, low-risk borrowers must pay interest rates in excess of their actual default risk, effectively discouraging them from applying for loans. At the same time, this causes an interest discount for risky borrowers which induces them to take loans, increasing the overall portfolio risk for banks.

4.3 The riskiness of agri-loan portfolios

Farm income and commodity prices increased sharply during the 1970s leading to raising farm land valuations which peaked in 1981 with a boom in farmland purchases leading to increasing debt-asset ratio of farms (Li et al., 2013, p. 121). During the coming six years, the value of land declined by 50 percent and the many farm bankruptcies that followed caused interest rates to soar (Li et al., 2013, p. 122). The farm crises of the 1980s were pointed out as one of the main precursors of the economic downturn during which, many researchers found that large exposures to agri-loans might increase the probability of bank failures (Li et al., 2013, p. 120). The debt to asset ratio was as high as 22.19 in 1985, compared only 10.74 in 2010 and overall, farms' economic situation has improved since the 1980s (Li et al., 2013, p. 122).

However, Li et al. (2013, p. 120) states that during downturns, it seems that there is less confidence in the agri-loans since the agricultural sector is still considered vulnerable to business and financial crisis. Similar conclusions are drawn in a study made by Harrison & Hoskin (2011, p. 9). The high degree of homogeneity in agri-loans means that similar stresses are affecting all participants in agri-finance during a severe downturn (Harrison & Hoskin, 2011, p. 9). In addition, the farm collateral markets tend to become highly illiquid

under these conditions. During a severe crisis, the combination of these two factors would cause problems. Receiving a new loan to repay at maturity would be highly improbable and selling the farming operation would be difficult given the similar situation faced by other farmers due to homogeneity which would force many farmers to sell at the same time (Harrison & Hoskin, 2011, p. 9). This causes loan maturities to be longer than the contractual maturities in practice (Harrison & Hoskin, 2011, p. 9). The changing capital requirements will also lead to increasing average risk weights among agri-loans (Harrison & Hoskin, 2011, p. 11). In addition, based on the study conducted in New Zealand, the lenders and borrowers are more aware about the consequences of the falls in farm values and actual loan losses which has appeared to increase the lending margins on rural loans (Harrison & Hoskin, 2011, p. 12).

Li et al. (2013) have developed an early warning model for commercial bank failures which includes factors that might forecast the upcoming failures, with special attention given to agri-loan portfolios. They found that agri-loan ratios cannot be used as predictors when forecasting banks' survivability as agri-loan activities are not correlated with the likelihood of bank failures. Instead, Li et al. (2013) found commercial, consumer, and industrial loans to be significant predictors of bank failures. Therefore, banks' decisions to lend to agricultural companies, which have been seen volatile and vulnerable to economic shocks, do not increase the likelihood of bank failures. Additionally, compared to their status during the 1980s, it seems as if that farms are now financially healthy enough to survive during financial crises (Li et al., 2013, p. 133) which could indicate that perhaps the risky reputation of agri-loans is exaggerated in today's environment.

4.4 Solutions to agricultural finance related issues

4.4.1 Structured finance instruments

One possible solution to banks' risks management issue is structured finance (SF) instruments. There is no one clear definition of SFs, but they are commonly known as a flexible engineering tools that can be used by those who are concerned about risk transfer and funding liquidity (Hartig et al., 2014, p. 168). SFs are currently not that common in agri-finance, but a study of their effects and usefulness in agricultural lending by Hartig et al., (2014) points to advantages of using SF in agri-finance. It, for example, allows farms to focus on high value cash crops which are more profitable (Hartig et al., 2014, p. 193). Moreover, small farms might get better access to credit and receive better loan terms due to the lowering of risks such as market and productions risks (Hartig et al., 2014, p. 193). However, it should be stated that SFs are not without their limitations as the setup of SF is costly and complex (Hartig et al., 2014, p. 193). Additionally, small farms remain a challenge due to the scale of their operations as they might not have the time, money, or knowledge needed for setting up the SF arrangements (Hartig et al., 2014, p. 193). Furthermore, the agricultural finance operations by professional banks in developing countries are likely to increase, which increases the demand for different structured finance instruments (Hartig et al., 2014, p. 193). New products in agri-finance should encourage financial institutions to better understand the advantage of implementing new technologies which corresponds to agricultural objectives and thus develop a deeper understanding of the agricultural risks and how to prevent and hedge against them.

4.4.2 Farm collaterals

As with any financing, collaterals in the form of fixed assets, cash or other securities are often required. Collaterals provided by the farmers are an important part of the lending process as the purpose of the collateral is to secure the receivables of the bank (Cadot, 2013, p. 344). If a farm defaults and cannot afford to repay the loan, the collateral is used to cover potential losses. Agriculture is an interesting industry as collaterals function differently

compared to other industries. As discussed earlier, the value of the land stays somewhat constant over the time and land usually do not depreciate (Zhengfei & Oude Lansink, 2006, p. 647). Because of this, land could be a secure collateral for financial institutions when lending to farmers. Land also contains the crops planted. However, since the crops growing on the land are what provides the cash flow enabling farmers to pay for their loan expenses, the fact that a farmer defaults on the loan would likely mean that the harvest is not bringing the value it was expected to (OCC, 2014, pp. 2–5). This would mean that the crops themselves do not make for very good collateral.

Moreover, most small farms possess only little to no assets and few farms have land or goods considered suitable as collateral by banks (Florenta & Georg, 2008, p. 831). The amount and form of collateral are normally subject to negotiations between the farm and lender and can be made up of both land and personal guarantees (Cadot, 2013, p. 345). This implies that small farms could use personal guarantees in a situation where both the land value and farm-assets are too low.

In the case of asymmetric information and moral hazard, it is likely that the loan terms are stricter and collateral requirements higher. Boucher et al., (2008) find that asymmetric information can result in two types of credit rationings: risk rationing and conventional risk rationing. Risk rationing occurs in situations where insurance companies are absent and the fear of asymmetric information by the lender shifts so much of the risk to the borrower that the borrower does not accept the deal (Boucher & et al, 2008, p. 409). For instance, the collateral requirements might be so high that the risk shift to the borrower is considered unreasonable and causes the borrowing party to pass on lending the money.

Yaldız Hanedar et al. (2014) find that in the case of SMEs, the collaterals in loan contracts are mainly determined by the characteristics of the borrower such as firm-risk and loan variables. Furthermore, company location and firm-size are important determinants (Yaldız Hanedar et al., 2014). For instance, companies located in big cities and with more employees are more likely to be offered favorable loan contracts with lower collateral levels (Yaldız Hanedar et al., 2014). This implies that, especially small farms located in the countryside, are treated less favorable compared to more centrally located big farms when it comes to collateral levels. Given that smaller farms should, on average, hold a lower total land value and that certain fixed costs associated with entering a loan contract exist, then financial institutions should be less willing to lend an equal amount to a smaller farmer as compared to a larger farmer (Hartig et al., 2014). This is reasonable as similar costs and less collateral to cover the loan should translate to higher risk and thus cause the smaller loan applicant to appear less favorable.

4.4.3 Monitoring systems

Einav et al., (2013) suggest that with new monitoring systems and technology, the major issues with adverse selection and moral hazard could be solved. Kahn & Winton (2004, p. 2532) notes that bad loans could be dealt with by having a separate department in a bank which would take care of the high-risk loans. However, as it once again is difficult for banks to differentiate the bad loans from good loans, this would not be the most ideal solution as it will not bring any preventive tools capable of combating moral hazards since information asymmetries are hard to identify in practice with current methods (Karlan & Zinman, 2009, p. 1994). New technology which enables more efficient tracking and monitoring in agriculture could improve the situation. For instance, if drones are heavily adopted in agriculture, the data they collect could be shared with financial institutions. Sharing this type information regarding farm performance to financial institutions could alleviate some of the problems related to moral hazard.

4.4.4 Warehouse receipt financing system

An alternative to traditional farm collaterals is warehouse receipt financing systems which uses stored goods, such as crops, as collateral (Höllinger et al., 2009). These warehouses are either bank approved or bank owned (Höllinger et al., 2009, p. 14) which gives the bank some level of control of the trustworthiness of the receipts being given out by these warehouses. These warehouse receipt works by having a farmer store the harvest in the warehouse, for which the farmer receive a guarantee of the quantity and quality of goods stored. Based on commodity prices, this gives the lender a proof of collateral possessed by the borrower and enables the lender to calculate the price of the loan. The warehouse receipt is then used as a collateral for the loan that has been granted (Höllinger et al., 2009, p. 16). At the maturity, the farm sells the commodity to a buyer who then pays directly to the lender (the bank) or the borrower (the farm) who, in this case, repays the bank (Höllinger et al., 2009, p. 16). In case the farm defaults, the lender can use the warehouse receipt to take control over, and sell, the commodity stored in the warehouse to offset the amount still unpaid by the borrower (Höllinger et al., 2009, p. 16). By using warehouse receipt system, the bank shifts the credit risk from the borrower (the farm) to the warehouse operator which issues the warehouse receipt (Höllinger et al., 2009, p. 22).

Warehouse receipt financing system has long traditions in western countries and in some developing countries (Höllinger et al., 2009, p. 7). Examples of countries that have advanced warehouse receipt systems are Slovakia, Moldova, Hungary, Kazakhstan, Bulgaria, and Lithuania (Höllinger et al., 2009, p. 10). However, the US has also been using warehouse financing since the mid nineteenth century (Höllinger et al., 2009, p. 14). Given the previous discussion of information asymmetry being more prominent in less developed countries, it could be assumed that these countries are also the ones who stand to gain the most from implementing a warehouse receipt system as it would reduce the information asymmetry in the lending process.

Warehouse financing does, however, not fully eliminate risks either as problems related to fraudulent activities has been reported on several occasions (Höllinger et al., 2009, p. 9). In case of fraud, small losses are compensated to the bank by the collateral manager, who is the warehouse receipt finance service provider. Larger losses are instead covered by insurances held by the collateral manager. Thus the clients of the collateral manager are well protected (Höllinger et al., 2009, p. 23). However, if fraud takes place which is covered by the insurance, the premiums paid to the insurance provider could increase to the point where the collateral manager is be priced out of the market (Höllinger et al., 2009, p. 23). Thus, losses to banks can still be incurred due to fraudulent activities. An example of this comes from the Czech bank Komerční Banka which lost 250 million US dollars in the late 1990s due to a fraud at their collateral management company (Höllinger et al., 2009, p. 22). Therefore, the system requires fraud prevention methods to better protect the clients. For instance, proper controlling systems set by the banks could reduce the risk of misusing the service.

Summary

- Agricultural financing differs from other industries due to its seasonality and other specific factors.
- The biggest risks for both farmers and banks are production risk, credit risk and market risk (It should also be noted that there are also several other risk categories such as political risks).
- Capital requirements require banks to disclose information related to the risks of their loan portfolios
- Banks use credit risk models to categorize farms into different credit quality classes which will impact the loan amounts, cost of capital, and collaterals offered to farms
- Politics, laws, and recommendations set by governments and organizations affect the operations of farms across Europe and even on a global scale.
- Agriculture can be very volatile which increases the risks for banks and the cost of capital to borrowers.
- The problem of asymmetric information increases the costs and risks of agricultural lending.
- While collaterals can minimize risks and moral hazard, using land as collateral is likely not an optimal solution.
- Even though agri-loans are seen as risky loans compared to other loan types, they do not properly predict bank defaults.
- Monitoring and controlling systems should be developed and updated to meet the needs of agri-finance

Next, the agricultural aspect is discussed in more detail. The risks and objectives covered previously are all related to agriculture as an industry and changes in agriculture will correlate with bank lending. Agriculture is an old industry and many farmers still operate in a traditional way. However, new technological innovations are often introduced early to agriculture, something which GPS provides clear proof of. Because of this, we will now turn our attention to the development of agricultural technology and how this might affect the lending to farmers.

5 Review of precision agriculture literature (lowe)

In this section the development of precision agriculture is introduced as well as in-depth information about the use of new technology within agriculture and how this affects the farm productivity and volatility. Finally, we will concentrate on precision farming and its effects to farm productivity and income volatility. New technological innovations as well as adoption processes are also discussed in the light of the theoretical framework.

5.1 Agricultural development

Given the complicated situation that exist in agricultural lending, we will now turn our attention to the agricultural side of the equation. The main way that agricultural production has been increased up until the 1940s was by simply using more land for agriculture. As can be seen in Figure 3 showing the increase in the area under cultivation, by 1940, 3,55 billion hectares were used for agriculture which is 73 percent of today's number at 4,86 billion hectares (Roser & Ritchie, 2018). However, the production of wheat was roughly $\frac{1}{4}$ of what it is today (Roser & Ritchie, 2018). Even though it should be noted that most of the agricultural land is being used for livestock (Roser & Ritchie, 2018), the fact remains that the increase in productivity up until the 1940s, though impressive in relative terms, is dwarfed by the increase which has taken place after this period of time and in particular after the 1960s. During the industrial age, agriculture was brought mechanization and synthesized fertilizer (Zhang et al., 2002, p. 113) which increased productivity (Roser & Ritchie, 2017). The use of machinery and fertilizer (Figure 4 & 5) in agriculture increased substantially and by 1960, the world was using some 10 million tonnes of fertilizer (Roser & Ritchie, 2018).

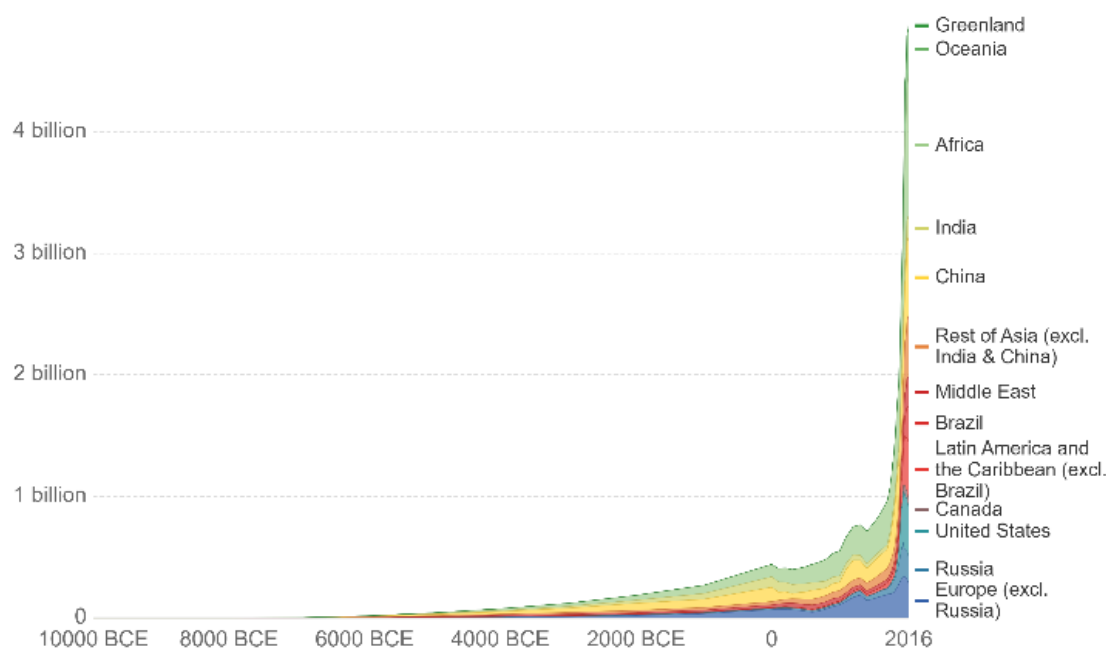


Figure 3 Total agricultural area including grassland
Source: (Roser and Ritchie, 2018)

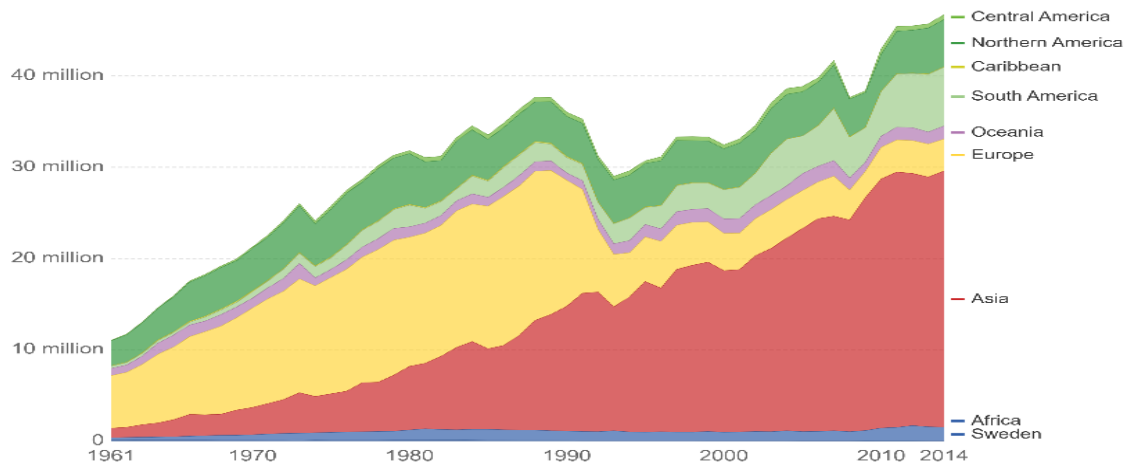


Figure 4 Annual phosphate fertilizer consumption in metric tonnes
 Source: Roser & Ritchie, (2018)

