Risk management for malting barley

Cost of quality risk and benefits from cross-hedging malting barley

Emil Bagger-Jörgensen

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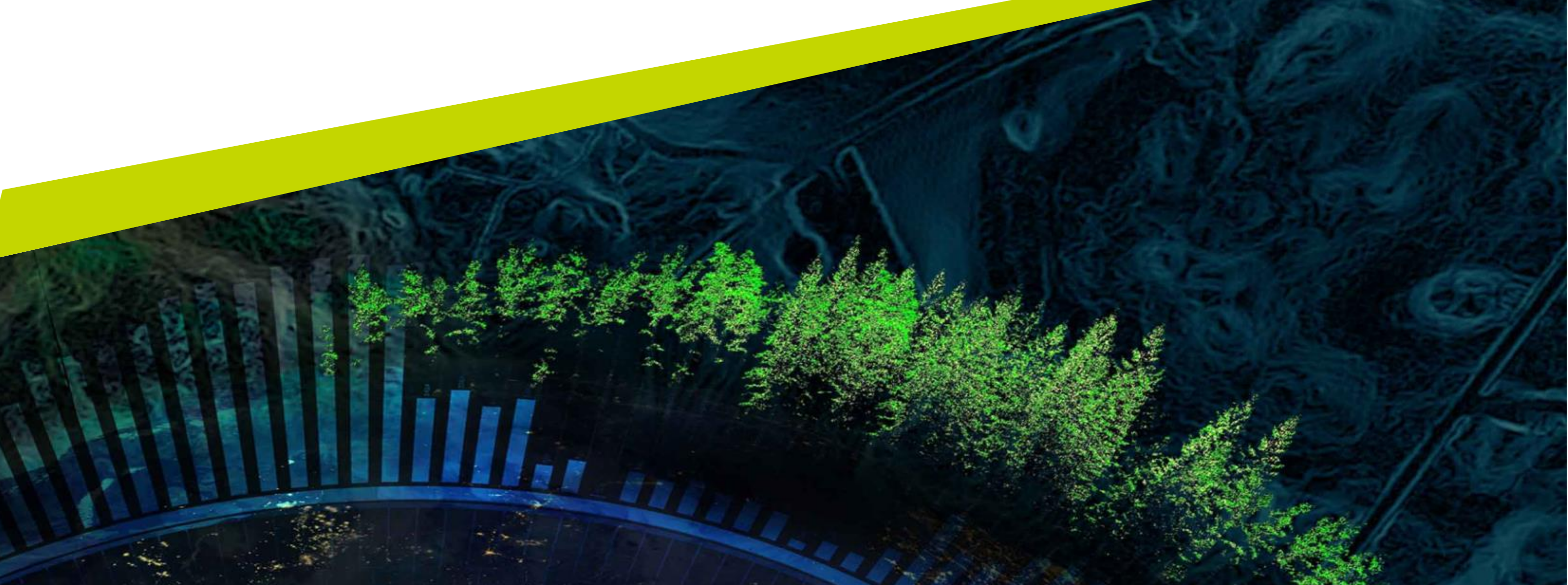

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Supervisor:	**Hans Andersson, Swedish university of agricultural sciences, Department of economics**
Assistant supervisor:	Shon Ferguson, Swedish university of agricultural sciences, Department of economics
Examiner:	Karin Hakelius, Swedish university of agricultural sciences, Department of economics

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Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Economics

Abstract

There are a lot of risks associated with agricultural production. Weather, diseases, pests, and price risk to mention a few. Farmers have some tools to use for transferring or mitigating some of the risks of farming. One way is the use of financial instruments such as futures where a price can be predetermined before the crop is even planted. One risky crop is malting barley. Due to the strict quality requirements the total acreage for a farmer not always accepted, on average is 59% of the crop in Svealands slättbygder accepted as malting barley, and 68% is accepted in Götalands södra slättbygder. The farmers have the option of growing three varieties of barley, feed, beer or whisky.

This study aims to make a comparison in the cost of quality risk in barley production between malting barley for beer and malting barley for whisky production depending on different levels of risk aversion. The study investigate also how Swedish farmers can benefit from using futures contracts and different hedging strategies for wheat, rapeseed, and if there are benefit with using a cross-hedge for beer and whisky barley and reach the highest utility.

This is done by constructing two fictitious farms using prices from Lantmännen, harvesting data from farms in SS and GSS, cost calculation from Agriwise and other data sources to calculate a gross margin matrix for different strategies and for either beer or whisky barley. This data is used to model an optimization model in Excel and together with the use of quadratic risk programming calculate the difference between different marketing strategies at different risk aversion levels and the difference between barley for beer or whisky.

The results from the study shows that there are a difference between the cost of quality risk between beer and whisky barley and the two areas of production. In SS was the cost of quality 334SEK/hectare and 61 SEK/hectare for malting barley intended for beer production in GSS. For whisky barley was the cost 131 SEK/hectare in SS and 134 SEK/hectare in GSS. The best strategy in lowering the price variability was the staircase strategy but the strategy that delivered the highest expected utility was the average strategy without cross-hedging the malting barley. The conclusion is that the farmer can handle their risk exposure depending on what crops to grow and what strategies to use.

Keywords: malting barley, hedging, cost of quality risk, risk management

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Abbreviations

CAP	Common Agricultural Policy
CBOT	Chicago Board of Trade
CE	Certainty equivalent
EU	European Union
GSS	Götalands södra slättbygder
OHR	Optimal hedge ratio
RRAC	Relative risk aversion coefficient
SCB	Statistics Sweden (Swedish: Statistiska centralbyrån)
SJV	Swedish Board of Agriculture (Swedish: Svenska Jordbruksverket)
SLU	Swedish University of Agricultural Sciences (Swedish: Sveriges Lantbruksuniversitet)
SS	Svealands slättbygder
UEP	Utility efficient programming

1. Introduction

Risk management has been a central part of the Agricultural industrialization, risks in agriculture are diverse and often linked together and require different strategies to transfer or mitigate the risk (Hohl 2019). Because farming is done out in the open air the link to nature's unpredictable forces is always affecting it (Debertin 2012). The amount of precipitation can be too much or too little or pests and diseases can be an issue a farmer faces and could be examples of a few of several unpredictable factors whose effects can be negative for a farmer (Debertin 2012).

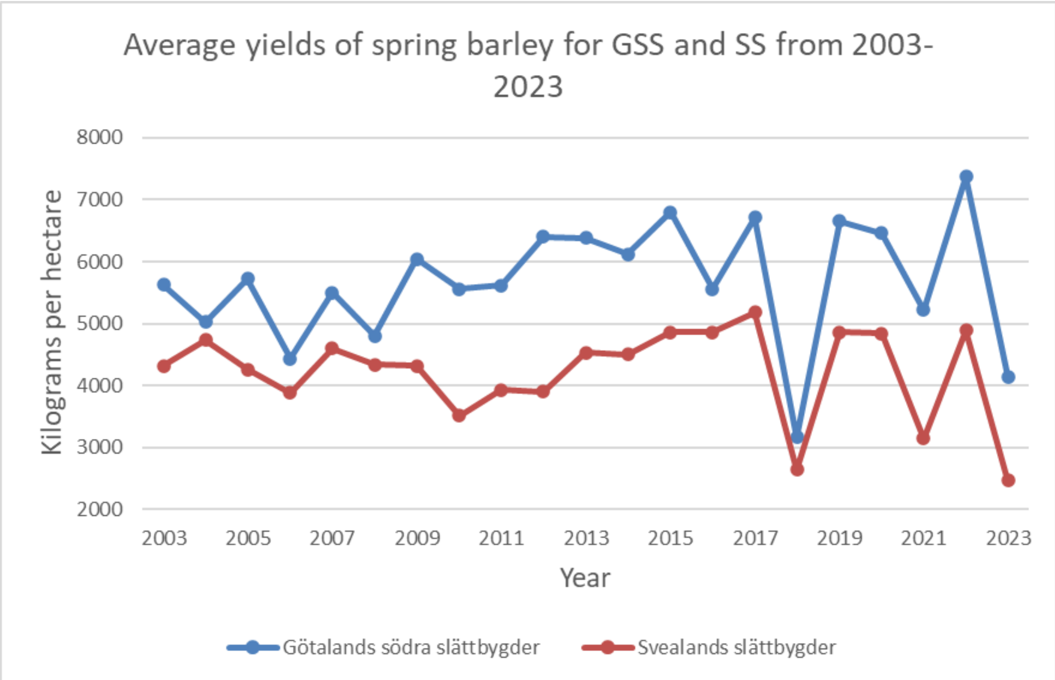

Figure 1. Average yields of spring barley in two different areas of production in Sweden (SJV 2024)(own illustration).