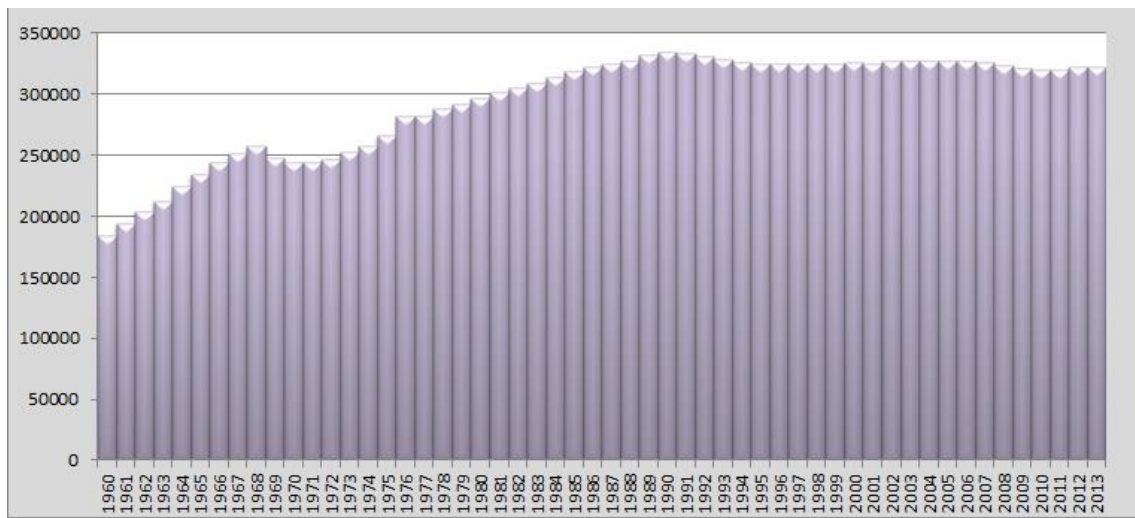


Figure 5 Number of tractors in Sweden 1960-2013
 Source: Karlsson, (2013)

The development of crops leaped in connection with the so called “green revolution” which started off in the first half of the 20th century and sped up significantly following the post-war period up to the late 90s (Acquaah, 2013, p. 12). In England, the hectare yields went from 2 metric tonnes to 6 metric tonnes during this period and China saw increases of 681 percent with significant, though lower, increases being reported around the world (Acquaah, 2013, p. 12). While not all of the increase during this period of time can be attributed to the improvements in plant breeding, it is believed to have contributed to 50 percent of the yield increases during this period of time (Acquaah, 2013, p. 13; Miflin, 2000, p. 2). The other 50 percent is thought to be caused by other means of agronomy which impacted crop yields independently of plant breeding (Miflin, 2000, p. 2). The improvement in crops that took place at this point was however not attributed to genetic modification (GMO). Plant breeding has been carried out for at least 10,000 years (Yara, n/d) and was the only way of improving crops up until 1973 when the first GMO successfully was created and even then, it did not receive USDA approval until 1992 (Rangel, 2015).

5.2 Genetic modification and plant breeding

The way genetic modification works differ from plant breeding even though the end goal is the same; better and hardier crops measured as their use for humans (Powell, 2015). In both cases, the needs of agriculture are identified and plants are then selected that exhibit the sought after traits which fit the needs (Powell, 2015). The next step is where the two separates from each other. In GMO, the genes that produce these traits are identified and inserted into the crop in order to alter its genetic structure (Powell, 2015) while in plant breeding, the plants are simply cross-bred over and over until a plant is raised which exhibit the right qualities.

These new developments, together with increasing mechanization and fertilizer use, (De Wit et al., 2011, p. 2403; Pretty, 2008, p. 449) fueled the increase in production up until the 1990s when both of these drivers started to taper off or even decrease in usage as was the case with fertilizer in the EU due to regulations (De Wit et al., 2011; Zhang et al., 2002). The increase in farm size and mechanization had reached a point where it became increasingly difficult to take into consideration the in-field variability without a large improvement to current technology (Zhang et al., 2002, p. 114). Together with the reduction in fertilizer use, the world cereal production started to plateau in the mid-1990s until the early 2000s (Roser & Ritchie, 2018)

5.3 Development of Precision agriculture

At this point, PA enters the scene. The development of precision agriculture started back in the early 1980s and developed into the first variable fertilization technique in 1988 which, based on satellite footage, created fertilization maps (Stafford, 2000, p. 267). With further civilian and commercial availability of technology such as GPS during the 1990s, and much research being conducted, PA became more reliable (Stafford, 2000, p. 268). Even with these improvements, adoption was not taking off with many large farmers even being unaware of the technology (Daberkow & McBride, 2003). By 1998, a large study in the U.S involving more than 8500 farmers concluded that only 4 percent had adopted at least one PAT (Zhang et al., 2002, p. 124). At the turn of the century, PA was considered to be at a cross road much due to uncertainty regarding the economic and environmental benefits of the technology (Stafford, 2000, p. 268). Researchers had difficulties measuring the effects of PA (Balafoutis et al., 2017, p. 19) and some found that even with a 10 year horizon, going from URT (uniform rate technology) to VRT (variable rate technology) would not cover the additional investment cost (Zhang et al., 2002, p. 117). The issue of availability of capital was also starting to be discussed during this period. A study by El-Osta & Morehart (1999, p. 93) found that availability to capital was positively associated with adoption of new farming technology. While others at this time were unable to find a similar connection between capital and adoption (Daberkow & McBride, 2003, p. 174), later studies have shown this to be a major contributing factor (Silva et al., 2011, p. 80).

Cook et al. (2000) cited in Zhang et al. (2002, p. 124) stated that the four major contributing factors to the slow adoption were: cost, lack of perceived benefits, unwillingness to be early adopters and, most importantly, lack of delivery mechanisms for the technology. For farmers, agricultural consultants are very important in helping them make decisions (EIP-AGRI, 2015; Olsson, 2008; Rydberg et al., 2008) and at this time, the consultants simply were not possessing the needed knowledge and skills to inform the farmers (Zhang et al., 2002, p. 124). The ones who did use PA at this time were mainly young and tech-savvy farmers who had a personal interest in the technology or those whose farms were very large and thus were quite certain that they would benefit from the technology (Daberkow & McBride, 2003; Pedersen et al., 2004; Zhang et al., 2002). Despite this, it was estimated that some 5000-10,000 units of PAT were operational in the U.S around 1997 (Zhang et al.,

2002, p. 122). By 2004, this number had increased to 20,000 in the U.S, 400 in the United Kingdom, 300 in Sweden and 200 in Germany (Pedersen et al., 2004). Early on, Denmark became one of the countries in Europe with the most dense use of PA and it was estimated that by 2004, 9 percent of the agricultural area in Denmark were utilizing some sort of PAT which correspond to roughly 400 farmers (Pedersen et al., 2004, p. 2). By 2004, a Swedish study showed that 50 percent of the farmers who got to try the Yara N-sensor (a VRT fertilizer spreading nitrogen) would definitely use it again with only 10 percent being sure that they would not (Söderström et al., 2004, p. 7). While some studies found that certain PAT were not perceived as positively as the VRT for fertilizer, such as yield mapping, (Pedersen et al., 2004, p. 4), many started reporting positive impacts of PA on productivity and profit (Aneslin et al., 2004; Biermacher et al., 2006; McBratney et al., 2005; Nistor et al., 2008; Pedersen et al., 2004; Söderström et al., 2004).

5.4 Farm size

One of the caveats in these studies, however, is the size of the farm required to reach these potential gains. A literature review study from 2013 found that the most commonly cited driver of PAT adoption was farm size (Pierpaoli et al., 2013, p. 64). While some studies reported that PAT could be profitable down to 80 hectare for basic systems (£4,500) and 300 hectare for more advanced systems (£16,150) (Godwin et al., 2003), others were estimating that roughly 900 hectares were needed for PAT costing \$10,000 (Knight & Malcolm, 2009, p. 30). While most researchers were settling for a minimum economically viable farm size of 200-300 hectare (Knight et al., 2009; Pedersen et al., 2004; Shockley, 2010) and this size correspond to the farm-size most likely to adopt PAT (Kutter *et al.*, 2011), this still only correspond to 2,3 percent of Swedish farms where the average size in 2007 was 36,5 hectare (SCB, 2010). It should be noted that farms with a size of 100+ hectare did farm roughly 40 percent of the total farm area in Sweden at this time (SCB, 2010). It is believed that around 2007-2008 is where the use of precision agriculture became effective for the larger amount of farmers (Abdullahi et al., 2015, p. 4) with the decreases in the lower bound of prices on PAT equipment which now could be as low as \$500¹⁸ (Abdullahi et al., 2015, p. 5). While this only included the price of the equipment and not the software or training needed to operate or take advantage of the information, a UK study found that investments as low as £1,000 into PAT would be sufficient to benefit even small farmers (Knight et al., 2009, p. 92). While some equipment could still cost up to, or even exceeding £41,000 (Knight et al., 2009, p. 31), the difference from the 2003 study by Godwin et al. (2003) was that there now existed cheaper entry level equipment for PA.

The adoption of new PAT is thus likely influenced by the stages in the product life cycle as a new product, previously unknown to the market, is likely sold by a company with little competition (Filson, 2002, p. 105). Over the years, as the interest in the technology increase, more and more firms are going to enter the market and with the rising competition, the prices drop (Filson, 2002, p. 105). As it would appear that profitable adoption of PAT is closely linked to the cost of purchase (Godwin et al., 2001, pp. 17–18; Olsson, 2008, p. 12), then, as prices drops, the farm size required for profitable adoption would follow the same trend (Olsson, 2008, p. 12).

Around this time, researchers also started to interest themselves in whether farmers would be willing to share or rent PA equipment to reduce the capital cost. In a study by Kutter et al. (2011) first published in 2009, the authors found that, while large sized farms prefer to own their PA equipment, smaller farmers often invested jointly or, in some instances, purchased the equipment to act as a contractor and sell the service to other farms in order to

¹⁸ This mostly refer to very basic drone applications.

take full advantage of the investment (Kutter et al., 2011). Indications of this behavior had been found in previous studies as well such as Söderström et al. (2004), which found that 600 Swedish farmers used the Yara N-sensor on 25,000 hectare (833 hectare per sensor) although the company declared that only 30 units had been sold at that time. Fountas et al., (2005, p. 128) found that 27 percent of Danish farmers in the study used joint ownership in order to increase the utilization of the machine and that each machine in joint use on average was used on 610 hectares. A large scale report funded by the European commission found, among other things, that one of the most important things to facilitate PAT in Europe was to enhance sharing of PAT among small and medium sized farms in order to reduce the investment risk and the need for investments (EIP-AGRI, 2015, p. 20).

5.4 Differences in adoption between countries

The development of PA adoption differs widely between countries. In their report, EIP-AGRI (2015, p. 4) found that the main areas which has adopted PA are central and northern Europe, the US, and Australia where it is now “relatively widely adopted”. The vague

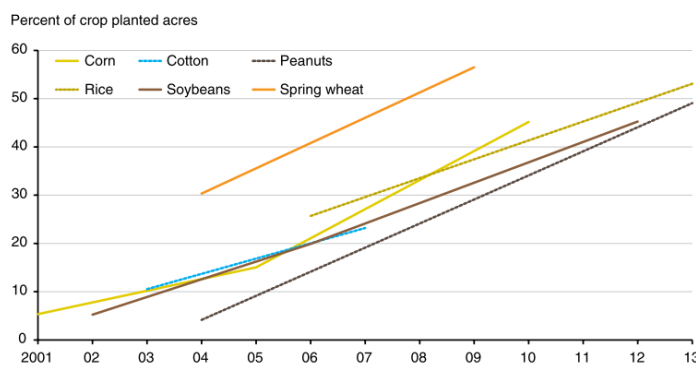


Figure 6 Adoption of guidance system (by crop)
Source: Schimmelpfennig, (2016)

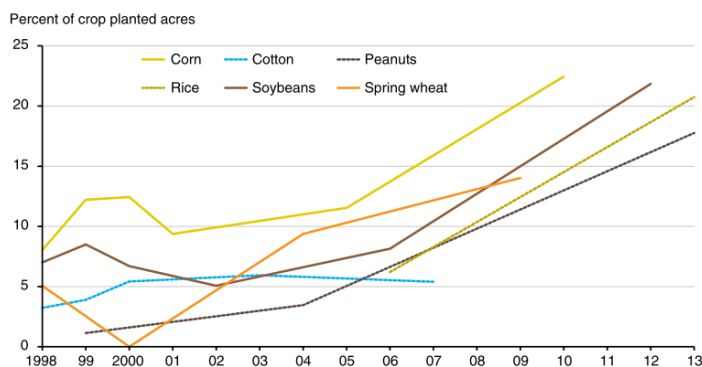


Figure 7 Adoption of VRT technology (by crop)
Source: Schimmelpfennig, (2016)

wording likely comes down to that it appears very difficult to measure the adoption rate of PAT. The problem seems to persist as a more recent report from another focus group within the EIP network also concluded that PAT adoption remains under expectation and is unevenly spread throughout Europe (EIP-Agro, 2017, p. 12). A study by Lawson et al. (2011) involving interviews with 413 farmers from four different European countries found that Germany had 24 % adoption, Denmark 9 %, Finland 3 % and Greece 0%. While Greece farmers were far smaller with an average of only 5 hectares, Denmark had the largest average farm at 55 hectares, while Germany, with higher adoption rate, had an average of 41 hectare. Another study involving German adoption published in 2017, found that among small farmers, 30

percent had adopted PAT (Paustian & Theuvsen, 2017), which would be a quite modest increase from the 2011 study (Lawson et al., 2011).

However, the same number for large farms in the study was 69 percent. It also varies between different PAT and also between what crops the farmer mainly grows according to a USDA report on the adoption of GPS-based mapping, auto-steer systems and different types of VRT (Schimmelpfennig, 2016). As can be seen from Figure 6 & 7, the adoption of guidance systems is much higher than the adoption of VRT and while wheat has the highest adoption when it comes to guidance systems, it lags behind in VRT (Schimmelpfennig, 2016, p. 7-8). Another US study from the same year report variations ranging from 85 %

for grid soil sampling to 11 % for telematics¹⁹ (Castle, 2016, p. 40; Schimmelpfennig, 2016, pp. 7–8)

As stated in the previous chapter, countries with more volatile farm income receive less financing for agriculture (Betubiza & Leatham 1995). Related to this, Cornaggia (2013, p. 438) found among other things that, through the management of risk, farmers with better access to financing were able to invest more in productivity improving technology. This would mean that countries with lower farm income volatility would have better opportunities to adopt new technology such as PA.

Thus it appears that, although numerous studies show the correlation between farm size and PA adoption (EIP-AGRI, 2015; Katalin et al., 2014; Lencses & Takacs, 2013; Schimmelpfennig, 2016; Takacs-György et al., 2013), it is not as clear cut as to simply state that a higher degree of adoption is always due to larger average farm size.

5.5 The impact of economic situation on adoption

Economic situation may also play a role in the equation. While one European study in 2012, found no significant connection between income and adoption (Takacs-György et al., 2013), an Indian study from the same year found that a better economic situation was positively correlated with adoption (Ali, 2012). However, the study also found that being well educated and belonging to a higher societal class and also having access to capital were things that positively affected adoption (Ali, 2012). Thus, the causal link between economy and adoption in the study can be questioned. Despite this, the fact that in India, a country on average not in a as favorable economic situation as some of the other countries previously mentioned, adoption was in a very nascent stage with much less development compared to the west (Ali, 2012) which might indicate that economy would play a role in PA-adoption.

Interestingly, it was also discovered that smaller farmers in India were more likely to invest in PAT compared to larger farms (Ali, 2012). The reason for this was thought to be that larger farmers often rented their land and were unsure about whether they would be able to continue renting the same area. Another factor which could cause uncertainty regarding conducting long term investments would be thinking about retiring from farming or for other reasons quitting farming. Kutter et al. (2011) found that farmers thinking about retiring were much less likely to invest in PAT. As PA is a somewhat long-term practice, which aims at keeping yields consistently high over time, it could also be speculated that farmers who are not sure whether they will reap the benefit of investing time and money into a certain plot of land would be more hesitant to practice PA. If this is the case, more short-term solutions to increasing yield is likely to be implemented instead such as increased use of fertilizer.

5.6 Precision agriculture compared to alternatives

Between 2002-2014, India almost doubled their use of fertilizer (Roser & Ritchie, 2017) and Asia as a whole is the leading driver of the increase in fertilizer use in the world (Figure 4) with India, Pakistan and China being the countries with the largest excess use of fertilizer in the region (Roser & Ritchie, 2017). Thus, it appears that countries which for economic or strategic reasons are inhibited in their ability to invest in PAT are trying to increase their productivity through the use of fertilizer instead. However, a Chinese study found that Asian countries over-use fertilizer to the point that they actually lower the productivity (Peng et al., 2010). By reducing the amount of fertilizer, traditionally applied, by 32 percent based on site specific measurements, farmers increased their yield by 5 percent (Peng et al., 2010).

¹⁹ Equipment for tracking machinery and making wireless data transfers

These measurements however do not have to come from expensive machines. Another Chinese study found that cheap handheld devices for measuring the need for fertilization in different parts of the field could reduce the use of nitrogen by 128 kg/hectare and were especially suited for smaller farmers (Cao et al., 2012).

Applying fertilizer is also a major source of cost for the farmers with an estimated impact of 15-25 percent on operating costs (Biermacher et al., 2006, p. 194). Through savings of nitrogen fertilizer alone via the use of VRT for application, reductions of up to 59-82 percent were achieved (Biermacher et al., 2006). This translates to savings which, after factoring in that VRT uses a more expensive type of fertilizer, amounts to \$22-33/hectare (Biermacher et al., 2006). One of the reasons for why such savings can be made is likely due to the economic optimal quantity of fertilizer and the uneven depositing of nutrients based on spatial and topographical differences in the fields. Crops can only absorb and take advantage of a certain quantity of fertilizer, after which there is no additional crop response according to a Swedish study (Delin & Stenberg, 2014). The way that nutrients deposit in different parts of the field also comes down to topography, weather and soil composition (Feder et al., 2016, p. 274). Thus, finding the optimal amount of nutrients without spatial sensors can be very challenging. Results from this study showed that that the economic optimum²⁰ of fertilization for any given area coincides with the point where minimum nutrient leaching occurs. What this means is that excessive fertilization does not increase the productivity of the field (Delin & Stenberg, 2014) but rather wastes money and cause environmental damage as the additional fertilizer paid for by the farmer will leach and pollute nearby bodies of water.

Other studies have looked at a more holistic picture of the economic impact that PAT might have on farming. A Danish study found that when only applying controlled traffic technology, the overall profit increased by €34/hectare for wheat farming, but when applying several PAT at once, the increase rose to €122/hectare (Jensen et al., 2012, p. 669). When investigating more high-profit crops such as sugar beet, the increase in profit could be as much as €316/hectare. While the ubiquitous belief appears to be that PAT does improve the economic situation of farmers (Abdullahi et al., 2015; Balafoutis et al., 2017; Candiago et al., 2015; EIP-AGRI, 2015; EIP-Agro, 2017; Far & Rezaei-Moghaddam, 2017; Schimmelpfennig, 2016; Yun et al., 2017), it should be noted that one study was found to question the causality behind this correlation. (Castle, 2016) was unable to find a significant causal relationship between adopting PAT and achieving higher profits. While the study did find that farmers who adopted the technology had higher profits, it could not be excluded that it was the increase in profits itself that made farmers more willing to invest in PAT.

5.7 Impact of spatial and temporal factors

Another factor to include in the equation is that of variability, both temporal and spatial. In 2017 in Sweden, heavy rainfall during the autumn harvest period lead to big problems as farmers were given a very short window to harvest (SCB, 2017). The reason was that the rain caused the fields to stay waterlogged for most of the harvest season preventing machinery to enter the fields causing some areas to experience up to 50 percent harvest loss (SCB, 2017). Unfortunately, this is not an isolated event as studies show that annually, 20 percent of farmers experience losses that amount to 30 percent of their 3 year average income (EIP-Agro, 2017, p. 4). Because of the unusually high exposure to environmentally related risks compared to other economic sectors, farming is also expected to experience further increase in risk as a result of climactic changes (EIP-Agro, 2017, p. 4). Thus, keeping

²⁰ The point where the relationship between the cost of additional application of fertilizer and the yield response is such that it is not economically viable to continue to increase the dosage of fertilizer.

up to date with the condition of the crop and the fields is very important and should increase in importance in up-coming years if extreme weather events become more frequent because of rising temperatures.

One way in which this can be achieved is through the use of drones equipped with cameras and sensors able to detect and provide early warning to farmers which enable them to take preventative measures to minimize the damage (Reinecke & Prinsloo, 2017). This could e.g. be to deploy pesticides when signs of fungus or insect damage occurs which thus enable farmers to reduce the risk or scale of harvest loss (Yun et al., 2017). When looking at smaller farmers, the use of drones for e.g. spraying pesticides is both more cost effective and saves time. As drones can cover 60-100 hectare an hour with minimal fuel costs, they are both faster than spraying with a tractor and saves money on fuel (Yun et al., 2017, p. 109).

5.8 The yield gap and room for improvement

Given the large improvements in agriculture that has taken place during the last 30 years, a valid question to ask would be: how much room for improvement is left in agriculture. Researchers have asked this very question for at least the last 20 years (Cassman, 1999) and developed a measurement known as the yield gap (Lobell et al., 2009, p. 180-181). The definition of the yield gap differs but is generally constructed as the difference between the average actual yield²¹ and the potential yield²² which then makes up the yield gap (Global Yield Gap Atlas). Because the yield gap has both a spatial and temporal component, the yield gap will not only vary between countries but also within a country based on factors which vary between years and within a given year (Lobell et al., 2009, p. 181). It is common that yield gaps in rainfed areas amounts to as much as 50 percent which means that it is considered to be a large room for improvement in these areas (Lobell et al., 2009, p. 179). However, because of the multitude of ways in which the yield gap can be calculated, there is inconsistency in the literature regarding the yield gap (Lobell et al., 2009, p. 181).

Some researchers point towards this inconsistency as a sign that the yield gap is merely a “policy framing device” designed to create the feeling of scientific analysis backing political decisions (Sumberg, 2012). Others have a more balanced approach. As part of a larger report financed by, among others, UN and the world bank, it is stated that due to the predictive model approach of yield gap models, they often inherently have conceptual flaws (World Resources Institute, 2013, p .66). Because of data errors caused by an inability to capture sufficient physical factors affecting the yield, in part due to a lack of scope, most yield gap models are crude tools subject to large inaccuracies (World Resources Institute, 2013, p. 66). However, a recent attempt at correcting these flaws known as the Global Yield Gap Atlas Project have, through a rigorous localized approach been able to, not only much more accurately calculate the yield gap, but also separate temporal and spatial conditions leading up to said yield gap (World Resources Institute, 2013, p. 66).

While one could assume that the best thing would be to always reduce the yield gap to zero, this might not always be a viable or even possible feat. Studies have looked at how close to the potential yield it is possible come and found that it would be possible to reach 95 percent of peak productivity which would increase aggregate yields by 58 percent if reached globally (Foley et al., 2011, p. 339). However, the same study found that by only achieving 75 percent of potential yield, the production would increase by 28 percent. Assuming that closing of the yield gap would first take place in areas where the relative increase in yield

²¹ The average yield achieved during the last 5 years for irrigated and the last 10 years for rain-fed land (<http://www.yieldgap.org/web/guest/glossary>)

²² The yield that could be achieved in a location under ideal conditions in that location (<http://www.yieldgap.org/web/guest/glossary>)

would be the greatest, it would then be reasonable to think that diminishing returns would exist for incremental progress. Thus, it would be likely that an economic optimum would lie somewhere lower than 95 percent of the potential yield. The study by Foley et al., (2011) did only focus on the actual increase in food available and thus made no mentioning of the economic optimum point to which the yield gap could be closed while still making economic sense.

This question has however been looked into in a book by Fischer et al. (2014) aimed at investigating the global food production from an economic standpoint. According to Fischer et al. (2014, p. 44), the profit maximization point of the yield gap is composed of two components: Technical inefficiencies²³ and allocative inefficiencies²⁴. Available technology sets a yield frontier upon which technical inefficiencies are minimized. The profit maximizing farmer should operate at the point of the yield frontier where marginal cost equal marginal return based on the price of inputs given that technology (Fischer et al., 2014, p. 44). Thus, the yield gap in an economic sense exist as the gap between the current point of yield/input compared to the optimum yield frontier point. The offset between the current point and the optimum could either be caused by technical inefficiencies in the operation or by applying a suboptimal amount of input given the frontier line which the farmer operates across (Fischer et al., 2014, p. 44). To understanding the aggregated deviation from the yield gap, we must first understand how close the attainable yield²⁵ is to the potential yield. According to Fischer et al. (2014, p. 33), any gap larger than 23 percent is to be considered economically exploitable. What this means is that, aggregated, farmers who return a yield that deviates more than 23 percent from the potential yield should strive to close the gap to 77 percent of potential yield but not exceed this point as that would not maximize the profit.

Given that PAT is focused on optimizing the technical efficiency by applying the correct amount of input at the right time, it would be reasonable to assume that the adoption of PAT would help farmers in approaching the attainable yield. This is also mentioned by Fischer et al. (2014, p. 40) who states that the main driver of yield improvements for farmers is the adoption of increasingly improving technologies. It should however be noted that the invention of better technologies without the adoption of the previous generation by farmers would increase the yield gap as the yield frontier would be moved. Closing the yield gap would thus require more farmers to adopt the available technology.

5.9 Economic gains through use of precision agriculture

The economic gains achieved through precision agriculture differs between the various technologies available. In a large recent review of literature on this topic, Balafoutis et al. (2017) have gone through a vast amount of studies and found that most technologies have clear financial benefits for the farmer. However, Balafoutis et al. (2017) find that these benefits can differ between farmers depending on spatial and temporal factors as well as size.

VRT fertilizer is one of the inputs in farming that is most closely related to an increase in yield and, with nitrogen being the most prominent fertilizer for many farmers, it is essential

²³ Failure in operating at the frontier level of technical efficiency (Fischer et al. 2014, p.44)

²⁴ Failure in operating in a cost minimizing manner related to input where marginal cost equals marginal return for the last unit sold (Fischer *et al.*, 2014, p. 44)

²⁵ The yield that can be achieved by a farmer under optimal economic practices considering the risk premium above cost of capital an investment must return given exposure to sources of volatility (Fischer *et al.*, 2014; p.32-33).

to farm economy (Balafoutis et al., 2017, p. 9). Given the quadratic relation between yield and nitrogen application, too much application reduce profit through wastage and too little reduce profit through decrease in yield which means that the right application quantity is the key (Balafoutis et al., 2017, p. 9). Using VRT to apply fertilizer can amount to savings of 4-37 percent in wheat and 6-46 percent in corn and is dependent upon the quality of the soil and how advanced the sensor deciding the application rate is (Balafoutis et al., 2017, p. 9-10). The biggest gains are to be had in nutrient poor soil or soil which is prone to either fertilizer retention or leaching. The increase in profit varies with the crop where cotton is seeing large improvements amounting to €113-480/hectare/year while wheat and corn see more modest improvements of €10-25 and €7-39 respectively (Balafoutis et al., 2017, p. 9-10).

5.9.1 VRT lime

Using variable rate equipment to apply lime is less beneficial compared to using it to apply fertilizer and large gains are usually only to be had for high value crops such as legumes (Balafoutis et al., 2017, p. 11). For instance, when lime is applied on soybeans, some studies have even shown a loss of €11,44/hectare/year when tested over a three year period while other studies on soybean, corn and wheat show increased profits of €6,51 for soybean and €3,61 for corn, all of which were calculated as profit increase/hectare/year (Balafoutis et al., 2017, p. 11). The reason for the differences in profit between these studies was found to mainly come down to the cost of grid soil sampling. If the farm uses this soil sampling method for other things on the farm, then naturally the cost of which will not fully be associated with the application of lime and subsequently the profit will appear higher.

5.9.2 VRT irrigation

A similar story goes for variable rate for irrigation. Researchers have had difficulties finding concrete evidence of the economic impact. The adoption cost is quite high ranging from €1300-2200 (if existing infrastructure can be used to a large extent), all the way up to €10,500-35,200 (if current infrastructure needs to be replaced) (Balafoutis et al., 2017, p. 12). This means that the cost of water as well as the scale with which this infrastructure can be used heavily decide the impact on profitability of the technology. On smaller farms (roughly 50-150 hectare), water savings of 21,8-26,3 percent can be made (Balafoutis et al., 2017, p. 12). Whether such savings of water usage translates to a profit would thus heavily depend on the price of water and the irrigation needs. Highly priced water in an area where heavy irrigation is needed could mean profit for farms in that area. Meanwhile, in another area with lower water cost or less irrigation need, this same system would not be profitable. For instance, in humid areas with large evaporation where current irrigation systems is over-irrigating the soil, savings could amount to as much as €30/hectare (Balafoutis et al., 2017, p. 13).

5.9.3 Controlled traffic farming (CTF)

CTF is highly correlated with farm size as the smaller the farm, the less driving will be required and thus the investment will be spread out over a lower sum of variable costs. However, CTF has two components in the profit analysis: direct savings and indirect savings. Direct savings amount to roughly 25 percent savings in fuel and 3-5 percent savings in fertilizer and pesticides respectively (Balafoutis et al., 2017, p. 15). The savings in inputs results from not having to apply these in the permanent wheel tracks that exist in the fields of farms using this technology. By taking indirect factors into consideration, the calculations change somewhat. When including these factors, fuel costs can be reduced by as much as 40-70 % and fertilizers by 10-15% with nitrogen being especially affected reaching efficiency improvements of between 40-80% (Balafoutis et al., 2017, p. 15). This comes as an effect of CTF allowing for: permanent lanes which reduce rolling resistance, a

reduction in tillage due to soil compaction happening only in traffic lanes et cetera (Balafoutis et al., 2017, p. 15).

5.9.4 VRT pesticides

VRT for pesticides is heavily dependent upon the proportion of a field that is infested by pests. Thus, savings compared to URT is found to range from 11-90 percent (Balafoutis et al., 2017, p. 17). The lower bound of this range could however be too low given that it is very hard to estimate future reductions in pesticide application from precautionary actions being taken in previous years to prevent the growth of weed in subsequent years. It is however thought that VRT for pesticides could lead to savings amounting to between €20-42/hectare for common crops such as wheat, maize, barley and sugar beets (Balafoutis et al., 2017, p. 17).

5.9.5 Other business impact of precision agriculture

What is not included in this analysis is the potential effect of using PA to comply with future regulatory changes concerning environmental compliance. The European union has imposed stricter regulations on the use of fertilizer and pesticides as well as having demanded reductions on emission levels from motor vehicles in the past (European Parliament, 2009). With current regulations regarding agricultural input (European Parliament, 2009), it is likely that regulations will become stricter in the future. By already adopting technologies which enables farmers to comply with future regulations, this reduces the farmer's exposure to such political risks. Also, through the adoption of PAT, which collects detailed data of current and future field conditions and also about what actions are being taken to secure a sustainable farming operation (Stafford, 2000), this information could be made available to stakeholders.

As mentioned, banks and lenders often find themselves in a disadvantageous situation when it comes to knowledge about past, current and future farm operations, and the impacts they would have on the risks involved in lending the farmer money. It is thought that by using the data collected by PAT, information sharing between farmers and stakeholders will provide more accurate and timely decisions regarding e.g. insurance claims in the event of crop damage (Michał et al., 2016, p. 16). However, one obstacle to overcome is the apparent reluctance of farmers towards sharing farming information with outside parties. Fountas et al. (2005, p. 132) found that 88 percent of US farmers were hesitant to share information digitally with outsiders, something which appears to still hold true even today (Wallheimer, 2017).

Summary

- The main driver of agricultural production until recently has been increasing inputs
- Precision agriculture became more commonplace from 1996 in the US and in Sweden from 2008
- Precision agriculture is found to be more profitable on larger farms with the lower bound estimated at around 200-300 hectares.
- The farm size on which PAT is profitable is likely to decrease as the technology matures
- Adoption rates of up to 69 % among large farms and 30 % among small farms are found in Germany with large US. farmers reaching up to 85 % adoption.
- Achieving the maximum potential yield is not economically viable
- Most precision agriculture technologies can amount to significant increases in profit if used correctly
- Precision agriculture has the potential to reduce the risk exposure of the farmer

6. Practical method

This chapter starts with the operationalization of the study after which we analyze the practical methodology of the study. The chapter will bring up the advantages and disadvantages of the chosen methods and discuss alternative methods which could have been used. Our methodological choices will be motivated using previous studies. Further, data collection methods as well as ethical and societal contributions are discussed.

6.1 Operationalization (anna)

The choice and adequacy of a research method stems from the assumptions which the researchers have about the underlying nature of the objectives in their research (Long *et al.*, 2000, p. 190) and therefore there is no exact right or wrong when choosing research approach. While a qualitative approach tends to often disregard reliability, quantitative approaches often overlook validity issues (Long *et al.*, 2000, p. 195).

Operationalization is required in a quantitative study. It means quantifying the concepts used in the study (Krishnaswami & Satyaprasad, 2010, p. 39) and enables us to assess the validity of hypotheses (Bryman & Cramer, 2005, p. 5). The operationalization process translates the concepts into variables (Bryman & Cramer, 2005, p. 5) which can be independent or dependent.

One of the major goals in quantitative research which have considerable practical importance is to establish causality (Bryman & Cramer, 2005, p. 9). However, stating causality is oftentimes difficult as dependent variables might not be totally influenced by the independent variables but rather by factors external to the model. Thus, perhaps it would be more correct to say that they are likely to be influenced by the independent variables (Bryman & Cramer, 2005, p. 9). Generalization is another feature of quantitative studies (Long *et al.*, 2000, p. 195). Given that our sample is based on a census, it should be sufficient for us to generalize based on our results. We find that the methods used provide the most appropriate and solid base for our research purpose. In addition, previous literature related to our topic applies similar methods (i.e. Betubiza & Leatham, 1995; Gupta *et al.*, 2017 Restuccia *et al.*, 2008; Schimmelpfennig, 2016).