As shown in Figure 1 the yield varies between different years and is different depending on the area of production, Svealands slättbygder (SS) or Götalands södra slättbygder (GSS). Potentially more frequent and dramatic weather events can increase yield variability and the volatility of stable food prices (Hohl 2019) also recent pandemic and Russia's war against Ukraine have affected the commodity prices in the world (Devadoss & Ridley 2024).

Farmers can manage risk by different strategies, (i) mitigation to limit the consequences of disasters through production and income diversification and management measures by using, for example, a larger variety of crop types, soil drainage, weather forecast, and optimal planting schedule. Another strategy is (ii) transferring the financial consequences to a third party through informal, formal, or semi-formal approaches like using insurance, capital market instruments, and financial derivatives such as forward or future contracts (iii) coping to manage financial consequences with for example income from other non-farm businesses and (iv) prevention, in the form of irrigation, drainage, and crop protection to name a few (Hohl 2019, pp.7-9). Illustrated in Figure 2 shows the loss probability and loss severity, on which level of society is affected, and what measures can be taken to mitigate the risk and dampen the impact.

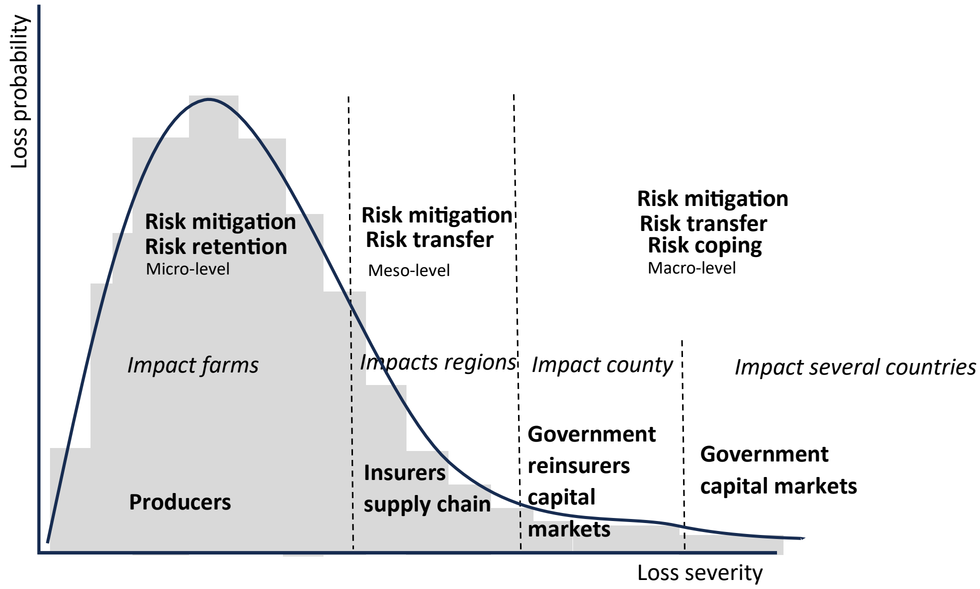

Figure 2. Layering of risk in function of loss probability/severity with typical risk management approach (Hohl 2019) (own rendering).

Free trade agreements and agricultural policies made by the European Union (EU) have made price risk a more immediate issue for farmers in EU the (Pennings 1998). When agricultural markets become more liberalized the price risk and volatility of the market increase which increases the need for risk management instruments (Pennings 1998).

Farmers have different possibilities to sell their harvest, they can choose to sell their harvest on the spot meaning an agreement that the delivery of the good and the price received is done at the same time. A different agreement is the forward contract, in advance are the price and time of delivery made up as could the quantity could be made up in advance (Hull 2012). Future contracts are a more formalized form of forward contracts. Forward contracts are completely customizable but futures the quantity, time, and delivery location are standardized and the only part negotiated between buyer and seller is the price. A high degree of standardization makes future contracts fungible and they are traded on an exchange (Peterson 2018). Using futures contracts is one way of transferring the price risk from the producers (farmers) to the speculators (Rolfo 1980).

The biggest exchanges on futures contracts are the Chicago Board of Trade and the Chicago Mercantile Exchange now merged into the CME Group (Hull 2012). Other exchanges are MATIF (Marché à Terme de international de France) and LIFFE (London International Financial Futures and Options) these two are the only ones in Europe for agricultural goods (Iwarson 2012).

A hedge allows the farmer to lock in or establish a selling or buying price months or even years in advance before the actual cash transaction (Peterson 2018). A hedge uses a position in the futures combined with a position in the cash market to manage price risk. Gains on one position offset the losses on the other position, note that a hedge requires a position in both the future and cash market. The purpose of the hedge is to stabilize the net price received (Peterson 2018). To protect yourself from a lower price when it is time to sell your commodity start with selling (going short) a futures contract which if the prediction is right on the price movement will earn you money when buying back (covering) the contracts when it is time to sell the physical commodity (Peterson 2018).

Table 1. Example of downside protection using futures contracts (own rendering).

Downside protection using futures	**SEK**
Future price t=1 selling price (shorting)	1,8
Spot price t=1	1,5
Basis t=1	-0,3
Future price t=2 buying price (covering)	1,6
Spot price t=2	1,3
Basis t=2	-0,3
Profit future contracts	**0,2**
Net price received	**1,5**

As shown in the example in Table 1 above the farmer is better off using a hedge than not hedging on a market where the price has declined until the sales of the commodity are made on the physical market if the basis remains the same. Not placing a hedge would have resulted in a lower price being received. Farmers must consider several risks when using a hedge, risks in price, basis, and production (Lapan & Moschini 1994). The production risk involves both uncertainty in quantity and quality (Hohl 2019).

1.1 Problem background

The problem of low profitability in Swedish Agriculture has been discussed for several years (KSLA 2022). In recent times it has been discussed even more when the government presented the Livsmedelstrategin should be updated to 2.0 (Kullgren 2023). With the ambition of strengthening the profitability and creating a more resilient agricultural sector from external shocks, as in reason times have been both war and a pandemic that has affected input and output prices.

The largest source of income variability is price variation and not always the production variability (Iwarson 2012). As shown in Figure 3 the prices fluctuate on different crops on several occasions during the last nine years and they are in constant change and can move a considerable amount just in a matter of months. The drought that occurred in 2018 gave an increase in prices the following year due to low supply. Another event that caused prices to spike at the beginning of 2021 was the Russian invasion of Ukraine (Devadoss & Ridley 2024).

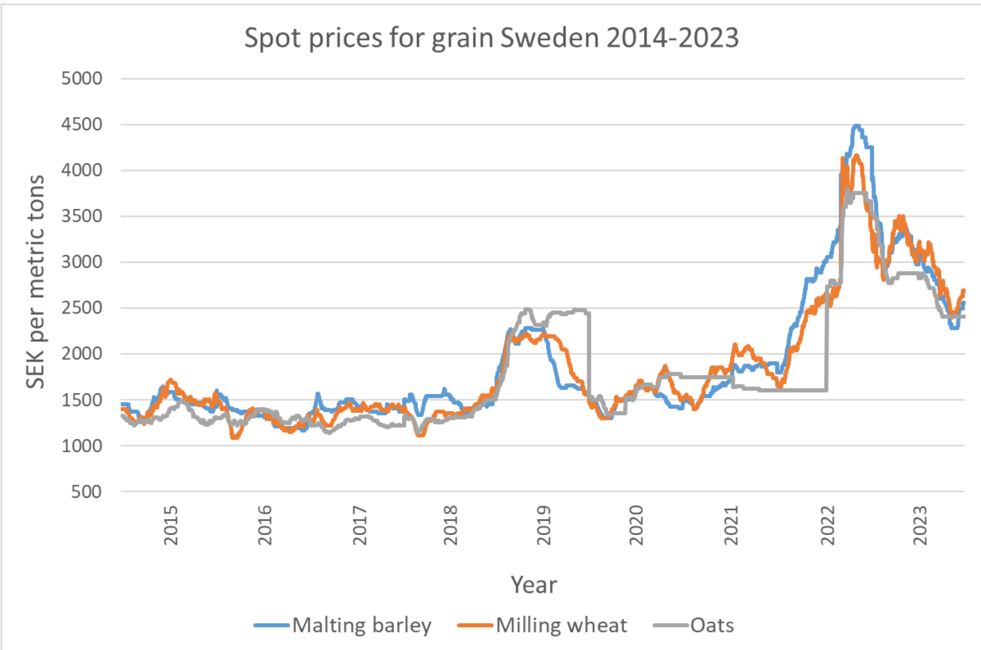

Figure 3.Spot prices grains Sweden 2014-2023 (per. comm., Gerhardsson, 2024) (own illustration)

The total area used for grain production is 960 000 hectares in 2022. Wheat and barley are the two biggest grain crops in Sweden (SJV 2022) wheat is the largest and barley is the second biggest. The average harvested acreage of wheat between the years 2014-2022 is 450 000 hectares and for barley is the number 300 000 hectares (FAO 2023). The production of malting barley for beer is about 500 000 tons and for whisky 50 000 tons annually (per. comm., Gerhardsson, 2024).