6.2 Analytical method (lowe)

The analytical method is aimed at reaching some pre-determined epistemic goal by following a set of ordered instructions (Kosterec, 2012, p. 84). Because the analytical method is derived from a series of steps, it very much resembles a process which relates input into output (Kosterec, 2012, p. 85) i.e. input of information into output of knowledge. In his article, Kosterec (2012, p. 100) find three (3) steps which dictates this process: 1. Selection (accessing information), 2. Execution (computation of information) and 3. Declaration (presentation of results). In this section we will present step one and discuss the methodological reasoning behind the execution step. The second part of the execution will be presented in chapter 7 after which the results will be presented and analyzed in chapter 8. This analytical method should allow us to draw some final conclusions from the information we have accessed.

6.3 Data (lowe)

6.3.1 Sources of data

To be able to connect any results relating to productivity or volatility found in our data, these results must be contextually connected to the adoption of precision agriculture among farmers in the studied area. To achieve this, we have chosen to rely mainly on data from the Swedish Board of Agriculture (SBA) (farming revenue, number of farmers, farm land

holdings etc.) and the Food and Agriculture Organizations of the United Nations (FAO) (harvest information). FAO is used extensively by researchers within the field as a source of data (Baráth & Fertő, 2017; Fischer et al., 2014; World Resources Institute, 2013). The SBA database is also used by previous researchers (Söderström et al., 2016). It studies Swedish conditions and post extensive quality reports related to their data and data collection methods which allows for us to understand any disruptions in the data or collection methods. The data gathered is aggregated and grouped based on farm sizes (hectares).

The data from the SBA is collected from their statistical database which includes comprehensive data on most aspects related to Swedish agriculture as well as their report “Yearbook of Agricultural Statistics” which includes additional information compared to the statistical database. All the data presented in either the database or the yearbook include notations related to the data gathering methods, gaps in the data and other important information such as changes in the underlying collection methods. Naturally, this information is vital to take into consideration when using this data for research purposes. The data presented by FAO does not as clearly state the quality declaration or the exact way in which the data was collected or compiled. However, it is stated that the data mainly comes from the national agencies of the country the data describes (FAO, 2017). As the SBA clearly state that they are collaborating and sharing data with the UN, which FAO is part of (SBA, 2017b), it can be assumed that the data presented by FAO falls under similar quality control and scrutiny as the data presented by the SBA themselves.

Data on weather has been collected from the Swedish Meteorological and Hydrological institute (SMHI) which are responsible for the official Swedish statistics related to weather and climate. They offer a research database where statistics regarding most aspects are covered when it comes to information regarding metrology or hydrology. It should be noted that not all data in this database is manually controlled but rather generated through automatic weather stations. This means that it would be possible for faulty data to be present in the database as it is not specified which weather stations that are manually corrected, and which are not. However, since the data we have been using from SMHI is aggregated data, which is later compiled and averaged, the influence of an individual false reading at one or a couple of stations are to be considered negligible. Additionally, as this data is part of the official statistics, any persistent errors being generated from these weather stations are likely to be discovered and corrected. This is especially true for the kind of temperature and rainfall data we are using as this constitutes the backbone of the reporting that SMHI does.

Some additional statistics has also been collected from the statistical blog of SBA. This blog is used by SBA to present additional analysis or statistics which are not a recurring item in the ongoing statistical publishing. While statistics on this blog might not always contain or be possible to modify to the time frame sought after, nor does it usually present the raw data, it does allow us to find specific pieces of information. While these analyses would be possible to order from SBA, the time available compared to the time it takes to have custom statistics delivered makes it unfeasible for this study.

6.3.2 Collection of data (lowe)

The SBA is mainly collecting data using surveys sent to farmers as well as conducting their own measurements in certain instances (C. Lundström, personal communication, March 16, 2018).

This means that any secondary data used in this study originating from SBA is not going to be of a higher quality than the collection method used by SBA in gathering the data. According to Crane et al., (2018, p. 9), one of the main problems in using secondary data is

to know how the data has been collected and treated by the primary collector. Given the extensive quality documentation available for the data we are using in this thesis, we feel confident in that the data is of sufficient quality for us to draw sound conclusions based on it. Having gone through the quality documentation has shown no indications of issues with the data that are such that it would affect the quality of the data for the purpose that we are using it for. In cases where there has been any uncertainty regarding a definition or value in the data, additional sources have been consulted to verify the correctness of the SBA or FAO data. It should be mentioned that there is no data available on farm income for 1993 and 1994 as no measurements were taken those years. To not distort the data, we have chosen to leave these two years out of the analysis of income volatility as extrapolation of data would likely not yield satisfactory results.

The majority of the data has been dumped from either the FAO or SBA statistical website in excel or csv format. Additional data have also been collected by hand from the Yearbook of Agricultural statistics and entered into excel manually. During this process, both researchers were present to minimize the risk of human errors resulting in false information being entered into the dataset. In the case of ecological farming, the data on the amount of land used for this type of farming was not available prior to 1993. As ecological farmland is reported to only represent 1.1 % of total farmland in 1993, we have assumed that the area of ecological farmland was to be considered negligible before this time. Additionally, the survey on ecological farmland has historically not been delivered annually throughout the period of measurement. This means that some gaps existed in the data. In these instances, we have extrapolated the missing years based on neighboring years assuming linear growth. Data on the difference between ecological productivity and the productivity of conventional farming has been collected from the statistical yearbook between the years of 2005 and 2016. The reason for not including the timespan from 1993, when ecological farming started, until 2005 is that data is simply not available. Given the very small amount of ecological farmland that was present during this period, this should not have a large effect on the average numbers that are calculated using the data available to us. The hectare yield data for ecological farming was collected at the individual crop level for the most common crops and the data has then been averaged to see the effect that ecological farming has on productivity over time per crop. This was done to spot any differences in the crop response from switching to ecological farming for different crops as this might deviate across species.

Most of the data from FAO and SBA has not been altered except being compiled in a way that enables statistical analysis. An exception to this is income volatility. This has been calculated as the percentage deviation of a year compared to the previous to analyze the inter-year changes in income that has occurred for a particular size of farmer.

To enable statistical comparison between farmers of different size classes, these have been converted to categorical variables ranging from 1-6 which corresponds to 6 sizes of farms in hectares (10-200+ hectares). We have opted to remove farmers smaller than 10 hectares from the dataset after consulting the statistical unit at the SBA. The reason for removing these is due to farmers smaller than 10 hectares making up a fraction (0.88%) of the total farmland and many do not have any agricultural land but rather grazeland or similar non-crop yielding land (SBA, 2017a, p. 13). As their contribution to the total agricultural output can be considered minimal, these farmers have been left out to avoid distorting the dataset.

The period before and after the commercial adoption of PA in larger scale by farmers have been separated using a dummy variable (further explained in the results section) to enable us to compare structural differences in the sample between these two periods in time.

Where:

σ = standard deviation

Σ = the “sum of”

n = the number of data points

\bar{x} = the mean of x

x = number of values in the data set

6.3.3 Deciding point in time for adoption (lowe)

Knowing exactly when a certain number of farmers have adopted a new technology such as PA is naturally very difficult as per the discussion in chapter 5. However, simply asking farmers in any larger scale whether they are using this technology appears to yield unsatisfactory results as the answers vary widely and seems unreliable and non-comparable over time²⁶. Because of this, we have borrowed economic methodology used by Jensen et al. (2012) who, in their study, apply the Agricultural Applied General Equilibrium model (AAGE) to calculate the percentage of farmers who are likely to have adopted the technology. The AAGE model was developed by Adams (2000) in order to analyze the difference in outcome based on two alternative sequences or, as described in a later publication, to answer the “what if” question of how the economy would react to a change or disturbance that happened in a preceding year (Adams, 2002, p. 2). Jensen et al., (2012) used this model to calculate the effect of PAT adoption in Denmark. By calculating the percentage of farms at which it would, on aggregate, become profitable to adopt PAT, the authors managed to quantify the effect. They were working under the assumption that adoption would take place at the point at which the technology became financially viable and thus this would be where farmers on aggregate would adopt. By then measuring the number of farmers large enough to profit from adoption, the adoption rate in the country was calculated.

We have adopted this methodology in this thesis to be able to estimate the adoption of PAT in Sweden. By analyzing Swedish sales numbers for PAT as well as research conducted in and around Sweden, we have estimated the approximate point in time when adoption by any significant number of farmers would have taken place in Sweden. The adoption should then trickle down from the largest farmers who enjoy the largest marginal scale economies effect of adoption down to the farmers who have the least financial benefit and stop at the size where farmers no longer gain utility from adoption. Research put the lower bound at between 200-300 hectares (Godwin et al., 2003; Knight et al., 2009; Pedersen et al., 2004; Shockley, 2010; Söderström et al., 2004; Takacs-György et al., 2013). We are, given the discussion in section 5.3 regarding the decreasing lower bound of adoption, going to use an incrementally decreasing lower bound for adoption based on the results found in these studies. This will stretch from 300 hectares between year 2000-2003, 250 hectares between 2005-2010, and 200 hectares from 2010 and onwards. When talking about adoption in the context used in this study, the amount of companies adopting could be somewhat misleading. The reason for this is that moving towards fewer, but larger farms means that the percentage of farmers adopting the technology could remain constant while the area on which the technology is being used increase. Thus, Jensen et al. (2012, p. 670) propose to instead use the proportion of total cultivated land that is being cultivated by farmers who are above the adoption point. This however brings about a somewhat problematic issue in that SBA has only reported more detailed data on the amount of land held by farmers with more than 100 hectares since the year 2000 and the information is not reported annually. Because of this, we have included a longer time series with farms above 100 hectares and a

²⁶ See section 5.4

shorter time series with farms above 200 hectares. This will allow us to correlate the two groups and see how well the development of the proportion of farms above 100 hectares correlate with the development of the proportion of farms above 200 hectares. If the correlation is high, then the development of 100+ hectare farms should functionally be able to model the correlation between an increase in PA adopting farms and changes in productivity.

Advantages of data (anna)

Aggregated secondary data has many desirable properties, such as being inexpensive, less time consuming, and easy to use (Shively, 1969, p. 1183). It is thus often used in studies because of these desirable properties (Shively, 1969, p. 1183). In this thesis, the indirect measurement approach of PA adoption brings with it both advantages and disadvantages. It does allow us to analyze the temporal development of PA and make comparisons between different countries as the information needed to compute the adoption rate via proxy is often readily available and is reported in a standardized format. Because of this, the method offers studies using it a high level of replicability. As there currently is no structured data incorporating any comprehensive information of adoption rate, making a connection between volatility and productivity without using a proxy measurement is near impossible. Additionally, the reliance on secondary data and proxy measurements allows for us to provide a more holistic picture of the study area. The interconnections between technology, farming and banking is naturally very complex. By only studying subsections as has been done previously, no clear connection would likely be possible. Even if studies would provide this connection, because of the changing technological environment, such a study would be inherently backwards looking and quickly rendered obsolete.

Additionally, previous research has encountered problems related to conceptual understanding among the farmers which is caused by the lack of consensus regarding what is considered precision agriculture. This misconception might affect the reliability of the answers provided by farmers regarding their PA use and could give clues to the varying adoption rates found in previous studies. The problem related to purchasing precision agricultural services from contractors or other farmers is also to be considered when thinking about what methodology to use. Some farmers might consider renting PAT or purchasing the service from a contractor to be considered adopting the technology while others might only think of it as personally owning the technology. We have not seen strong indications in previous studies of farmers whose own farm is too small to support the investment in PAT instead financing it by renting out excess capacity of their PAT. Thus, by measuring adoption via proxy at an aggregated level, we can reduce errors related to misunderstood questions or concepts and should end up with more reliable data.

Disadvantages of data (anna)

With this said, it should be noted that this methodology also has its inherent disadvantages. As with any proxy, causation becomes lacking if the proxy fails to correctly estimate what it is supposed to measure. If the number of farms with farmland above 200 hectares is not a good determinant of PA adoption, then the causal link between PA and access to finance should come into question. Because of this, we have made sure to control the backwards compatibility between the estimates suggested by our proxy on adoption and studies aimed at revealing actual adoption at that point in time.

Another factor which needs to be taken into consideration is that a percentage decrease in total farmland could be misinterpreting as an increase in the adoption rate. This comes as an effect of that our aggregated data measures adoption as the relation between farmers who are believed to have adopted and those who have not. An example would be a scenario

where the total farmland rapidly decreased while the farmland held by adopting farmers was constant. In this case, the proportion of large farmers would increase and would subsequently indicate that a higher proportion of agricultural land was cultivated using PAT. While this is the case, the reader could interpret it as if there had been an actual increase in the area under cultivation using PA methods which is not the case.

The use of aggregated data also implies the assumption that the relationship between the economic variables used is homogeneous across individuals (Garrett, 2003, p. 61). Thus, we imply that farms within a specific size group are somewhat similar. However, if the behavior of those farms within the groups are not the same, a regression analysis based on aggregated data can provide different conclusions than less aggregated data (Garrett, 2003, p. 61). Because of the somewhat crude nature of aggregated data which does not allow for measurements on farm level, we are unable to see the nuanced patterns of precision agriculture usage and adoption. For instance, we cannot know the exact adoption rates of precision agriculture among companies. One also loses the ability to observe what type of PAT is being used and how this has changed over time as well as whether a farmer uses only one type of PAT or several. Furthermore, the farm level effects of PAT on income volatility and productivity is not decipherable in our data. This means that recommendations in lending to unique farmers is rendered impossible. While this is out of scope for this thesis, it should be made clear that any assumptions of individual farm level effects of PA are based on previous studies alone and used to understand the aggregated data.

6.4 Methodology used in results section (both)

The results section will be divided into separate sections which each will look into a specific part of the data collected for the thesis. We have started by describing the structure of the data and its composition as well as presenting the estimated adoption rate in order for the reader to have a context of the Swedish adoption rate when going into the subsequent sections. Following this, we are looking into income volatility by first finding how well the data fits with statistical assumptions. By doing this we were able to select a suitable statistical test to see how PAT adoption influence the income volatility of farmers. Once we had established the effect of PAT on income volatility, we turned our attention to its effect on productivity. This was done in two steps where the first included comparing the hectare yield of Sweden to that of a, before PAT adoption, comparably productive country (US). This was used to calculate a difference variable which comprised of the annual hectare yield difference between the two countries. We then found the point of adoption in the US and compared the difference in hectare yield before and after the point of adoption to look for any significant deviations which would indicate a change in productivity resulting from the adoption. Once the effect of adoption was established between the two countries, we instead looked at the effect of adoption in Sweden before and after the point of adoption. The methodology used was the same as between Sweden and the US but instead of creating a difference variable, we compared the actual aggregated hectare yield in Sweden before and after the point of adoption. The final section analyzed the correlation between additional factors found to have had an effect on productivity. These factors include such things as the use of fertilizer and pesticides, the investments in machinery and the use of ecological farming methods. This was done in order to understand how factors not directly related to PA is correlated with changes in hectare yield and allow for us to enrich the analysis.

6.5 Alternative methods (anna)

There are alternative methods that could have been used in our research. Firstly, we could have used interviews to collect the data needed. This method would have given us a better understanding of precision agriculture at an individual farm level. By interviewing Swedish farmers, we could have gained solid picture of the level at which PA is used and what the

reasons behind the adoption decisions are. Interviewing individual farms would however be time consuming and the sample size thus relatively small. A study carried out in this manner would thus run the risk of misrepresenting the adoption rate which would be highly problematic. Such a study would also be faced with replicability issues if the study would be constructed again in Sweden and also have problems being compared between different countries.

Another alternative would have been to work together with financial institutions. For instance, we could have worked together with a bank to see the effects of PA on the objectives banks are interested in to notice how the cost of capital changes. This could have provided us with a better understanding of the banks' interests and how they perceive precision agriculture when lending money to farms. There are however issues related to this method. Firstly, working with every major bank in Sweden to have a good coverage would have been very time consuming. If instead concentrating on only one bank, the sample size would have been unsatisfactory as not every farm is using the same bank. Further, banks might be hesitant to work as closely with us as would have been needed to gather the information required. They would e.g. have had to give us insight into, and perhaps even some access to, information regarding their screening criteria and methodology. With the additional help in screening farmers looking to borrow money that we would provide the bank, we would also run the risk of skewing the results through our presence. The reason would be the additional attention and non-standard process that would surround these lending decisions which could make bank-personnel more or less likely to grant the loan. Lastly, it would be difficult to get to work with banks due to regulatory systems which could potentially disallow us to access the data that we would need in order to carry out the research in a practical manner.

A third alternative could have been to purely study the difference between countries in depth. For instance, we could have studied a country which have high adoption rates in precision agriculture and a country with low adoption rates. This could have allowed us to compare the differences in access to finance between high and low adoption situations and draw conclusions based on that. In addition, data would have been relatively easy to gather. What makes this method problematic is the effects of other factors exogenous to precision agriculture. For instance, political situation or extreme weather conditions in one country can change the results and without knowing all the external factors, those cannot be excluded from the study which could have made such a study biased.

The last alternative is to use an experimental approach where we could have looked at the lending process of two groups of farmers and compared the results between these two groups. The first group would include farms that use PA whereas the farms in the other group would not use precision agriculture at all. By conducting a study using this kind of experimental approach, we would be able to measure the effects of PA in accessing financing. For instance, to see if the group of PA users get better loan terms than the group without PA. For all the advantages of such a study, it is still likely to be unfeasible as it would have been extremely hard to carry out. It would include finding a sufficient number of similar sized farms with similar agricultural practices and credit history which would then have to be persuaded to either adopt or not adopt PA over an extended period of time. They would then have to seek financing and do so in such a way that biases would not ruin the results. Such a study would be difficult to carry out even with little to no constraint regarding scope and time limitations. Additionally, a study where being randomly assigned to one of two groups where one of the groups is likely to be put at an disadvantage compared to the other group brings up some clear ethical considerations (Panter and Sterba, 2011, pp. 185–186).

6.6 Ethical and societal considerations (anna)

Ethical considerations in research is a sensitive topic where one has to balance between the advancement of knowledge and the risk of harming individuals in and/or around the research study (Vetenskapsrådet, 2002, p. 5). This means that what is considered ethical in research is always consisting of a sliding scale between the good that a study could provide society and the potential harm that said study could lead to (Vetenskapsrådet, 2002, p. 5). According the Swedish research council (Vetenskapsrådet, 2002, p. 5), ethical considerations can be summarized in four principles which researchers should adhere to in order to minimize the risk of ethical issues in their research projects:

1. Giving proper information to participants
2. Participation out of free will
3. Preserving confidentiality
4. Information usage in research purpose

We have followed these guidelines to the best of our abilities during this thesis. All participants who have given us information in any form have been clearly informed of who they were talking to, what the purpose of talking to them were, and what we were planning to do with the information. Additionally, they were asked whether they gave us their consent to connect any of the information they gave us with their name in the thesis. Additionally, everyone we talked to were offered to read the thesis and asked if they wanted to be informed of where the thesis would be made available.

Since this study is quantitative in nature, the ethical considerations that must be made deviate somewhat from those that would be present in a qualitative study. All of our data used for analysis comes from secondary sources such as FAO, SMHI and the SBA and has been made publicly available. This means that we do not run the risk, in our own data collection, of behaving in an unethical manner. Our method is also such that no individual or company can be identified neither through direct mentioning in the study nor indirectly by means of elimination methods. This is further enhanced since we as researchers have no way of identifying individuals or companies and could thus not make unconscious mentioning of such.

What has been identified as a potential risk factor when it comes to ethical conduct is the presentation of results. As the aim of the thesis is to provide banks with a deeper understanding of how to carry out lending to farmers who are willing to invest in new technology, a potential positive result could have certain negative implications for those farmers who are not investing in this technology. This could come from a result which shows that certain risk factors are decreased in farmers who invest in PAT. By default, if potential borrowers' risk is perceived as relative to the aggregated sum of borrowers, then a reduced risk perception in one group would cause a relative risk perception to increase in the other group of non-adopters unwilling/unable to adopt. This group could thus become subject to more scrutiny and/or find it more difficult to access financing for activities other than PAT adoption. However, given the perceived unlikeliness of this occurring, the potential benefits that could be gained from this research, both practical and theoretical, as well as the potential positive effect for all farmers from the data collection and subsequent understanding from banks regarding agricultural lending has us convinced of the ethicality of this research.

6.7 Statistical method (both)

In order to test the effects of precision agriculture on income volatility and productivity we have run a series of statistical tests. Starting with income volatility, we conducted the Breusch-Pagan/Cook-Weisberg to test for heteroskedasticity and the hausman test to decide between fixed or random effects for our panel data. Based on the outcome from these tests, we have conducted a random effects regression using robust standard errors. In the regression equation, the variable income volatility is the dependent variable.

Equation 2 Breusch-Pagan/Cook Weisberg test

3 step process:

1. Estimate OLS model

$$Y_i = \beta_0 + \beta_1 X_{i1} + \dots + \beta_n X_{in} + \epsilon_i$$

2. Estimate auxiliary regression using OLS

$$\hat{\epsilon}_i^2 = \delta_0 + \delta_1 \hat{y}_i$$

Where:

δ = Coefficient

3. Calculate chi-square statistics

$$\chi^2 = nR_{\delta}^2$$

Where:

n = number of variables

Equation 3 Hausman test

$$H = (b_1 - b_0)' (Var(b_0) - Var(b_1)) \dagger (b_1 - b_0)$$

Where:

\dagger = denotes the moore – penrose pseudoinverse

b_1 = random effects estimator

b_0 = fixed effects estimator

Equation 4 Regression equation

$$\text{Income volatility} = \beta_0 + \beta_{\text{Hectare size}} + \beta_{\text{SD market price}} + \beta_{\text{PA adoption Sweden}} + \epsilon_i$$

Where:

ϵ_i is the error term.

In order to calculate the correlation between productivity and the adoption of precision agriculture, we conducted two (2) independent two sample t-tests. The first was calculated based on the mean difference in the hectare yield in the USA and Sweden before and after the point of adoption in the USA. The second was calculated based on the mean difference in the hectare yield in Sweden before and after the point of adoption in Sweden.

Equation 5 Independent two-sample t-test

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_{\bar{x}_1 - \bar{x}_2}}$$

Where:

\bar{x}_1 = the sample mean for group 1

\bar{x}_2 = the sample mean for group 2

$S_{\bar{x}_1 - \bar{x}_2}$ = the estimated standard error of the difference in means

6.8 Data analysis software

The data in this thesis has first been imported into Excel to be compiled and structured after which it has initially been tested using the data analysis tool pack in Excel. After the initial analysis, the structured data was exported to STATA. In STATA, the data has been analyzed more thoroughly and also checked for problems with the data such as heteroskedasticity and other violations of OLS.

7. Results (data handled by both but written by Lowe)

In this section, the results of the study will be presented. The results are divided into three parts which each aim at investigating different subsections of our research question. We will start off by looking at income volatility and whether it is affected by the adoption of PAT. We will also investigate the adoption rate of PA in Sweden. Then we will move on to comparing the productivity of Sweden to that of the US to see whether the productivity differ when PAT became commercially used in the US while not commercially used in Sweden. Finally, we will focus our attention on the Swedish agricultural market. Here we will look for structural patterns as well as additional factors which might influence whatever results we have found in the first two sections such as changes in the use of fertilization and pesticides.

7.1 Productivity and income volatility

To better understand the specifics of our dataset, we will start off with discussing the descriptive statistics found in Table 1 relating to productivity and income volatility. When investigating the income volatility, the farms have been divided into 6 categories with 29 annual observations for each category which makes up a total sample size of 174 observations. The observations for income volatility range from 1985 to 2016²⁷.

- Category 1 -> 10-20 hectare
- Category 2 -> 20.1-30 hectare
- Category 3 -> 30.1-50 hectare
- Category 4 -> 50.1-100 hectare
- Category 5 -> 100.1-200 hectare
- Category 6 -> 200.1+ hectare

The between year income change was found for each farm size by means of calculating the percentage difference of the aggregated average income for that farm size from one year to another. We can see that the income was quite varying during the period with a range spanning from a low of only 70 % of previous years income to a high of 140 % while the series trended slightly upwards with an average increase of 3.1 % annually.

During the period, the market price for wheat also fluctuated quite significantly and ranged from a high of €7.5/bushel to a low of €2.34/bushel with a majority of the movement taking place after the year 2007, with the preceding period being relatively calm in comparison.

²⁷ Note that data from 2016 is presented as 2015 in the table as it shows the percentage change from 2015 to 2016

7.1.1 Descriptive statistics

Table 1 Descriptive statistics

<i>Variable</i>	<i>Observations</i>	<i>Mean</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
Category ID	174	3.5	1.712	1	6
Hectare Size	174	84.167	68.597	15	200
Income volatility	174	1.031	.080	.70	1.401
Average market price (€)	174	4.155	1.463	2.347	7.509
SD market price	174	.557	.434	.137	1.932
PA adoption Sweden (dummy)	174	.276	.448	0	1
Hectare yield Sweden (Hg/ha)	56	40767.98	8333.268	25438	60536
Hectare yield USA (Hg/ha)	56	48330.64	14944.92	25223	81429
Difference Sweden-USA (Hg/ha)	56	7562.661	8826.584	-11939	27047
PA adoption USA (Dummy)	56	.375	.488	0	1
Percentage 100+ Ha (%)	36	.348	.119	.196	.558
Sales of pesticides (Metric tons)	36	2217.228	1150.589	986	5585
Sales of fertilizer (Million kg)	36	1115.139	298.835	567	1571
Investments in machinery (Million SEK)	36	7479.139	2199.109	4036	12420
Percentage ecological farming (%)	36	.052	.053	0	.156
Annual deviation temperature (°C)	36	1	.136	.673	1.238
Annual deviation precipitation (mm)	36	1	1.123	.790	1.195
Percentage 200+ Ha (%)	7	.198	.094	.752	.327

Note: Values rounded to 3 decimals if applicable. The variable “Percentage 200+Ha” reflects a sliding scale between 200-300 hectares depending on year as per the discussion in section 6.3.3

The standard deviation variable being used for calculating the income volatility is measured as the annual average standard deviation of the global wheat prices and it shows that the volatility of the prices annually goes from a lower bound of 0.137 standard deviations to a high of nearly 2 standard deviations with the lower volatility belonging to the relative calm period in 1999 while the highest standard deviation is found in 2008 (See Figure 9). The last variable used to explain income volatility is a dummy variable set to 1 if an observation

belongs to a year where PAT were commonly used commercially in Sweden (after 2008) and to 0 if before this.

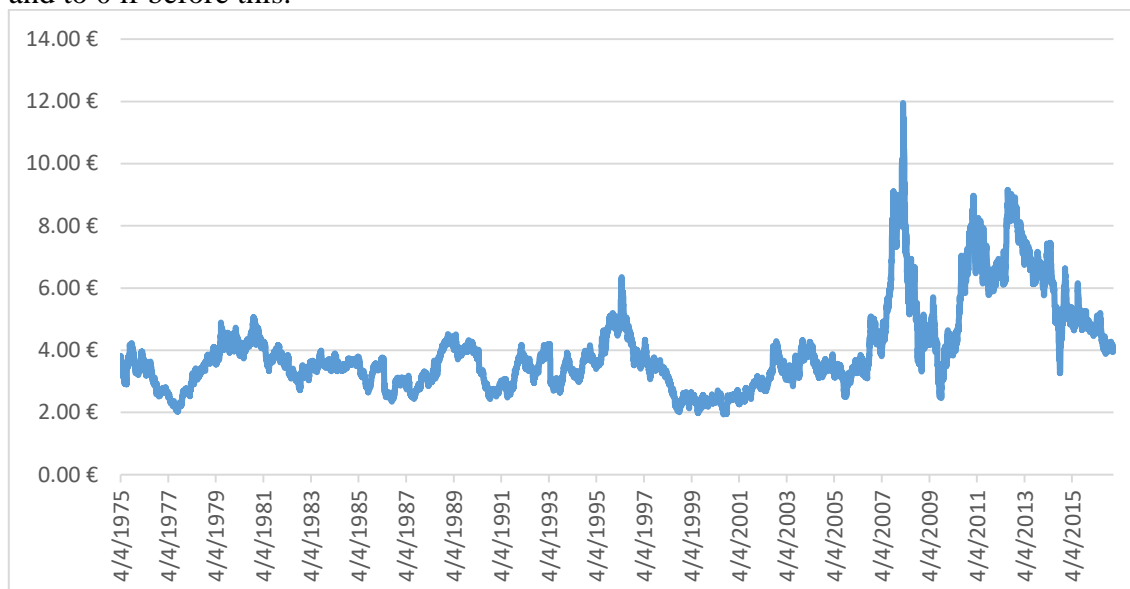


Figure 9 Global price of wheat 1975-2016

When instead looking at the data used for analyzing the productivity of farms, there are five (5) variables that have been used. Aggregated average hectare yield for cereals for Sweden and USA is presented with data stretching from 1961-2016. While Sweden and USA both have roughly the same minimum production, the maximum productivity is higher in the USA which also have a higher volatility in their production together with a higher mean production over the period. The difference between the productions in the two countries is measured through a difference variable set to be the amount that the annual aggregated average production of cereals in the US is higher/lower than in Sweden measured in hectogram/hectare. This ranges from a production difference surplus of ~ 12000 hg/hectare for Sweden to a production deficit of 27047 hg/hectare. Finally, for this dataset, we have a dummy variable which corresponds to 1 for years where the US can be considered to have commercially started to adopt PAT (1996 and onwards) and 0 for years prior to 1996. When looking at Figure 15, we can see the divergence between the Swedish and US hectare yield occurring at around 1996 where, apart from the heavy drought years in the US around 2012, the hectare yield started to diverge upwards in the US compared to Sweden.

7.1.2 Adoption of precision agriculture technology

In Figure 10 we can see the estimated adoption rate of PAT among Swedish farmers using our methodology. As was to be expected, the adoption rate was fairly low between 2000-2007. With the dropping prices of PAT and the growing number of large farmers, the adoption rate started to increase more rapidly from 2008 and our model estimate that the technology currently should be used on around 32 % of the total farmland area in Sweden. This should put the adoption at the early majority stage. This number should be sufficient to have an effect on any changes in volatility or income productivity that we are seeing.

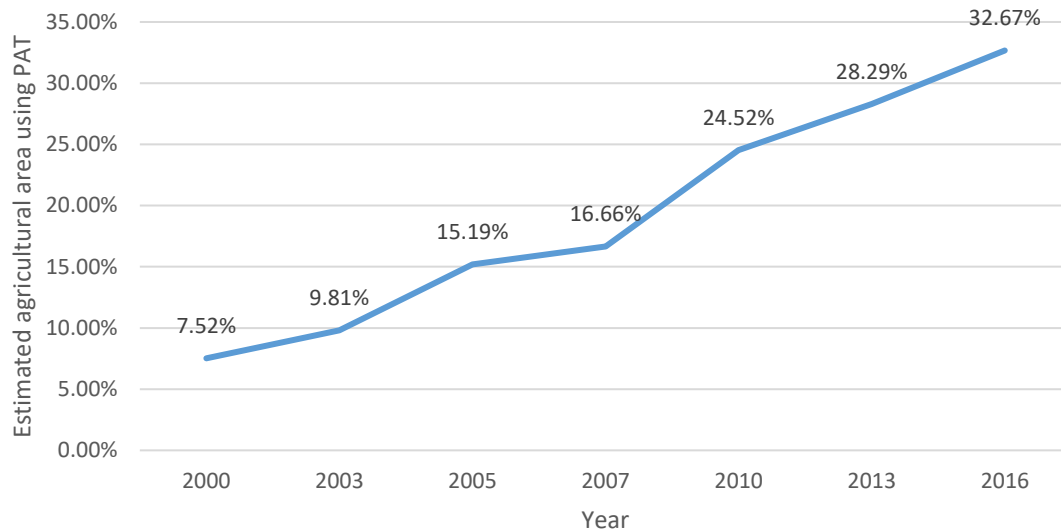


Figure 10 Estimated adoption of precision agriculture in Sweden 2000-2016

7.2 Income volatility

As we now have some familiarity with this part of the data, we will begin a deeper analysis of the effect of PAT adoption on income volatility. The data used here is panel data which inherently provide certain advantages such as the ability of analyzing trends between groups over time and alleviating problems related to multicollinearity (Kennedy, 2008, p. 282). However, it also brings about some statistical challenges such as the possible composite nature of the error term which might include both a time-variant and time-invariant component (Hilmer and Hilmer, 2014, pp. 373–374). Panel data is generally analyzed by either a pooled OLS analysis (Hilmer and Hilmer, 2014, p. 376) or by using either a fixed or random effects model (Kennedy, 2008, p. 284). To decide which model to use is a two-stage process whereby one first analyze whether all the intercepts in the dataset are equal or not (Kennedy, 2008, p. 286). If they are equal, then the data can simply be analyzed using a pooled OLS as the groups of observations in the panel data are not providing additional information. In our case this would mean that the ability to spot differences between different sized farms would be lost. However, pooled OLS would only be suitable if the assumptions for pooled OLS to be the best linear unbiased estimation (BLUE) are not violated (Hun, 2011, p. 7).

According to (Hilmer and Hilmer, 2014, p. 257), these assumption are as follows:

- A1. The linear regression model is correctly specified
- A2. Observations comes from a random sample
- A3. The conditional mean should be zero.
- A4. There is no multi-collinearity
- A5. Errors are spherical: No heteroscedasticity and no autocorrelation
- A6: Error terms should be normally distributed.

To test for the appropriateness of pooled OLS, we will start with the Breusch-Pagan test for heteroskedasticity, the output of which can be seen in Table 2.