More than 60% of the world supply of barley is produced in Europe (Bindereif et al. 2021). The majority of barely, 60 - 70%, is used for animal feed and 30-40% is used for malting barley for beer and whisky, only 2 - 4% is used for direct consumption by humans (Oser 2015).

Farmers have the choice of either producing feed or malting barley, however malting barley has a larger premium if certain quality measures are met so those varieties are mostly planted if the requirements are not met it is classified as feed and the price is lower (Wilson et al. 2009).

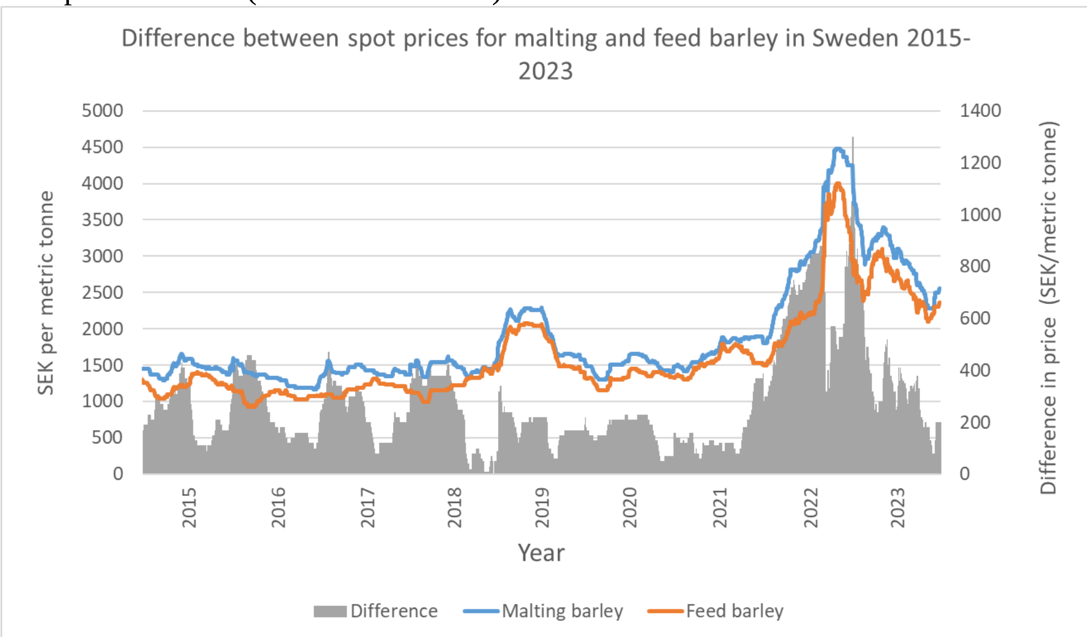

Figure 4. Difference between spot prices for malting and feed barley in Sweden 2015-2023 (per. comm., Gerhardsson,2024) (own illustration)

The average price of malting barley between 2014-2022 was 1839 SEK/ton and feed barley was 1564 SEK/ton (per. comm., Gerhardsson, 2024). The average price penalty for not meeting the quality requirements is a reduction of the price by 15% when malting barley is forced to be sold as feed. As shown in Figure 4 the difference in price paid for different quality of barley between years and during years is quite significant and can make a lot of difference if the crop is sold as feed or malting barley. The accepted rate of malting barley fulfilling the quality requirements is on average 59% in SS and has been varying between 26-84% these rates of acceptance are on average 68% in GSS and between 31-86% in the years 2014-2022 for both areas (per. comm., Gerhardsson, 2024).

A farmer in SS expecting a harvest of 1000 tons of malting barley but only achieving quality on 59% will be forced to sell the rest as feed barley and will not receive the price premium on the total 1000 tons (see equation 21). Below in Table 2 is an example of the difference in revenue between different shares of varieties of barley quality.

Table 2. Example of difference in revenue between shares of varieties of barley qualities. (own rendering)

Different shares of qualities of barley	**Scenario 1: 100% Malting barley**	**Scenario 2: 59% Malting barley 41% Feed barley**	**Difference between Scenario 1 and 2**
Total revenue SEK	1 839 000	1 726 250	112 750

The malting barley must fulfill certain strict quality requirements such as, the correct variety, protein content must be even and in the right interval, shells should be undamaged, and germination high (Petterson 2006).

Malting barley can be grown for either beer or whisky production and the quality requirements differ between them (per. comm., Pettersson, 2024). Barley for beer must have a protein content of ideally 10,7% but a range between 9,5 - 11,5% is acceptable. Whisky barley protein content has different requirements on protein content, often is there a minimum of 12% is required (per. comm., Pettersson, 2024). It is not easy for a farmer to produce barley within this quality requirement, which is often a consequence of weather conditions and access to water and nutrients in the field (Söderström et al. 2009). Dry periods can lower the yield and lead to high levels of protein content even at bas-level amounts of nitrogen fertilizer applied (Sverigeförsöken 2023), which can be problematic when the protein has to be within a certain range. Another quality difference between whisky and beer barley is the tolerance of pink kernels. In whisky this is not an issue and will not affect the quality requirement however for beer barley cannot be accepted and pink kernels could be a sign of fusarium (per. comm., Pettersson, 2024). Fusarium is fungi that can create "gushing" which makes beer spray uncontrollable when the bottle is opened and heavily controlled to not exist in malting barley for beer (Virkajärvi et al. 2017).

There are also some quality risks associated with growing other types of grains such as wheat or oats (Lantmännen 2023). Since wheat can be classed as milling wheat there are also certain quality parameters that must be met such as protein content, falling number, gluten, and space weight. If the parameters are not fulfilled they can be subject to a deduction from the top price and in the worst case be classed as wheat for animal feed or ethanol production which is lower paying than milling wheat. (Lantmännen 2023). Oats also have certain quality requirements that must be fulfilled in order to be sold for human consumption and not feed.

1.2 Problem statement

2023 was a difficult year for Swedish farmers, a dry spring and beginning of summer followed with extensive rain which resulted in both a lower yield and lower quality (LRF 2023). The overall yield in Sweden 2023 was 24% lower compared to the normal yield. Recently observed climate changes in Europe are characterized by more frequent weather extremes and this poses a threat to the agricultural production of barley in Europe (Bindereif et al. 2021). In the last two decades, most of Europe has experienced severe droughts which lead to both losses in yield but also in quality and is a major threat to farmers' profitability (Bindereif et al. 2021).

In the future it is necessary to do targeted site- and crop adaptations to help mitigate the potential yield losses (Sjulgård et al. 2023). In Sweden, there is a difference between areas of production and the possibility of achieving the required quality standards (per. comm., Gerhardsson, 2024). Barley is sensitive to drought during its flowering and kernel-filling and that can affect both the yield and quality of the harvest. When the quality requirements are not met for beer malting then the farmers are forced to sell the malting barley as feed instead for a lower price (Bindereif et al. 2021). Barley grown for human consumption as an ingredient for producing beer and whisky is generally produced with more intensive managerial practices including irrigation, fertilizer amendments, and the implementation of pest/disease mitigation strategies than feed barley is (Oser 2015). Different varieties of barley are used for different purposes a feed variety is not used for beer and whisky but these malting varieties could be used as feed if the quality requirements are not met (Deme et al. 2020).

Currently, there are no active malting barley futures contracts in the world (GRDC 2018). Previously there was a possibility to hedge malting barley on the Euronext exchange but it ended in 2015, given that the low liquidity of the contracts introduced more market risk and one of the benefits of a futures market is the high degree of liquidity (Peterson 2018). There is also no feed barley on the Euronext exchange (Euronext n.d.) Therefore can European and Swedish farmers not hedge their barley on a domestic or European exchange using a specific barley futures contract but it is possible to hedge using a cross-hedge.