Table 2 Breusch-Pagan/Cook-Weisberg test for heteroskedasticity

H0: The error term has constant variance		
HA: The error term has non-constant variance		
Variables		
<i>Hectare size</i>	<i>SD market price</i>	<i>PA adoption Sweden</i>
Chi2 (3) = 16.70		
Prob > Chi2 = 0.0008		

Given that the result of the Breusch-Pagan test was significant ($p \leq 0.05$), we reject H0 which state that our error term has constant variance and assume that heteroskedasticity likely is present in our error term. Because of this, one of the assumptions (A5) for pooled OLS to be the best linear unbiased estimation (BLUE) is violated and thus we will settle for either fixed or random effects for our model as these are more robust against heteroskedasticity (Hun, 2011, pp. 7–8).

To discern between whether fixed effects or random effects will be most suitable for our data, we have conducted a Hausman test to see if there is covariance between our error term and our independent variables. If there is correlation in the coefficients between our independent variables and our error term, this would mean that a fixed effect model would have to be used (STATA, n/d)

H0: There is not systematic differences in coefficients

HA: There is systematic differences in coefficients

Table 3 Hausman test

<i>Variables</i>	Coefficients			S.E
	<i>Fixed effects (b)</i>	<i>Random effects (B)</i>	<i>Difference (b-B)</i>	
SD	.0361	.0361	-2.35e-15	.0024
PA adoption Sweden	-.0391	-.0391	1.03e-15	.0023

Test: H0: difference in coefficients is not systematic
 Prob>chi2 = 1.0000

Because the Hausman test result ($p = 1.000$) was not significant at the 0.05 level, we do not reject H0 and find no reason to believe that there are systematic differences in our coefficients leading us to using random effects modelling. Random effects have the additional benefit over fixed effects of producing a more efficient estimation of the regression slope as well as allowing for analysis of time-invariant variables (Kennedy, 2008, pp. 283–284).

However, because of the likely presence of heteroskedasticity in the data, we will run our random effects model using robust clustering for our standard errors as it helps alleviate the problems that arise due to heteroskedasticity (Kennedy, 2008, p. 345; Williams, 2015, p. 7).

From the results of the random effects regression presented in Table 4, we can see that all the variables are significantly correlated with income volatility at the 0.05 level. While income volatility among farmers increase slightly (coefficient of 0.036) with an increase in the market price fluctuations as was to be expected, the adoption of PAT appears to decrease the income volatility of farmers. This result would suggest that the commercial implementation of PAT in Sweden has decreased the average income volatility by roughly 4 %.

Table 4 Random-effects GLS regression with robust standard errors

Group variable: ID	R-square			No. of obs.	No. of groups	Obs. per group min	Avg	Max	Prob.> chi2
	Within	Between	Overall						
Income volatility	0.0397	0.8693	0.0517	174	6	29	29	29	0.0000
Variables	Coef.	Robust S.E	Z	P>[z]	[95% confidence interval]				
Hectare size	.00013	.00002	6.31	0.000	.00009 .00017				
SD market price	.03619	0.0059	6.11	0.000	.02458 .04780				
PA adoption Sweden	-.03915	.01157	-3.38	0.001	-.06184 -.01647				
Constant	1.01074	.00162	620.94	0.000	1.00755 1.01393				
sigma_u	0								
sigma_e	.08004								
rho	0 (fraction of variance due to u_i)								

Note: result have been rounded to 5 decimals when applicable

7.3 Productivity

We will now turn our attention to the impact of PAT on productivity measured as the aggregated average hectare yield of cereals. As many factors could be influencing the harvest size per hectare such as the use of fertilizer, pesticides, machinery temperature, and precipitation, we will start by analyzing the effects of these factors on the productivity of farmers. From Figure 11, we can see that the sale of pesticides has ranged significantly over the period from a high of 5585 metric tonnes to a low of 986 metric tonnes. Similarly, the sale of fertilizer has also changed from a high of 1571 million kg down to 567 million kg

(Figure 12). It can be noted that both the use of fertilizer and pesticides have been declining since around the early 1980s. The same goes for investment in machinery (Figure 14) which decreased down to a low of around 4 Billion SEK following the economic crisis in Sweden in the early 1990s and has since then been holding rather steady with smaller fluctuations between 6-8 Billion SEK between years.

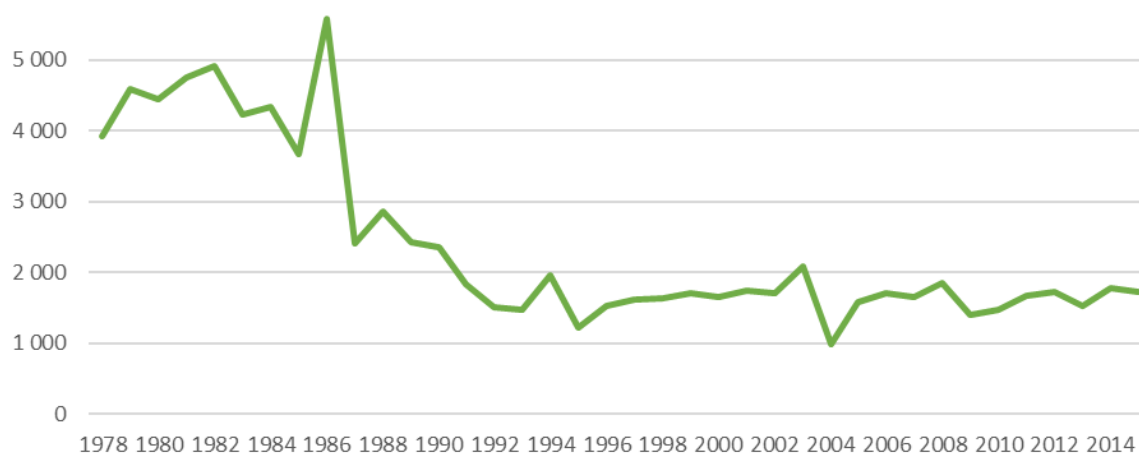


Figure 11 Total sales of pesticides in Sweden in metric tonnes (1978-2014)

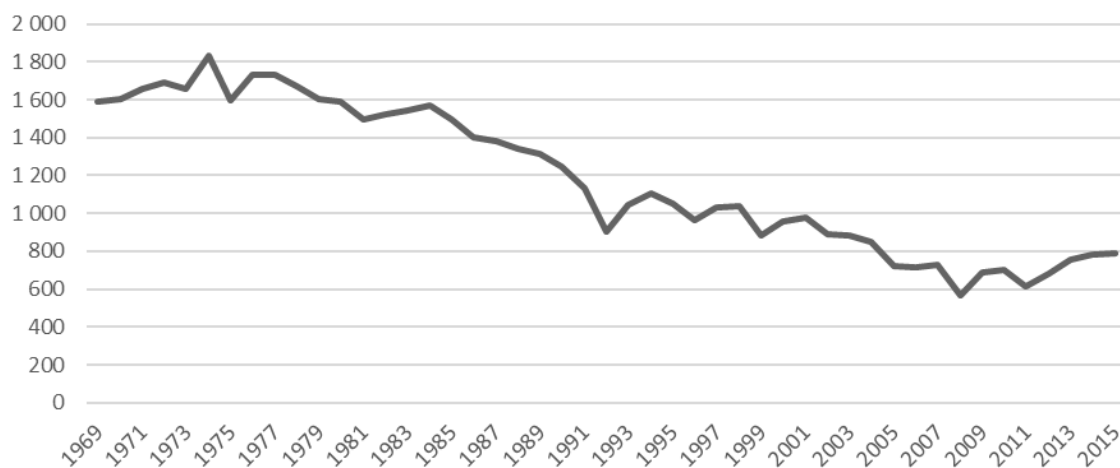


Figure 12 Total sales of fertilizer in Sweden in million kg (1969-2015)

Table 5 Ecological harvest vs Conventional harvest between 2005-2016 (kg/ha)

<i>Crops</i>	<i>Ecological</i>	<i>Conventional</i>	<i>Eco/Conventional</i>
Fall wheat	3586	6451	56%
Spring wheat	2756	4435	62%
Rye	3213	5754	56%
Spring barley	3340	5588	60%
Fall barley	2741	4463	61%
Oat	2631	3998	66%
Meslin	2861	3262	88%

Note: The numbers presented in the table are averaged over the period

Looking at table 5 which deals with the productivity difference between conventional and ecological farming methods, we can see that ecological farming is causing a reduction in harvest across all included crops. The only crop which appears to be less affected by ecological farming methods is meslin which was only reduced to 88 percent of the harvest level achieved by conventional farming methods.

From figure 13, we can note the general weather pattern for the major growing areas in Sweden since 1981 have generally been warmer than average but with roughly average precipitation. The annual temperature has fluctuated between 67.3 and 123.8 percent of the period mean while the precipitation varied between 79 and 119.5 percent.

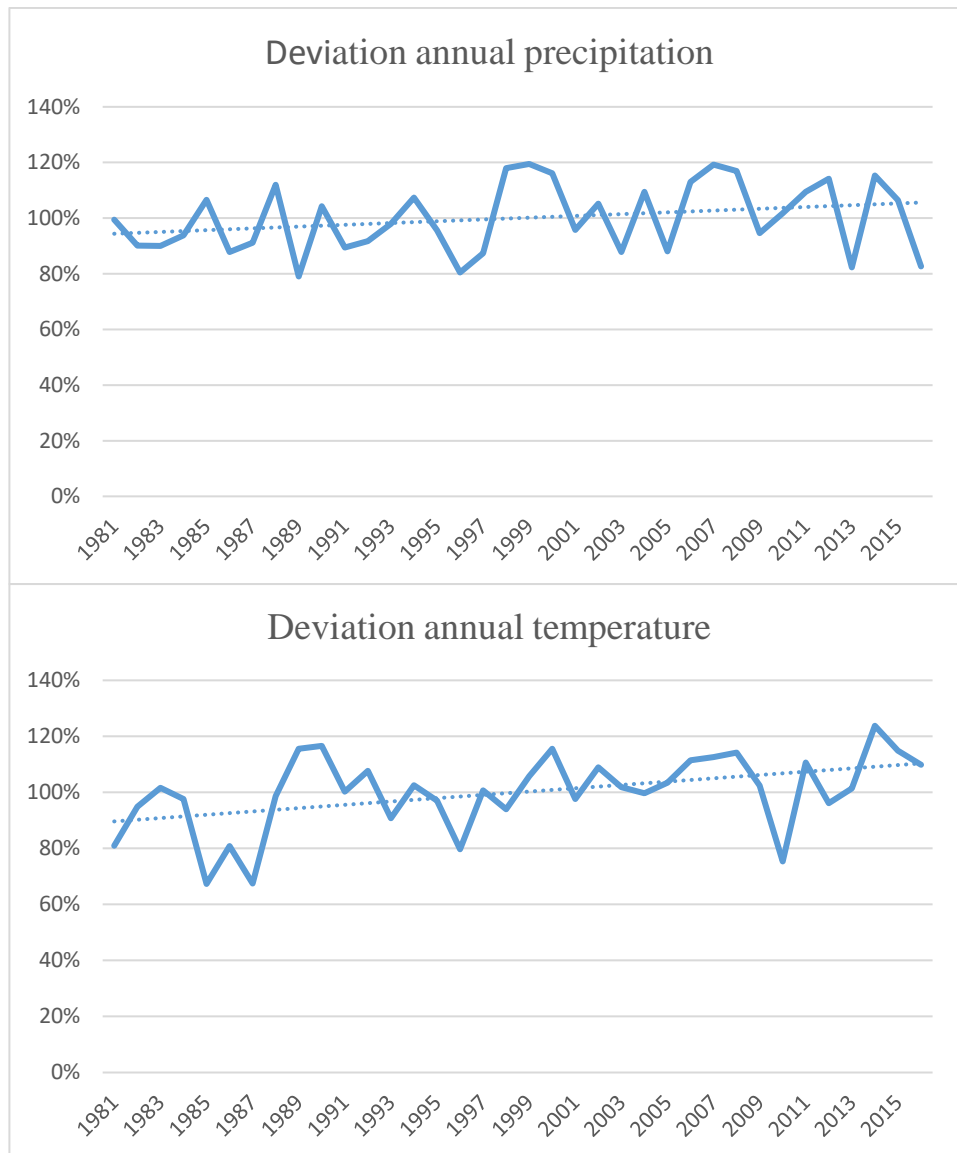


Figure 13 Annual deviation in precipitation (upper) and temperature (lower)

Table 6 Correlation between hectare yield (Sweden) and monthly weather deviations

Hectare yield	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0,154	0,0512	-0,463	-0,332	0,039	0,239	0,291	0,015	-0,143	-0,082	0,109	-0,018
Temperature	0,214	0,3239	0,3530	0,5375	0,046	-0,010	-0,033	0,267	0,2205	0,146	0,303	0,237

Note: Numbers displayed in this table refers to the difference in degrees Celsius (temperature) and mm rainfall (precipitation)

We have broken these annual temperature and precipitation charts down into monthly data and the correlation between this data and hectare yield (1981-2016) is presented in Table 6. We can see that that monthly weather is rather weakly correlated with hectare yield overall with a few exceptions. Temperature appears to be most highly correlated with hectare yield during the later winter months leading up to the sowing season in April where the highest correlation between yield and temperature is found. The correlation then drops significantly going into May and moving on into June and July and even turns negative before becoming stronger again as harvest season approaches in August and September. Overall it appears that colder months have positive and stronger correlation with temperature while warm months have weaker and close to zero or negative correlation. Precipitation appears to act very differently from temperature. It would seem that farmers really do not want a wet spring or fall with particular emphasis on heavy rainfall during March and April. On the other hand, rain during the summer months of June and July is positively correlated with higher hectare yield.

In Table 7, we have presented the correlation between hectare yield and explanatory factors. Hectare yield is strongly positively correlated with both the percentage of large farmers (above 100 hectares and above 200 hectares) and with our dummy variable for adoption of PAT. It is also positively correlated with temperature although with a weaker correlation coefficient. It is however negatively correlated with the sales of pesticides, fertilizer, investments, and precipitation. This points to the fact that an increase in any of these factors are not a probable cause for the increase in hectare yield seen in Sweden. The correlation between weather and productivity is not surprising. Warmer years often leads to a longer growing season and a lack of rainfall could negatively affect the development of crops. This becomes more evident in the light of additional analysis of Swedish precipitation in the major growing areas which shows that years with below average precipitation usually comes down to a dry spring season which could hamper the crop development for the entire growing season (Blum *et al.*, 1990).

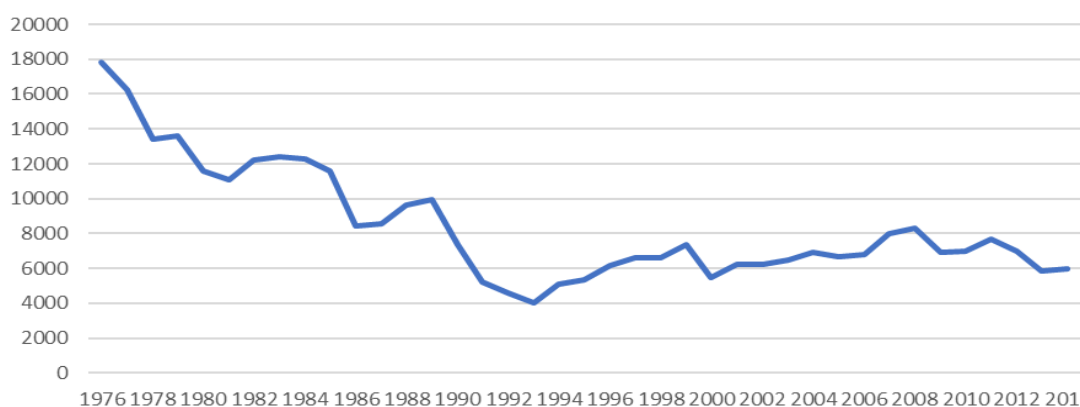


Figure 14 Investment in machinery 1976-2014 (million SEK)

Table 7 Correlation matrix

	Year	Hectare yield Sweden	Percentage 100+ Ha	Sales of Pesticides	Sales of fertilizer	Investments in machinery	Percentage ecological farming	Annual deviation temperature	Annual deviation precipitation	PA adoption Sweden	Percentage 200+ Ha
Year	1										
Hectare yield Sweden	0.7978	1									
Percentage 100+ Ha	0.9952	0.7857	1								
Sales of Pesticides	-0.0081	-0.3500	-0.0283	1							
Sales of fertilizer	-0.6451	-0.4210	-0.6326	0.0133	1						
Investments machinery	0.2942	0.03246	0.2997	-0.7935	-0.4505	1					
Percentage ecological farming	0.9628	0.7481	0.9624	0.1645	-0.5251	0.04031	1				
Annual deviation temperature	-0.2556	0.3413	-0.2714	-0.4384	0.5298	-0.1084	-0.2185	1			
Annual deviation precipitation	-0.5314	-0.4096	-0.5836	-0.2982	0.2739	0.2334	-0.6208	0.2050	1		
PA adoption Sweden	0.8733	0.4577	0.8636	0.4035	-0.5285	-0.0264	0.9128	-0.5168	-0.4763	1	
Percentage 200+ Ha	0.9872	0.7986	0.9710	-0.0595	-0.6946	0.3693	0.9248	-2.470	-0.4029	0.8517	1

Given that factors other than the proportion of large farmers, percentage of ecological farming and the period in which PAT have been commercially used to a larger extent, are weakly or negatively correlated with productivity, we will focus our attention on the influence of PAT. We will begin by analyzing the development in productivity between Sweden and the US as these two countries have had similar hectare yield as well as a similar development of the hectare yield before the start of PAT (Figure 15). As the US adopted PAT earlier than Sweden and are more heavily adopting the technology, this gives us the ability to spot any deviations occurring between the two countries after the adoption of PAT in the US around 1995-1996.

Table 8 shows a two-sample t-test of the annual hectare yield difference between Sweden and the US divided via dummy variable into two categories where 0 corresponds to the yield difference before 1996 and 1 corresponds to the hectare difference after 1996. The mean yield difference between Sweden and the US is found to be 0.2467 tonne/hectare (2467 hg) before the adoption of PAT in the US and 1.57 tonne/hectare (15754 hg) after the adoption. This mean difference is significant at the 0.01 level and shows that it is likely that the adoption of PAT in the US has caused the productivity to increase faster there than in Sweden. The deviation between the two countries can also be seen graphically in Figure 15. In this Figure, we can also see the hectare yield development of Finland as a comparison. As previously stated, the development of PAT adoption in Finland has not taken off and remains at a low level. Finnish total hectare output remains below that of both Sweden and the US, likely due to its relatively larger proportion of land being situated at a more northern latitude. However, productivity in Finland does not show the same relative increase as occurred in Sweden and the US after adoption took place in these two countries. Since Finland should have similar agricultural resources outside of PAT, this strengthens our certainty in that the change in productivity we see in Sweden and the US is related to PAT.

H0: There is no difference in hectare yield between Sweden and the US before/after 1996
HA: There is a negative difference in hectare yield between Sweden and the US before/after 1996

Table 8 Independent two-sample t-test of difference between Sweden/USA

<i>Group</i>	<i>Obs</i>	<i>Mean</i>	<i>S.E</i>	<i>SD</i>	<i>[95% confidence interval</i>	
<i>Pre-adoption</i>	35	2647.457	1019.769	6033.033	575.0378	4719.877
<i>Post adoption</i>	21	15754.67	1373.73	6295.222	12889.12	18620.22
<i>Combined</i>	56	7562.661	1179.502	8826.584	5198.886	9926.435
<i>Difference (Pre-post)</i>		-13107.21	1592.44		-16500.35	-9714.071
<i>Degrees of freedom</i>	54					
<i>T-statistic</i>	-7.7446					

Ha:diff <0
Pr (T<t) = 0.000

Ha:diff /= 0
Pr (T /= t) =0.000

Ha:diff >0
Pr (T>t) = 0.000

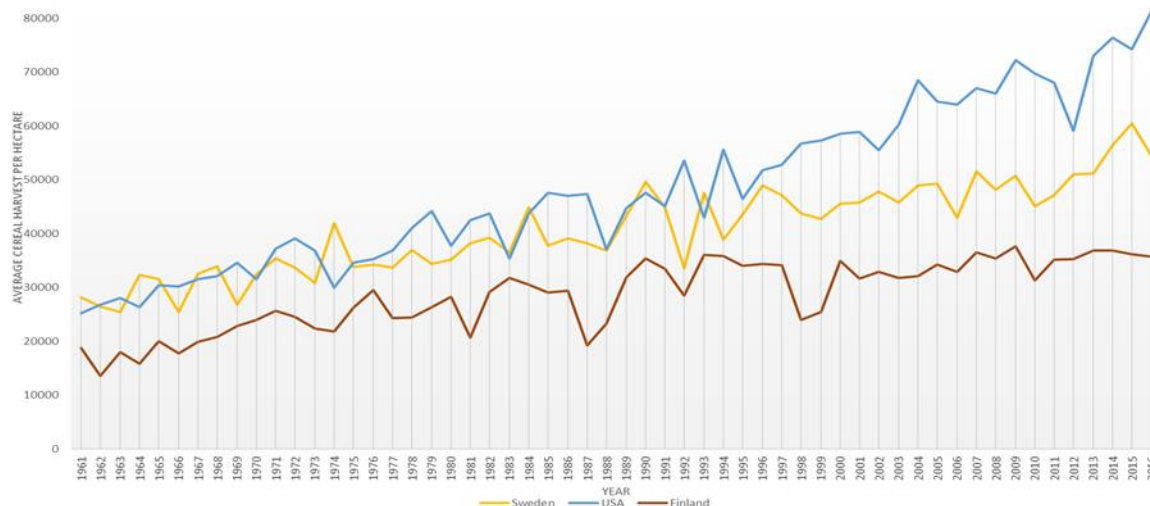


Figure 15 Average hectare yield for cereals in hectogram 1961-2016 (Sweden, USA, and Finland)

As it appears that periods of technological improvement are correlated with increased yield/hectare for adopters, we will now focus on the Swedish market.

To further investigate the effect of PA adoption on the Swedish market, we have conducted a two-sample T-test of the difference in hectare yield in Sweden around the time of commercial adoption. The results in Table 9, show that the hectare yield averaged 4.4 metric tonnes before 2008 and 5.4 metric tonnes after 2008 with a standard deviation of around 0.52 metric tonnes prior and 0.55 metric tonnes post the assumed adoption point. The mean difference in harvest/hectare in Sweden is 1.04 metric tonnes higher after adoption compared to before adoption. Focusing on the p-values, we can see that this result is significant at the 0.01 level meaning that we reject our null hypothesis and assume that there is a positive impact of PAT adoption on hectare yield in Sweden.

H₀: There is no difference in hectare yield in Sweden before and after 2008

H_A: There is a positive difference in hectare yield in Sweden before and after 2008

Table 9 Independent two-sample t-test of difference before and after adoption in Sweden

Group	Obs	Mean	S.E	SD	[95% confidence interval]	
Pre-adoption	27	43954.08	998.0093	5185.809	41902.64	46005.51
Post adoption	9	54357.31	1833.378	5500.133	50129.53	58585.09
Combined	36	46554.89	1151.863	6911.179	44216.48	48893.29
Difference (Pre-post)		-10403.23	2025.136		-14518.8	-6287.662
Degrees of freedom	34					
T-statistic	-5.1371					

H_a:diff <0
Pr (T<t) = 0.000

H_a:diff =/= 0
Pr (T =/= t) = 0.000

H_a:diff >0
Pr (T>t) = 0.000

In figures 16, 17, 18 and 19, we can see the correlation between the hectare yield and the percentage of large farms holding more than 100 hectares of agricultural land (according to Table 7 the correlation between farmers with 100+ hectares and farmers with 200+ hectares are very strong). As larger farms are thought to have better access to financing and benefit more from the adoption of new technology purchased, it would be reasonable to assume that in periods of commercially available technological improvements that are considered viable and shown to improve productivity, an increase in the proportion of large farms would correlate with an increase in hectare yield. On the other hand, when the farms are technologically saturated, there would not be a correlation between these factors. Up until around 1995, there was still an increase in motorization in Swedish agriculture as seen in Figure 5 but with no increase in fertilizer or pesticide use (Figure 11 & 12). Thus, much of the structural development in Swedish agriculture was stagnant from 1996 to 2008 when PAT started being more wide-spread in Sweden going forward. As can be seen in Figure 19, leading up to 1996, the proportion of large farmers was positively correlated with an increase in productivity. This correlation weakened and flattened considerably during the technologically stagnant period of 1996-2007. After 2007 when the possible benefits of PAT started to catch the eye of farmers, the adaptation increased and an increase in the proportion of large farmers started to correlate positively and rather strongly with hectare yields again with an r-square value of 0.5456. This points towards that productivity is positively affected by the adoption and increased usage of PAT.

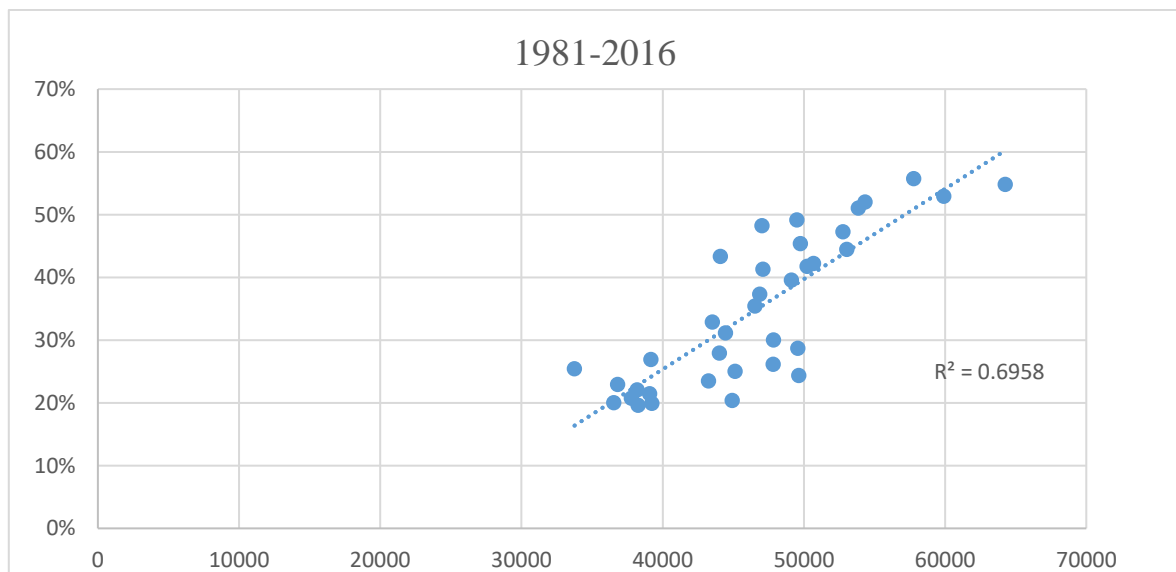


Figure 16 Correlation between farms with 100+ hectares and hectare yield (1981-2016)

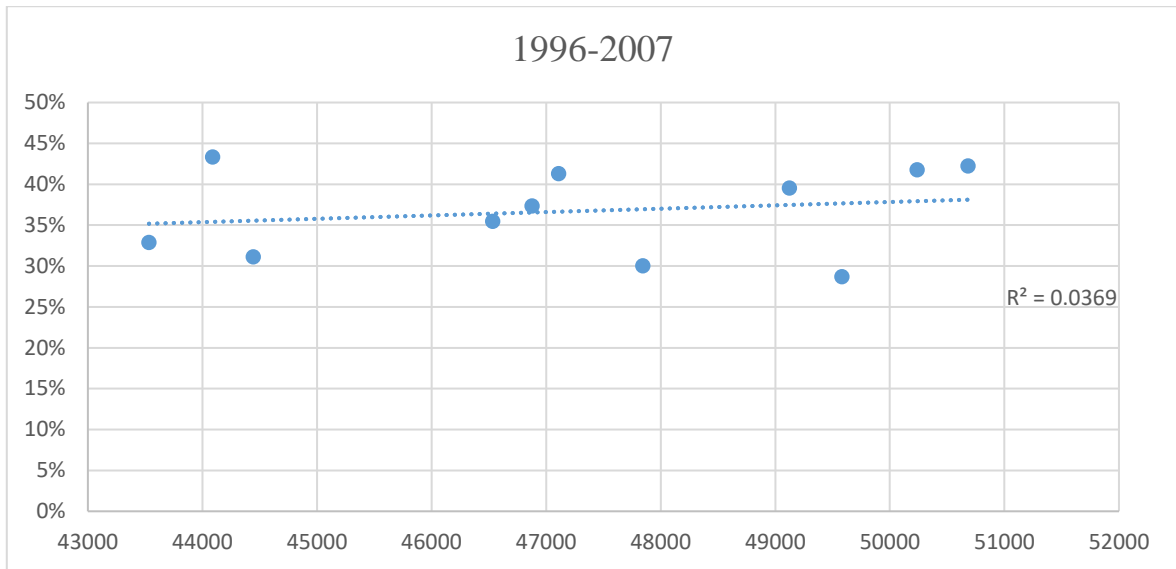


Figure 17 Correlation between farms with 100+ hectares and hectare yield (1996-2007)

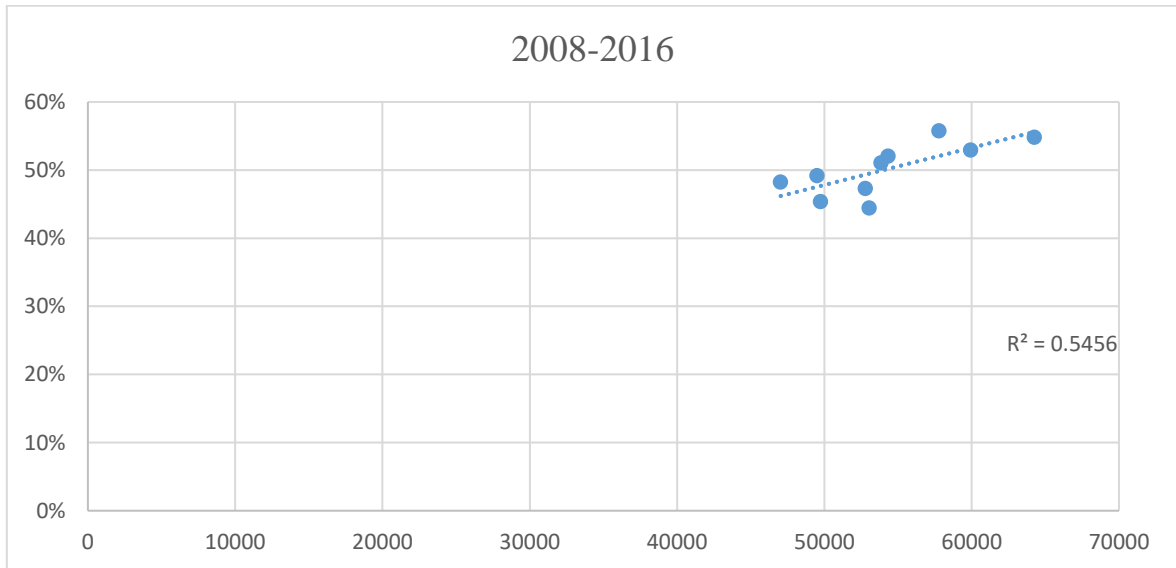


Figure 18 Correlation between farms with 100+ hectares and hectare yield (2008-2016)

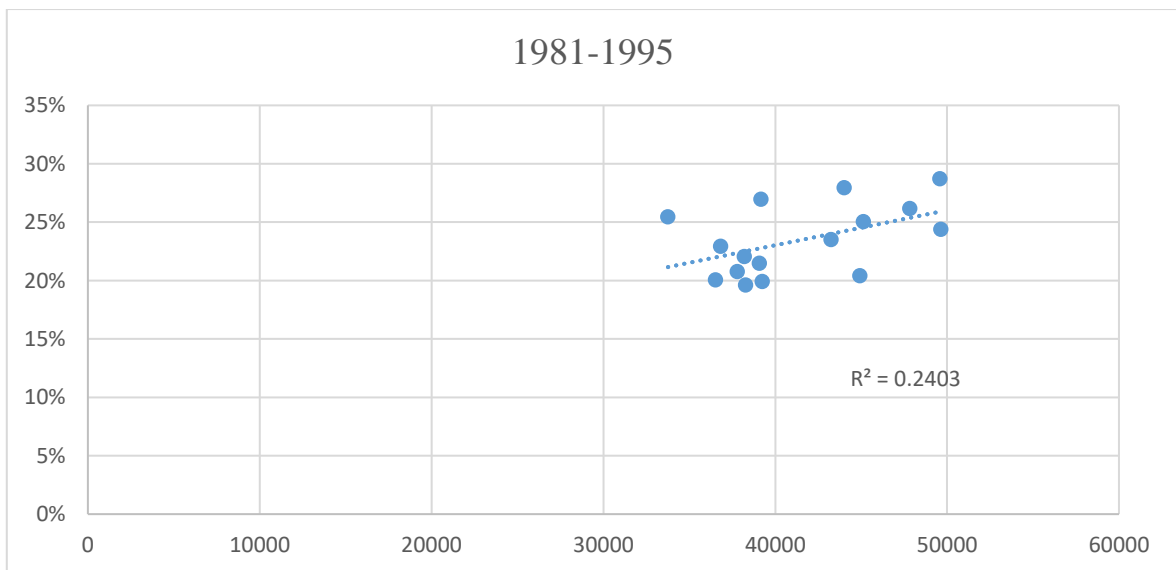


Figure 19 Correlation between farms with 100+ hectares and hectare yield (1981-1995)

8 Discussion (everything related to banking and finance- anna)

In this chapter, the authors discuss the findings of the thesis. The results will be critically evaluated and recommendations about agri-finance related to PA are presented. The discussion regarding the results will be done with respect to the theoretical framework and be compared to the previous literature within the field.

While researchers before us have concluded that funding to farmers could make their lives easier and more productive (Aneslin et al., 2004; Biermacher et al., 2006; EIP-AGRI, 2015; McBratney et al., 2005; Nistor et al., 2008; Pedersen et al., 2004; Olsson, 2008; Rydberg et al., 2008; Söderström et al., 2004), the fact of the matter is that this money is not generated out of thin air. As is concluded by the World Bank, the money needed in tomorrow's farming must come from private pockets and these pockets will not open unless farmers become more attractive as borrowers.