A commodity can be hedged by taking a position in a similar commodity that has similar price movements, a so-called cross-hedge. Malting barley can be hedged by taking a position on a similar commodity, the feed barley market, and these are situated on exchanges in Australia and Canada (GRDC 2018). However, using a market located further away introduces a dimension of currency exchange risk and increasing basis risk. The basis is the difference between the future market price and the spot market price which can be different from one marketplace to another even in the same production area (Peterson 2018). The risk involved with the basis is how the difference between the cash and futures market prices changes over the time the hedge is placed and later lifted. Because if the basis changes the outcome of the hedge can be different than expected and the benefits from using a hedge can be lower (Peterson 2018).

1.3 Empirical and theoretical problem

The empirical problem of this study is how crop farmers in Sweden can lower their income variability and choose marketing and crop choice strategies that can help them manage their risk exposure. Farmers in Sweden can choose a variety of crops to grow and for different purposes is the crop grown, this gives the farmer a risk management tool to reduce income variability and risk exposure (Pannell et al. 2008; Peterson 2018). Methods such as futures or forward contracts are also risk management tools used to lower risk and income variability. A literature search was made to find studies made on malting barley cost of quality risk and benefits of hedging, both for beer and whisky. Only one study was found to be similar, made by Andersson (2018). However, he only investigated malting barley for beer and not whisky and used future contracts for malting barley when these were still around. This means there is a gap in the literature for a comparison between the differences in cost of quality risk from choosing either malting barley for beer or whisky and the use and benefits of cross-hedging malting barley are not found to have been explored in earlier studies.

The theoretical problem of this study is that no previous study has investigated the expected utility of growing malting barley for beer or whisky and making a comparison between them and the cost of quality risk. The subject of risk involved with growing malting barley has been covered in previous studies (Gustafson et al. 2006; Wilson et al. 2009; Hakala et al. 2012; Oser 2015; Andersson 2018). However, there is no comparison made between beer and whisky barley cost of quality risk. The cost of quality risk is the difference in profitability when achieving the quality requirements on all acreage and the profitability when a share of the crop does not fulfill the quality requirements and is sold as a lesser paid crop such as feed barely instead as shown in Table 2. Neither has the potential in cross-hedging malting barley using wheat been investigated in a Swedish context.

1.4 Aim and research questions

This study aims to make a comparison in the cost of quality risk in barley production between malting barley for beer and malting barley for whisky production depending on different levels of risk aversion. The study investigates also how Swedish farmers can benefit from using futures contracts and different hedging strategies for wheat, rapeseed, and if there are benefits with using a cross-hedge for beer and whisky barley and reach the highest utility. To be able to reach this aim the following research questions are formulated.

- What is the cost of quality risk between malting barley for beer and malting barley for whisky in SS and GSS
- Which strategies have the expected highest utility when cross-hedging malting barley?

1.5 Delimitations

This study uses fictitious case farms to study the expected utility of grain producers. In Sweden there are three main production areas that produce a majority of the total grains in Sweden (Fogelfors 2015) these are SS, GSS and Götalands norra slättbygder (GNS). In this study the fictitious case farms are situated in SS and in GSS because these are the regions where most of the barley is produced in Sweden. GSS is characterized by a different possibility to grow a bigger variety of crops than SS but this makes a comparison interesting. Figure 5 shows the amount of spring barley produced in different areas of production.

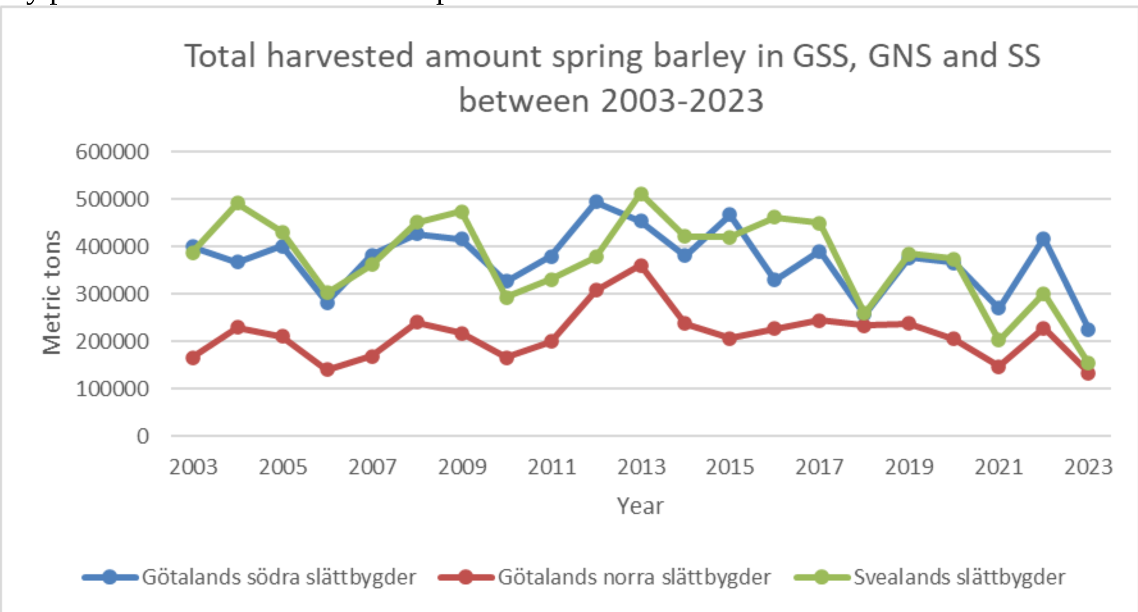

Figure 5. Total harvested amount of spring barley in the biggest production areas from 2003-2023 (SJV 2024).

The size of the fictitious case farms is 1000 hectares. This study only focuses on larger farms and not medium or small farms. The reason for this is that a smaller farm can have a more diversified income portfolio that in itself can lower the hedging ratio (Lence 1996), hereby creating a need for other risk management strategies, such as other income sources, of-farm income, income support, or government-sponsored prices that also can lower the hedging ratio (Mahul 2003) this reduces the incentive for a farmer to hedge (Pannell et al. 2008). The farmers should also be interested in closely monitoring the future markets and what could happen and take the opportunity cost into account when spending time studying the market (Mahul 2003). Therefore are the farms of such a size that their agricultural operations could be the main source of income and full-time work to create incentives to use futures to some extent.

In this study, the currency risk of dealing with futures is not examined. Currency risk is one of the risk factors producers face when dealing with on foreign exchange because of the change in exchange rates between currencies (Thompson & Bond 1987; Haigh & Holt 2000; Jouamaa et al. 2020). The risk of currency exchange affects how offshore hedgers strategies to manage the risk. In this study, all the futures prices were calculated by using daily exchange rates to convert them from Euro to SEK so the effect from the currency exchange is embedded within the data.

In this study, there are no strategies for oats taken into consideration when creating the models. There are no available future contracts for oats in Europe and using futures contracts on an exchange outside Europe are not used in this study in order to mitigate the risk for oats. A cross-hedge is not used for oats either. Oats are possible to hedge as mentioned but not common among Swedish producers (Iwarsson 2012).

The choice of crops to cross-hedge malting barley against is the milling wheat on the Euronext exchange. The cross-hedge should have a similar price movement (Peterson 2018) and milling wheat is the only similar grain on a European exchange that is suitable for cross-hedging malting barley.

In this study, only conventional agricultural practices have been taken into account. Other methods like organic, regenerative, or conservation agriculture are not accounted for, because there are no futures contracts where these farming practices are demanded as a quality and are paid any premium for using these practices. The most common practice in Sweden is conventional (Fogelfors 2015), so the possibility of generalizing the results of the farmer community is greater than when using some other practices.

These case farms are assumed to be only producing grains for commercial purposes and not for any internal use such as feed for livestock. The crops that are marketed are wheat, barley, rapeseed, and oats for both GSS and SS. However, in GSS sugar beet is part of the rotation taken into consideration in the optimization of crop portfolio. Sugar beet is only part of the crop portfolio for GSS because 95% of the production of sugar beet is situated in GSS because of the beet requirements of climate and soils and the fact that Sweden's only sugar mill is located in Örtofta Skåne (Fogelfors 2015). Because the case farms are assumed to not operate livestock there is no manure to take into consideration with cost or effect on the crops by using manure from the farm's own livestock.

Transaction costs were not taken into consideration in this study. Transaction costs are the costs associated with using the market and having any form of exchange with another firm, both before and after the exchange (Hobbs 1996). Transaction costs can be categorized as information costs, negotiation costs, and monitoring costs. Information costs arise for example when the cost associated with searching for information on price and potential customers, negotiation costs are created when the contract is being written and negotiated for the physical product and the monitoring costs are the cost of making sure the involved parties fulfill the agreements (Hobbs 1996). A common issue is to what extent the impact of transaction costs affects the overall profitability of hedging for the farmer (Penone et al. 2021). Direct transaction costs are the commissions paid to the brokers for administrative costs and for the operation and regulation of the futures exchange (Hull 2012). These costs can change depending on the complexity of the hedging strategy (Penone et al. 2021). The indirect costs associated with using futures should not be treated as significant and are estimated to be around 2% of the value of the futures contracts by Simmons (2002).

2. Literature review

2.1 Previous international studies

Peck (1975) examines how a portfolio analysis could be used for developing hedging strategies in the US egg market and for egg producers in order to manage price risk. Her conclusion was that a hedging ratio of 75-95% of expected production was optimal. Hedging was also shown to be an effective measure to manage the exposure to price risk for the producers. The cost of hedging was not taken into account neither was the production risk. One conclusion according to Peck (1975) is that producers can lower their income variability by using the futures markets.

Ederington (1979) describes the three major theories of hedging: the traditional theory, the theories of Holbrook Working, and the portfolio theory. The traditional theory emphasizes the risk avoidance of futures markets. Hedgers are envisioned as taking futures market positions equal in size but on the opposite side of the cash market (Ederington 1979). The second theory, Holbrook Working implies that hedgers are more prone to profit maximization than just risk minimization. Holbrook Workings views are that hedgers function much like speculators but, since they hold positions in the cash market as well, they are concerned with relative price changes and not absolute ones. Workings argue that hedging is done in expectations of a change in spot-futures price relation. The paper by Ederington shows that it is possible to use portfolio theory and integrate the risk avoidance of traditional theory and Working´s expected profit maximization (Ederington 1979). Ederington (1979) provides a measure of hedging effectiveness as the percent reduction on the variance of the portfolio (see equation 16).

Rolfo 1980 examines optimal hedging under price and quantity uncertainty by using two models of optimal hedging. The assumption is that there is a difference between the physical (cash/spot) market and the futures market and that both price and quantity uncertainty exist. One model being used is a mean-variance. The conclusion from the study is that the ratio optimal hedge and expected production should be well below unity. This is because, unlike traditional hedging where the ratio of unity is recommended agriculture has to take into account production risk when hedging the output.

Myers and Thompson (1989) developed a generalized approach to estimating an optimal hedge ratio using the futures market. In this study was the analysis made on corn, soybeans, and wheat prices for US farmers using their national futures exchanges. By using mean-variance analysis could the hedging rule be derived through the use of time-series econometrics (Myers & Thompson 1989). The results from the study were that a hedging ratio of 94% was optimal for hedging wheat.

Pennings (1998) conducts a comprehensive study of futures trading in agricultural commodities. He criticizes studies for not taking more into account than the price-risk when using hedging, there are quite a few more risks. These risks are basis risks such as temporal, spatial, and quality basis risk, market depth-risk, marking-to-market risk, and lumpiness. Pennings (1998) argues that hedging not only simply eliminates risk but also introduces risk to the hedger. If the hedger chooses to use the futures market as a measure of handling price risk depends on their risk preferences and their own subjective assessment of the reliability and performance of the futures market (Pennings 1998).

Anderson and Dillion (1992) present a proposal for grading the different degrees of risk aversion which is based on the relative risk aversion when taking wealth into account. The relative risk aversion coefficient (RRAC) can be used in an analysis and the value of RRAC used depends on how the analyst perceives the decision-maker (Anderson & Dillon 1992). The scale is between 0,5 to 4, where 0,5 is hardly risk-averse at all and 4 is extremely risk-averse, unity or 1 is somewhat risk-averse and considered “normal”. This method is suggested by the author to be used in the future to make comparisons easier between studies.

Brorsen et al. (1998) use utility efficient programming (UEP) in order to incorporate the hedgers' risk aversion, which affects the choice of hedging strategy when comparing hedging wheat on the Chicago Board of Trade or the Kansas City Board of Trade. Different levels of risk aversion used in this study ranged from near-risk-neutral to extreme risk-averse. Brorsen et al. (1998) show that producers who are more risk-averse are more likely to hedge than producers who are less risk-averse and that they actually prefer the spot market rather than the futures market. Brosen et al. (1998) also showed that more risk-averse producers benefit from hedging and that transaction costs are a negligible factor in optimal hedging choice.

Pannell and Nordblom’s (1998) article investigates the impact of risk on farms in Syria and their management. The main focus was how the management practices were affected by risk aversion and farm size. The risk aversion was modeled by including a utility function and using the Direct Expected utility maximizing

Mathematical Programming (DEMP) and UEP approach. The findings were that the farm size impacted the optimal practices under risk aversion (Pannell & Nordblom 1998). Using diversification helped reduce the risk and was more prominent at higher levels of risk aversion and storage was a good strategy to handle risk.

Lien and Hardaker (2001) use a UEP model to investigate how the degree of risk aversion and choice of utility function affects the optimal farm plan for farms in Norway. The results show that a farmer's risk-aversion level made little to no difference in the composition of the farm plan. The research also concluded that a different utility function for the farmer had little effect on the farm plan (Lien and Hardaker 2001). The main explanation of the variability for a farmer's gross margin and income is the large variance in yield and quality of the harvest, which impacts income, not the risk or the utility function.

2.2 Studies of Swedish grain market

Lidfeldt and Andersson’s work from 1994 shows the utility of using futures contracts for managing risk for Swedish farmers situated in Skåne, Östergötland and Uppland. Lidfeldt and Andersson take accounts for price and currency risk as well as production risk. Different strategies were considered, and the efficient frontier (EF) was calculated for each, and different levels of the absolute risk aversion for the farmers were taken into consideration. The results reveal that the risk reduction from using hedging strategies varies between 3 - 29%. The most efficient strategies were the ones that used both spot and futures positions. Furthermore, the results reveal that the optimal hedging ratio was estimated to be between 60 - 100%.

Nilsson (2001) investigated the optimal hedging strategies for Swedish grain producers and hedge effectiveness from 1989-1999. The grains studied were milling wheat, feed, and malting barley using futures on European exchanges and the CBOT in the US (Nilsson 2001). The method and model used are based on the econometric study made by Myers and Thompson (1989) investing the optimal hedge ratio and the method by Ederington (1979). One result from Nilsson (2001) was that the optimal hedge ratio for milling wheat, feed, and malting barley hedged on a European exchange was between 38 - 62% for a Swedish grain producer. The hedge effectiveness when using the optimal hedging ratio was between 40 - 72% for milling wheat and 17 - 21% for malting barley when cross-hedging it using feed barley contracts.

Ugander et al. 2012 examined the profitability of drying grains on smaller and medium-sized farms considering price, production, and quality risk. Ugander et al. 2012 use a Quadratic risk programming (QRP) to get the greatest EF-value when considering price, production, and quality risk under the assumption that the farmer is risk-averse and strives to minimize risk. The model was designed to take cropping-systems, crop-rotation, type of drying/ storage facilities, and time of sale of the god into consideration. Price and production risk were simulated as normally distributed variables, but the quality risk was considered a binary, whether a given proportion of the harvest was of premium quality or not. The grains that were studied by Ugander et al. (2012) accounting for quality risk were malting barley, milling wheat, and oats. Crops like sugar beet and rapeseed were also used in the model calculations but were not subject to quality risk. Different methods were used to produce the study´s results, previously mentioned was QRP but also qualitative interviews and analyses of existing data were done. The probability of achieving premium quality was estimated by interviews with knowledgeable professionals. One noticeable result from the study was that growing oats and sugar beet in GSS could not be motivated in economic terms based on the historical data for the study period between 1995-2010.

Andersson and Grunér's master thesis from 2015 used quadratic risk programming in order to maximize the certainty equivalent (CE) crop portfolio when the new CAP-policy restrictions were introduced. Anderson and Grunér developed a covariance matrix that incorporated the crop rotation effects on the gross margin for different crops and from historical yield data collected from farms. Anderson and Grunér also used a method by Cooper et al. (2009) to fill in the gaps in the data from the farms by using modified regional statistical data from SCB. Their results were that the new CAP-reform impacted the profitability negatively for risk neutral farmers but also showed that different crop portfolios may reduce the negative effects of the new policies.