We found that the factors mainly involved in improving the credit worthiness of farmers include a reduction in income volatility and an increase in productivity. Previous studies have found that PA is likely to help generating a higher yield and maintain a more consistent crop output (Basso et al., 2013; Schrijver et al., 2016). Because of this, we expected to find that with increased adoption of PAT, we would in fact see an improvement in both factors related to credit worthiness among farmers.

The results we have presented show that the adoption of PAT has led to an average reduction in income volatility among farmers by roughly 4 % and that it is strongly correlated with an increased hectare yield (79,86%). The difference in average hectare yield before and after the adoption took place in Sweden is found to be roughly 1 metric tonne which translates to a 23.7 % increase over the pre-PA period. Both of these results are found to be statistically significant at the 0.05 level. It also appears that increases in productivity are not isolated to Sweden as countries such as the US who adopted PA have also seen increases.

These results are strengthened by our additional analysis which indicated negative correlation between current productivity increases and factors which historically have generated productivity increases. These factors include such things as the amount of fertilizers and pesticides used as well as the investment in machinery not related to PAT. We are likely seeing these finding as a result of the more efficient usage of input that was forced in place by the regulations put on the amount of pesticides and fertilizer allowed to be dispersed on the fields. As studies have shown that applying e.g. fertilizer in excess of the economic optimum is not yielding a better crop response (Delin & Stenberg, 2014), then the general decrease of these inputs in connection with an increased productivity should naturally show a negative correlation. This is likely also playing a role in the actual increase that we are seeing in terms of productivity for the farmers that use PA. Allowing a larger percentage of the field to grow with an optimal quantity of fertilizer and pesticides dispersed at the right time should result in a better crop response compared to conventional farming.

When looking at the investment in machinery, we see a decrease until the early 90s followed by a steadying of the investment in machinery which appears to coincide with the number of tractors in Swedish agriculture. The number of tractors increased until the early 90s and has kept still since. It would thus appear that the tractor market in Sweden was non-saturated until this point in time and now the sales relates mainly to natural replacements or upgrades. This increase would likely have influenced the productivity until the point of saturation and as the increase stopped, the correlation with productivity was nullified.

Something which we found very interesting was the, albeit minimal and overall decreasing, higher volatility for larger farmers compared to smaller farmers. Given the previous discussion regarding the hedging ability of larger farmers, we expected the results to be reversed with larger farmers having lower income volatility. We find it likely that this comes from larger farmers selling more on the international market compared to smaller farmers who are focusing on the domestic market. Because of the increased competition from other countries and the exposure to economic crises and political interventions affecting the global market, then these farmers are likely to be more vulnerable to such price fluctuations compared to smaller farmers. Thus, we contribute much of the higher volatility in income among larger farmers to factors external to the own production. If this assumption holds true, then the fact that these farmers have decreased their income volatility after the implementation of PA despite the turbulent landscape could be seen as them being better at minimizing harvest fluctuations compared to non-adopting farmers. This would be in line with our assumptions as larger farmers should benefit more from PA and thus be able to invest more in the technology which then should translate into lower farm level fluctuations.

Turning our attention back to productivity, we found that productivity was not strongly correlated with environmental factors such as temperature and precipitation. In annual terms, temperature was found to be positively correlated with increased hectare yield while precipitation was negatively correlated. When stating this, it should be noted that the correlation differs between months. Temperature is most strongly positively correlated with yield during April (0.537) while being most weakly correlated during June and July (-0.01; -0.03). Precipitation on the other hand has a strong negative correlation with yield during March and April (-0.46; -0.33) while having a rather positive correlation during June and July (0.24; 0.29).

Additionally, it appears that rainfall during harvest time in September is having a negative impact on the yield. Overall the impact of weather on the productivity follows common knowledge where early thaw with no waterlogging of still frozen ground will give an early start to the growing season. With plentiful precipitation and normal temperatures during the summer, the crops are given the opportunity to grow without suffering from heat damage or frost. If this is then followed by a rather dry and warm fall, the optimal conditions for a good harvest season are fulfilled. While we were expecting weather conditions to have an impact on productivity, the correlations we find are so low that they by themselves are far from explaining the variation and trend in productivity we see in our data.

It should also be noted that the increase in productivity and decrease in income volatility are found in spite of an increase in ecological farmland which now amounts to 15.6 % and an increase in the overall commodity price volatility on the market compared to before the point of adoption in Sweden. These factors are important as ecological production was found to reduce the productivity to 56-88% of conventional farming and, with the close ties of commodity prices to farm income, fluctuations in the market prices should have a significant impact on income volatility. The decrease in productivity with ecological farming is consistent with previous studies which found that ecological productivity was only 80 % (SD 21 %) of conventional farming with even larger decreases being found in northern European countries (De Ponti et al., 2012). Thus, with these two factors working against the results that we are seeing, the underlying shift has the potential of being greater than what is found in this thesis.

For farmers not involved in ecological farming or for farmers acting in a market with less price volatility, the effect of adopting PAT is probably aggravated above the current levels found. With this said, the impact of ecological farming cannot be seen in isolation from the

market. Given the lower yield of ecological farming, the prices should subsequently be higher for the crops cultivated in this way. When analyzing the effect of ecological farming on the credit worthiness of farmers, one will have to take into consideration the offsetting impact of higher prices on the yield. If this price difference is sufficiently large, then the ecological farming should not affect the decision of the bank in terms of productivity. With this said, the fact that fertilizers and pesticides are used in a different way compared to conventional farming could result in higher harvest fluctuations which in continuation could give the farmer a greater income volatility.

The benefits of PA in terms of improving the credit screening process for financial institutions lending to farmers appears to not only be restricted to better credit worthiness. With the ability to generate data which easily can be transferred between farmers and lenders, the issues of information asymmetry, adverse selection and moral hazard should be reduced. By better understanding the fundamental ability of farmers to service their loan obligations in terms of making farm level decisions which are in line with proper farming practices, the banks should have an increased ability to price loans to farmers properly. This transferring of knowledge between the two parties which results in an equalization of information could also help banks in requesting suitable collateral and make sure that the collateral properly reflects the actual risk of the loan. This kind of data should prove especially valuable in areas within agriculture or places where it is hard for the lender to observe the actual operation of the business to which it lends. For example, remote complex farming should gain more from the sharing of data compared to farms with relatively simple operations in close proximity to population centers. In the long run, this kind of information should not only help reduce the information asymmetry between the bank and farmers already invested in the technology; By utilizing the information from one adopting farmer to benchmark other surrounding farmers, the adoption of one farmer could help improve the loan terms for other farmers.

An understanding of the additional information that could be gained when lending to farmers investing in PAT could also help guide the covenant requested by the bank. As the information the farmer collects for the agricultural practice of PA could be shared with the bank, then covenants which requests this information, or allows for more favorable terms if the information shared, could help reduce moral hazard. As the bank then could keep up to date on the actions the farmer takes on the field, it could continuously ensure that the best farming practice is being upheld. The information could also act as an early warning sign for such activities which might be part of a risk shift from the farmer to the bank. The ability of banks to better monitor the activities of the farmers could help deter farming practices which enable short term gains but risk long term financial stability and thus the farmer's ability to service the loan. This type of information is also likely to reduce the adverse selection bias in agricultural lending. As banks are given the opportunity to more granularly adjust the price of the loan based on information gained from PA-practices, the distance between the price a farmer was to be quoted given perfect transparency and the offered price should decrease, leading to a more efficient market. This requires that farmers are willing to share their information with the bank. Studies show that farmers oftentimes are hesitant to share their farm information with outside parties (Fountas et al., 2005, p. 132). If this perception among farmers is not changing as the practice of data collection among farmers becomes more commonplace, then the banks might have to offer some kind of advantage in the lending process to farmers who are willing to transfer this knowledge to the banks.

Another factor of investing in PA that banks should take into consideration is the suitability of adopting PAT based on farm level conditions. Particular attention should be put to the hectare size of the farm as this appears to be the biggest determinant for the overall

profitability of an investment in the technology (Pierpaoli et al., 2013, p. 64) as it spreads the cost over a larger body of income. Through our review of previous studies, we have concluded that current PAT require an approximate size of 200-300 hectares to make economic sense. Given the assumption of rational economic behavior among the aggregated number of farmers, our methodology resulted in an approximate adoption rate of 32% among Swedish farmers in 2016. This number is in line with recent research which have found the adoption to be around or above 30% in comparable countries (Paustian & Theuvsen, 2017). By understanding the scale of operations needed for a farmer to sustain an investment in PAT, banks should be able to better judge the risks involved in financing this investment. As has been pointed out by Kutter et al. (2011), the ability for farmers to rent out the equipment or act as a contractor for the service of PA should enable farmers with otherwise insufficient land holdings to justify the investment in PAT. Armed with this understanding, the banks should be able to discuss such matters with the farmers during the screening process. If e.g. a farmer is able to sign sufficient additional hectares from other farms on which to use the equipment, then a bank could still grant a loan even if the initial screening of the farmer indicated that the equipment would not be profitable for that particular farmer. What this means is that banks who are lending to farmers could inform the farmer of the economic suitability of the investment and, if the area the farmer cultivate is insufficient to sustain the investment, the bank could then inform the farmer regarding the possibility of renting out the service to neighboring farms.

9 Conclusion

This chapter provides final concluding words about the topic, results and their contribution to business. Lastly, limitations are discussed and ideas for further research are presented.

In this thesis we set out to investigate how precision agriculture affects banks' willingness of agricultural lending by improving productivity and lowering income volatility among farmers. By doing so, we hope to achieve several things:

- Generate a better understanding of how the ability of farmers to access financing is affected by the adoption of precision agriculture.
- Increase banks' understanding of how to properly value and factor in the effects of precision agriculture in their risk evaluation models.
- Help both banks and farmers realize the possibilities for increased access to financing overall in farming by analyzing what additional information could be made available and how this could be used.
- See how information gained through precision agriculture could help create a sounder agricultural finance market in order to facilitate a more correct pricing of capital and, through this, higher total lending to farmers.

In our study we found that the factors most important to financial institutions when lending to farmers is low income volatility and high productivity. We also found that these two factors were improved in Sweden through the adoption of precision agriculture. In addition to the main findings, we also uncovered the following:

- Factors historically involved in improving productivity (increased use of fertilizer, pesticides, and machinery) has not played an important role since the adoption of precision agriculture in Sweden
- Weather related factors are not fully able to explain the increases or fluctuations in productivity seen in recent years in Sweden
- Ecological farming decreases the average productivity of Swedish crop farmers
- The adoption of precision agriculture among Swedish farmers in 2016 is estimated at 32,67 %
- Farmers currently need approximately 200 hectares to profit from the use of precision agriculture technology and this number is likely to decrease in the future.

While we clearly recognize that this study is merely a first step in this area and that much more research is needed, we still feel that we have answered the research question that we set out to investigate and fulfilled the purpose of the study.

9.1 Contributions (anna)

Farmers seeking access to financing will be able to read this thesis and understand what banks are looking for, how precision agriculture impacts these factors, and what steps the farmer can take in order to be perceived as a better loan candidate. The banks on the other hand can advance their credit models with the knowledge of the improvements that precision agriculture brings with it related to income volatility and productivity. They should also gain a better understanding of how risk factors such as asymmetric information and moral hazard can be positively improved through the investment in precision agriculture among their loan candidates and what information is to be available.

We also feel that this study has helped further the theoretical knowledge in this area. This thesis builds on the foundation being laid down by researchers in both agriculture and

finance who have explained the effects of precision agriculture and the risks banks in agricultural lending are subjected to and the ways of handling them. We expand upon this body of knowledge by breaking a new path in the direction of agricultural finance which focal point is not the farmer but rather the lender. By turning the research question around and work more closely towards the financial side of agricultural finance, we hope to help researchers explore this new body of knowledge rather than focusing on finding micro-fissures in the already existing one. We feel that this is an important building block in a field which long has revolved around the benefits of financing to farmers but forgotten how and why the money actually makes its way into their pockets.

9.2 Limitations (lowe)

As with any research, this thesis has certain limitations which the reader should have in mind when interpreting the findings. This thesis has focused on Swedish farmers as they are considered to be on the forefront of technological development and operates in a financial environment which is highly functional. This setting was chosen in order to facilitate the best possible opportunity to measure the effects of precision agriculture on productivity and income volatility. However, this also means that it might be hard to transfer the findings from this study to other settings.

The uncertainty of the state of adoption among farmers forced us to use aggregated data and measuring methods in order to make assumptions regarding the adoption rate. While this had the obvious benefit of allowing for an understanding of the actual usage and allow for us to put the findings in perspective and judge whether they were reasonable or not, it does also pose some issues. Since the technologies in precision agricultural technology are widespread both in terms of application and price, this means that the data lacks the depth to allow for us to analyze the viability of different technologies in terms of affecting lending. Also, while we have found that sharing, renting out, or contracting the equipment used for precision agriculture could help farmers whose own scale of operation does not justify the investment, we have not developed this reasoning further. While research points towards that this kind of behavior is somewhat rare still and thus should not have a big impact on the findings, it is possible that this kind of action could cause our methodology to misjudge the adoption rate. If farmers are able to adopt precision agriculture by offering additional services to other farmers, it is possible that farmers smaller than what we estimated could adopt the technology. If the scale of this practice increase, it might void our methodology in the future and make follow up studies more difficult. Additionally, if we have misjudged the current and past practice of PA then it is possible that we have underestimated the adoption rate.

Finally, there is still the likelihood of factors not included in this thesis to have an impact on the increase in productivity and decrease in income volatility. While we have taken strides to solidify the relation between the independent and dependent variables, the fact that the adoption rate is estimated at only 30 % means that there is still ample room for other factors external to this study to influence the dependent variable. Thus, the reader should be cautious assuming causation rather than correlation.

9.3 Future research (lowe)

This thesis aims at opening the topic and generate initial understanding on which later studies build upon. Thus, naturally there are numerous places to start branching future research topics from.

The lack of understanding gained in this thesis regarding the way that contracting or renting precision agricultural technology functions, both from the perspective of the farmer owning the equipment and the farmer paying for the service, opens up for studies which further develops this knowledge. As renting out the equipment provides the farmer with additional income then this income might help the farmer hedge by not only relying on income from the success of the own harvest. However, these contractual obligations might be such that the farmer is forced to focus on the harvest of others instead of the own harvest. An understanding of how renting out the equipment or offering the service affects factors related to financing would thus be interesting

The fact that we have not distinguished between the different types of precision agriculture technologies opens up for studies which attempt to find the effect of different types of precision agriculture technologies on productivity and income volatility. This analysis could also attempt to discern the effect of different price levels within each technology to allow for more granular analysis by banks when lending to investments in these technologies. This could also be combined with renting or contracting the equipment in order to generate a more holistic picture of the full cost/benefit of a certain piece of precision agriculture technology.

Our selection of Sweden for this thesis was, as previously explained, based the likelihood of finding results because of certain structural conditions such as a well-functioning banking industry and a well-developed technological level among farmers. It would thus be interesting to carry out a similar study in a country where these conditions are not present. This would however likely include new measures of what factors are important as banks in countries with a more unstable economic and legislative environment might be more reliant upon factors such as warehouse financing to secure collateral.

Finally, the difference between agricultural banks and conventional banks could be looked at further. How would precision agriculture affect credit worthiness if the lender is specialized in agriculture. This analysis could also include investigating the effect of VaR one the part of the loan portfolio including a higher proportion (or exclusively) of loans made to farmers investing in precision agriculture. This could help create a better understanding of how precision agriculture affects the risk in the banks' loan portfolio among banks who are experts in this type of lending.

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Appendix

Variable description

Category ID → The six (6) size categories into which we have divided the sample of farms and is measured from 1-6 depending on what hectare size span the farm belongs to.

Hectare Size → The hectare size of the farms in the sample divided into 6 categories

Income volatility → Standard deviation of farm income

Average market price → The average global market price of wheat in Euros/bushel

SD market price → The standard deviation of the variable "average market price"

PA adoption Sweden → Dummy variable dividing between pre/post-adoption in Sweden

Hectare yield Sweden → Annual aggregated average hectare yield for cereals in Sweden measured in hectograms/hectare

Hectare yield USA → Annual aggregated average hectare yield for cereals in the USA measured in hectograms/hectare

Difference Sweden-USA → The difference in annual aggregated average hectare yield for cereals between Sweden and the USA measured in hectograms/hectare

PA adoption USA → Dummy variables dividing between pre/post-adoption in the USA

Percentage 100+ Ha → The percentage of total farm land area that is cultivated by farmers with holdings exceeding 100 hectares

Sales of pesticides → The total annual sales of pesticides in Sweden measured in metric tonnes

Sales of fertilizers → The total annual sales of fertilizer in Sweden measured in million kg

Investments in machinery → the total annual sales of machinery in Sweden measured in million SEK

Percentage ecological farming → The annual percentage of total agricultural land devoted to farming using ecological farming practices

Annual deviation temperature → The annual deviation in temperature in Swedish major growing areas measured as the aggregated temperature deviation in degrees Celsius compared to the average for the period 1981-2016

Annual deviation precipitation → The annual deviation in precipitation in Swedish major growing areas measured as the aggregated precipitation deviation in millimeters compared to the average for the period 1981-2016

Percentage 200+ Ha → The percentage of total farm land area that is cultivated by farmers with holdings exceeding 200 hectares