Karlsson and Skog (2016) evaluated how different hedging strategies for grains could affect the choice of crops in the portfolio and the effect on profitability with respect to risk. The method used was a mathematical optimization based on quadratic risk programming and this was used on farms in GNS and SS to derive the efficient frontier for different hedging strategies. These strategies were examples provided by Iwarson (2012). The results revealed that all of the tested strategies resulted in a lower variance compared to a spot strategy and farmers therefore benefited from using one of the studied strategies.

Andersson (2018) investigated how future contrast can be by Swedish grain producers in GNS and SS to maximize their expected utility for hedging malting barley for different levels of risk aversion and the cost for quality risk of malting barley. Andersson (2018) used QRP to optimize the crop portfolio and take into account for yield, price, and quality risk exposure using data from 2009-2017. The study shows that farmers can reduce their price risk significantly through hedging barley and that the cost of quality is not a reason not to hedge. The crop rotation did not change significantly between different levels of risk aversion it remained fairly the same.

2.3 Summary of literature review

In the summary of the literature review below are the most influential articles and literature presented in Table 3.

Table 3. Summary of the literature

Article	**Method**	**Topic**
Peck, 1975	Portfolio analysis	Optimal hedge ratio, egg producers
Ederington, 1979	Econometrics	Hedge effectiveness
Rolfo, 1980	Mean-variance analysis	Optimal hedging ratio under production risk
Myers & Thompson, 1989	Econometrics	Optimal hedge ratio
Pannell & Nordblom, 1998	DEMP/UEP	Risk management, Syria, farm plan
Pennings, 1998		Risk of hedging
Anderson & Dillion, 1992		Risk aversion, RRAC
Brorsen et al., 1998		Hedging risk, wheat producers, transaction costs
Lien & Hardaker, 2001	UEP	Risk aversion, optimal farm plan
Nilsson, 2001	Econometrics	Optimal hedge ratio, hedge effectiveness, Swedish grain producers
Lidfeldt & Andersson, 1994	QRP	Optimal hedge ratio, hedge effectiveness, Swedish grain producers, production risk
Ugander et al., 2012	QRP	Quality, price, and quantity risk, Swedish grain producers

The literature review gives insight into the researched field of hedging, risk aversion, and methods of solving the maximal level of utility. It gives the frames and insight into the use of hedging agricultural commodities and assessing different portfolios. The methods used for solving the optimization of utility for different levels of risk are the combination of mean-variance analysis and quadratic risk programming. The literature on optimal hedging ratios is fundamental for the choice of hedging ratio used in this work. The literature presents different strategies that should be used when hedging and is a vital part of this work. How efficient these strategies are evaluated by the suggestion from Ederington (1979) of variance reduction.

This work is greatly inspired by the work of Lidfeldt & Andersson (1994), Ugander et al. (2012), Andersson & Grunér (2015), Karlsson & Skog (2016) and Andersson (2018). The methods are similar to the now mentioned works from writers and are used to create a tried and tested method to find the optimal farm plan where the expected utility is maximized for different levels of risk aversion. By using similar methods as previous writers can the comparison between studies with different results be made. The difference between my study and previous ones is the comparison between the quality risk of malting barley for beer and malting barley for whisky and the use of a cross-hedge for malting barley together with hedging wheat and rapeseed.

3. Theoretical framework

3.1 Risk theory

Within risk theory, two definitions are important to differentiate between and they are risk and uncertainty (Hardaker et al. 2015). One distinction between risk and uncertainty is that risk is imperfect knowledge where the probability of possible outcomes may be assessed, and uncertainty exists when these probabilities are not known (Hardaker et al. 2015). Agriculture production is characterized by high levels of uncertainty from yields to, quality, market prices, pests, and diseases (Hohl 2019).

Risk perceptions may vary greatly between individuals and corporations. This difference is a result of the experience of a certain risk and how it is recognized, evaluated, and/or mitigated (Hohl 2019). The farmer's willingness to take on risk is linked to the farmer's perception (Debertin 2012). Risk preferences are an important factor that influences a variety of economic behavior under conditions of uncertainty and are a main driver of farm management (Jin et al. 2020). In a study made by Hansson and Lagerkvist (2012), they found that there was a significant correlation between farmers’ risk preferences and farm income volatility.

Maximization of utility is subject to constraints imposed by the availability of income (Debertin 2012). The farmer strives to maximize the utility and makes decisions based on what will increase or have a positive effect on the utility and this can be accomplished in different ways (Debertin 2012). The utility function is a mathematical function that refers to overall satisfaction and is a measure clearly affected by a variety of factors. The utility function ranks different alternatives depending on the level of utility (Nicholson & Snyder 2017).

The risk-averse individual has a utility function that increases at a decreasing rate as income rises. A risk-neutral individual has a utility function that is expressed by a constant slope. And the risk preferring individual utility function is increasing at an increasing rate (Debertin 2012).

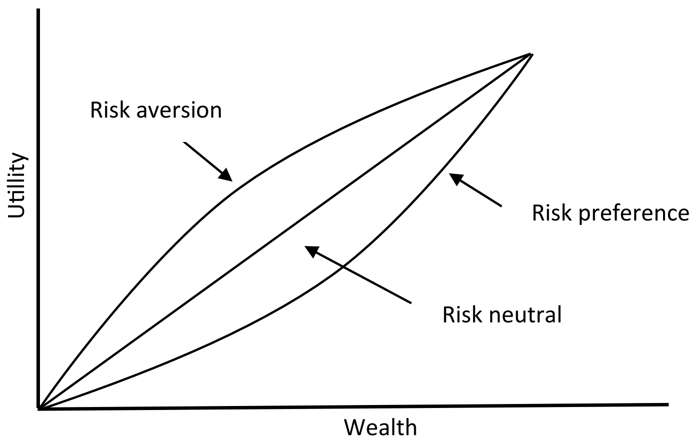

Figure 6. Attitudes towards risk and the utility functions shape (Hardaker et al. 2015) (own rendering).

In order to calculate an individual's risk preferences their utility (U) functions needs to be studied. To be able to find the individual risk preferences a constant absolute risk aversion (CARA) utility function is assumed (Hardaker et al. 2015).

$$r_a = \frac{U''(w)}{U'(w)} \quad (1)$$

Anderson and Dillion (1992) propose to use a relative risk aversion coefficient $r_r(w)$ to facilitate a comparison between studies. The RRAC is a product of wealth (w) and the absolute risk aversion coefficient ($r_a(w)$.The RRAC is therefore different between individuals despite sharing the same CARA and this is because of the difference in wealth.

$$r_r(w) = w * r_a(w) \quad (2)$$

This formula cannot strictly be used for this study. Assume the rational decision maker considers their wealth (w) to be equal to the capitalized value (k) of future income flow (y).

$$w = ky \quad (3)$$

$$r_r(w) = r_r(k * y) = r_r(y) \quad (4)$$

Then the wealth would be considered a constant capitalization factor multiplied by the income (Hardaker et al. 2015). Therefore the decision maker should have the same risk attitude towards the payoff expressed in wealth or income. This approach is used because the income is relatively large compared to the wealth. (Hardaker et al. 2015).

$$r_a(y) = \frac{r_r(w)}{y} \tag{5}$$

$$r_r(w) = y * r_a(y) \tag{6}$$

Anderson and Dillion (1992) suggest that the interpretation of the RRAC should be as follows:

$r_r(w) \approx$ 0,5 hardly risk-averse at al
$r_r(w) \approx$ 1 somewhat risk-averse (normal)
$r_r(w) \approx$ 2 rather risk-averse
$r_r(w) \approx$ 3 very risk-averse
$r_r(w) \approx$ 4 extremely risk-averse

3.2 Portfolio theory

Portfolio theory was first developed by investors to predict the earnings or returns on the portfolio of stocks, bonds or real estate (Markowitz 1952). By combining different assets that moved in opposite directions could the portfolio's standard deviation on return be lowered consequently creating a more predictable investment. The same principle can be used for a farmer planning which crops, resource allocation, growth, and financing in agriculture to use (Robison & Brake 1979).

In the process of choosing a portfolio historical data and available information are interpreted as a measure for predictions about future performance and the different assets (Markowitz 1952). The second stage is to actually choose a portfolio based on the beliefs and predictions made in the previous stage (Markowitz 1952). This process could be used for a farmer deciding on a farm plan and crop portfolio. For an investor or a farmer, a high expected return is desirable and a high variance of the return is undesirable (Markowitz 1952). The point with diversification of your portfolio is to obtain a better return than a non-diversified portfolio (Markowitz 1952). Important to recognize is that most decision-makers have their resource allocated at the beginning of the decision period and altering their existing portfolio is a seldom costless activity (Robison & Brake 1979). Farmers cannot change their decision once they have planted a certain crop without using a lot of resources.

Covariance is central when evaluating a portfolio (Brealey et al. 2017). Covariance is a measure of how much two assets or activities covary (Brealey et al. 2017). If two assets have a negative covariance the two assets would move in opposite directions, if the covariance is zero the assets movement is not related to one another and if the covariance is positive they would move in the same direction. The covariance of the expected return is defined as follows (Brealey et al. 2017).

$$cov(x_i, x_j) = \sum[(\tilde{x}_i - \bar{x}_i)(\tilde{x}_j - \bar{x}_j)] \quad (7)$$

where:
$cov(x_i, x_j)$ = covariance of asset x_i and x_j
$\tilde{x}_i$ = return on asset x_i
$\bar{x}_i$ = average return on asset x_i
$\tilde{x}_j$ = return on asset x_j
$\bar{x}_j$ = average return on asset x_j

A portfolios risk when consisting of two or more assets can be calculated using covariance (Brealey et al. 2017). A farmer has the opportunity to produce two different goods x_i and x_j. Due to price and output variability, there is income variability associated with x_i and x_j. The income instability associated with x_i is $x_i^2\sigma_i^2$ and for x_j it is $x_j^2\sigma_j^2$. The income variability of the first god is affected by the covariance. This term that adjusts for income variability interaction is $2(x_i x_j cov_{ij}\sigma_i\sigma_j)$ (Debertin 2012). This method of calculating the portfolio variance can be used for portfolios with three or more assets (Brealey et al. 2017).

$$\delta = x_i^2\sigma_i^2 + x_j^2\sigma_j^2 + 2(x_i x_j cov_{ij}\sigma_i\sigma_j) \quad (8)$$

where:
σ_j^2 = variance of asset j
σ_i^2 = variance of asset i

One way to handle the variability and reduce it is through diversification (Brealey et al. 2017). By reducing the variability is the risk lower therefore is diversification a measure of handling risk (Brealey et al. 2017). Preferably, an asset should have movement in opposite directions in price and therefore have a negative covariance and lower the risk that way. All risk can not be eliminated because diversification cannot eliminate the market risk, portfolios are exposed to variation in the general market (Brealey et al. 2017). In an agricultural context is this complicated because the farm's different crops often have a high degree of positive correlation (Iwarson 2012). If the world market price for feed wheat increases so will feed barley and the reason is that they can be to some extent be replaced with each other. Therefore, the diversification effect is larger between crops that cannot be substituted for one another (Iwarson 2012). Malting barley is a different crop because it can not be substituted (Grow Notes 2018). In an agricultural context, diversification has other benefits such as better utilization of labour and more efficient use of capital over the whole year that may increase productivity and consequently income (Debertin 2012). Diversification is also beneficial for utilizing a proceeding crop value which may increase the yield of the subsequently planted crop and manage pests and diseases (Fogelfors 2015).

3.3 Mean-variance analysis

The Mean-variance analysis is a mathematical method where the farmer's utility function is approximated for different levels of risk aversion based on different portfolios (Hardaker et al. 2015). Those portfolios with a high mean and a low variance are preferred over those with a low mean and a high variance (Hardaker et al. 2015).The expected income-variance criterion assumes that a farmer's preferences among alternative farm plans are based on expected income (E) and associated income variance (V). This is referred to as the E, V decision rule or mean-variance decision rule (Hazell & Norton 1986).

$$E = \sum_{j=1}^{n} x_j \, \overline{ER}_{jf} \tag{9}$$

$$V = \sum_{i=1}^{m} \sum_{ij=1}^{n} x_i x_j cov_{ijf}(ER_{jf}, ER_{if}) \tag{10}$$

where:
$\overline{ER}_{jf}$ = Expected return for crop j given sales strategy f
$cov_{ijf}(ER_{jf}, ER_{if})$ = Covariance of the expected return for crop j given sales strategy f and expected return for crop i given sales strategy f

The mean-variance analysis is suitable for accessing and choosing the crop portfolio for each year (Luenberger 1998) and expected return on hedging strategies and yield variations (Hardaker et al. 2015). The standard approach for defining a selected hedging strategy requires an objective function in which both the level and variability of total returns are taken into account (Thompson & Bond 1987). Hence, the mean-variance framework is suitable for assessing different hedging strategies. This study examines the different hedging strategies effect on the farms economic results and the expected returns of the mean of a certain crop j $\left(E(R_j)\right)$ and the variance of the expected returns $var(R_j)$ and can be calculated using historical data over a number of time periods (Wahlin 2011).

$$E(R_j) = \frac{\sum_{j=1}^{n} R_j}{n} \tag{11}$$

$$var(R_j) = \sigma_j^2 = \frac{\sum_{j=1}^{n}\left[(\tilde{R}_j - \bar{R}_j)^2\right]}{n-1} \tag{12}$$

The use of mean-variance analysis can be subject to some criticism. The critics argue that EV-analysis only is reliable if variables are multivariable and normally distributed and the utility function is quadratic (Markowitz 1952). These shortcomings are brought up by Rolfo (1980) since framework assumes that the producers have a constant absolute risk aversion or that their preferences are defined only on expected value and variance of income and this should be considered unrealistic.

A realistic planning model should take into account for farmers subjective probabilities of uncertain events and preferences, reflecting the farmers level of risk aversion (Lien & Hardaker 2001). One other limitation is that not all farmers find their optimal crop portfolio on the proposed efficient mean-variance set (Robison & Brake 1979). However, it is argued that the method is exact enough to solve even complex problems (Markowitz 2014).

The optimal hedge ratio (OHR) is defined as the portion of cash position covered by an opposite position on the futures market (Myers 1991) and by using futures contracts the price risk can be managed (Peck 1975)When securing a price using a hedge the farmer can actually know what expected revenues should be and make decisions accordingly (Peck 1975). Studies has shown that an optimal hedge ratio can be anything in between 0-100% (Peck 1975; Rolfo 1980; Lidfeldt & Andersson 1994). The equation for OHR is as follows (Peck 1975; Rolfo 1980; Lidfeldt & Andersson 1994) :

$$\text{Max}\, h \left[\bar{P}_{s1} * \bar{Q}_1 + h(P_{f0} - \bar{P}_{ft1})\right] - \frac{r_a}{2}\begin{bmatrix} var(\bar{P}_{s1} * \bar{Q}_1) + h^2 * var(\bar{P}_{f1}) \\ -2 * h * cov(\bar{P}_{s1} * \bar{Q}_1, \bar{P}_{ft1}) \end{bmatrix} \tag{13}$$

$$h^* = \frac{cov(P_{s1} * Q_1, P_{f1})}{var(P_{f1})} + \frac{P_{f0} - P_{f1}^e}{r_a * var(P_{f1})} \tag{14}$$

where:

$h =$ expected harvest quantity sold in the futures market

h^* =optimal hedge ratio as a percentage of expected harvest quantity

P_{f1} =spot market price at time of sales t = 0
Q_1 =1
P_{f1} =futures market price at time of sales t= 0
P_{f1} =futures market price at time of buying back t= 1
P_{f1}^{e} =expected futures market price at time of buying back t = 1
$var(P_{f1})$ = variance of futures market price
$var(P_{f1})$ = variance of spot market price
$cov(P_{s1} * Q_1, P_{f1})$ =covariance of expected return and futures market prices at time t = 1

A liquid and well-functioning market where everybody has access to all the information creates the second term in the equation because no one can predict the futures prices better than anyone else (Peck 1975; Rolfo 1980; Lidfeldt & Andersson 1994). Therefore is $(P_{f0} - P_{f1}^{e})$ equals zero. Without loss of generality let Q_1 =1. The OHR is therefore calculated by dividing the covariance between spot market and future market prices $\left(cov(P_{s1}, P_{f1})\right)$ with the variance of the futures market prices $\left(var(\bar{P}_{f1})\right)$.

$$h^* = \frac{cov(P_{s1}, P_{f1})}{var(P_{f1})} \quad (15)$$

As mentioned previously Ederington (1979) developed a measurement of the effectiveness of the hedge and portfolio. The effectiveness is measured by comparing the unhedged portfolio with the portfolio which uses a combination of both spot and futures positions. The equation is as follows:

$$\theta = 1 - \frac{var(P_f)}{var(P_s)} \quad (16)$$

3.4 Quadratic risk programming

By applying mean-variance analysis it is possible to make decisions about a mix of risky prospects as an investment portfolio or a farm plan (Hardaker et al. 2015). With one or more constraints on the object function such as budget restrictions, land, labor, and capital constraints on a farm plan can decisions be made on the farm plan (Hardaker et al. 2015). These possible varieties of farm plans form a convex set in the mean-variance space for a risk-averse farmer see Figure 7 (Hazell & Norton 1986). The optimal farm plan is on the efficient mean-variance boundary Q in point P where the iso-utility curve meets the efficient frontier (Hazell & Norton

1986). The efficient frontier can be derived with the aid of quadratic risk programming (QRP) (Hazell & Norton 1986). Certainty equivalent (CE) is the amount of income a person would be indifferent towards having a secure or risky income. This is however dependent on the individual risk attitude of the person (Hardaker et al. 2015). QRP can be used to calculate the CE (Hardaker et al. 2015):

$$CE = E - 0{,}5r_aV \tag{17}$$

E is the expected return, r_a is the constant absolute risk aversion (CARA) coefficient and V is the variance of income (Hardaker et al. 2015). This creates the efficient frontier that is quintessential for evaluating different strategies and the use of the mean-variance analysis.

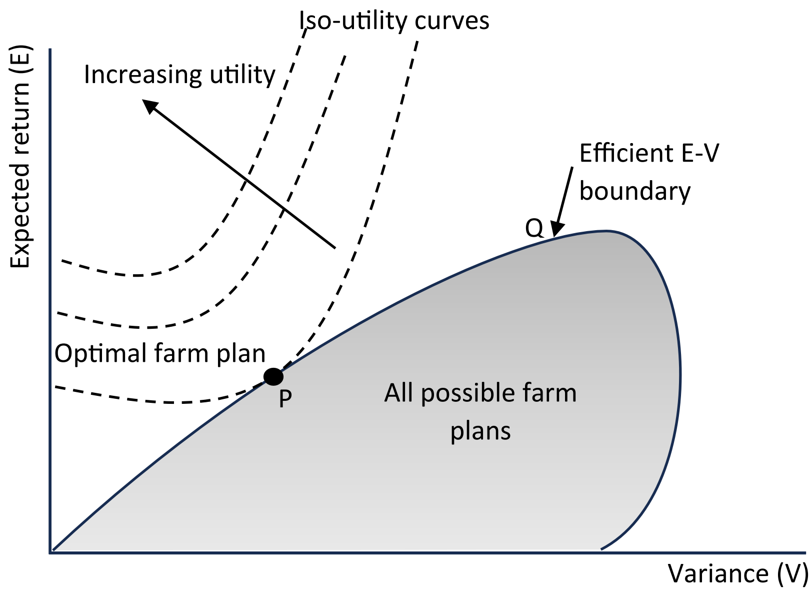

Figure 7.The optimal E,V farm plan (Hazell & Norton 1986) (own rendering)

3.5 Motivation of theories

This study aims to make a comparison in the cost of quality risk in barley production between malting barley for beer and malting barley for whisky production depending on different levels of risk aversion. The study investigates also how Swedish farmers can benefit from using futures contracts and different hedging strategies for wheat, rapeseed, and if there are benefits with using a cross-hedge for beer and whisky barley and reach the highest utility. When risk aversion is taken into account is there careful consideration to be made for selecting the model for expected utility maximization (Hardaker et al. 2015). One method is the use of

MOTAD (minimization of total absolute deviation) programming, in which the variance constraint of the QRP is replaced with a constraint on the mean absolute deviation of net income (Hardaker et al. 2015). This makes the expression simpler and can be solved only using linear programming. The use of MOTAD models are commonly used for this purpose even though there are more methods that are more appropriate and more theoretically and empirically suitable (Hardaker et al. 2015). The MOTAD model could create some problems with utility maximization and create a less favorable solution due to the simplification and the need to have a defined target makes it not as suitable. The QRP model in this study therefore is the mean-variance model more appropriate as the QRP model.

The other possible method to use is the UEP model. The UEP model could be used if the subjective utility function of the farmer is known (Hardaker et al. 2015). Such an approach is used in similar studies (Brorsen et al. 1998; Lien & Hardaker 2001; Pannell et al. 2008). The model is developed for farm planning under risk when the farmers' utility function is known as well as the attitude toward risk (Patten et al. 1988). The utility function in the model must be realistic since it has a great effect on the reliability of the results for a farm plan (Patten et al. 1988; Lien & Hardaker 2001). In this study the farmers' true utility function is not known and therefore is UEP not an appropriate model to use for this thesis.

By having a measurement on the income variability of the hedge introduced by Ederington (1979) can the effectiveness of different strategies be measured and compared with other strategies for a predetermined hedge ratio and allows for an indication for which handle risk exposure in price the best.

A QRP model can be constructed in many different ways and can be used to assess different crop portfolios for different levels of risk and find the optimal solution (Hardaker et al. 2015). By changing the values in the model, it is also possible to calculate the cost of quality risk and the expected utility of different hedging strategies.

4. Method

4.1 Applied quadratic risk programming

4.1.1 Optimization

Optimization and to optimize is to do something as well as possible (Andreasson et al. 2005). In many cases, this is a decision problem on how resources are used to the best use to achieve the goal objective as well as possible. To solve this decision problem from the “real” world must the problem first go through a modeling process to be turned into an optimization model (Andreasson et al. 2005). First, must the researcher understand the problem to be solved, and to create a mathematical model of the problem it is often necessary to simplify and limit the problem somewhat. The model can then be designed with objective function, constants, and constraints to generate an optimal solution if one exists, but only if provided with the correct data (Andreasson et al. 2005). The solution is then interpreted and evaluated, which can lead to an altercation in the model to improve upon it. Important to remember is that the solution should be useful in the original problem that was formulated from the real world (Andreasson et al. 2005). The modelling process is illustrated in Figure 8 below. The assessment of the validity of the model and results can be done by comparing them with existing literature and the results of others.

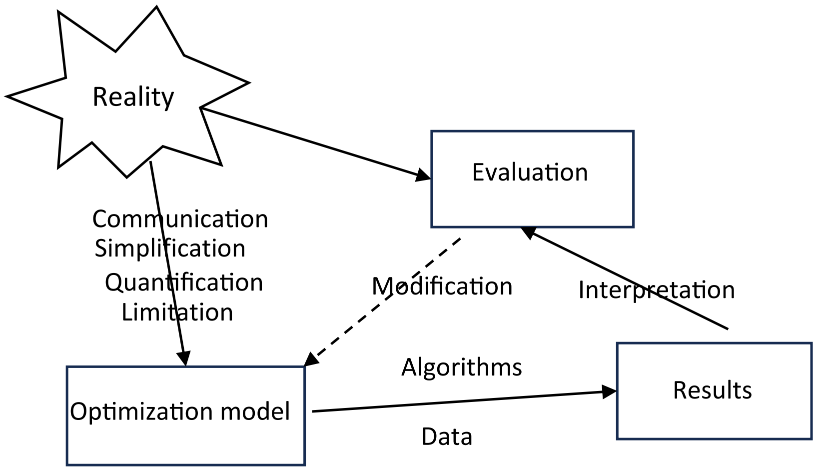

Figure 8. Flow chart of the modelling process (Andreasson et al. 2005) (own rendering).

The optimization in this study is done by using quadratic risk programming and the efficient frontier is being maximized for the different crop portfolios, marketing strategies, and level of risk aversion. The optimization is done through the use of Excel Solver and a non-linear algorithm that tries different combinations of crop ratios of the farm plans portfolio to find the optimal point. An example of the optimization model in Excel can be seen in Appendix 1.

4.1.2 Restriction

The model has restrictions/constraints based on the empirical problem in order to create a frame where a possible realistic solution can be found by using the optimization model (Griva et al. 2009). In this work there are some main groups of restrictions, these are land, crops, and hedging strategy.

The farms' optimization model has a land restriction of a maximum of 1000 hectares. The total amount is not used for crop production because 5% (50 ha) must be ecological focus areas in order to qualify for greening payments, these rules have been since 2015 (SCB 2017) and they are assumed to have been so for the whole time period that this study looked at from 2014-2022.

To make the model reflect the reality of Swedish growing conditions is restriction on the crops and the crop portfolio necessary. Due to crop rotation diseases, it is not sustainable or recommended to only grow one single crop, but variety is necessary for better longevity. There are also pre-crop effects that have a positive effect on the yield by growing certain crops in a specific order (Fogelfors 2015). The restrictions are defined for the maximum amount of land cultivated for spring barley, winter wheat, oats, and rapeseed as in the work of Andersson (2018). The maximum share of land for winter wheat, barley, and oats is 40% of the total land is reasonable due to agronomic reasons (Fogelfors 2015) and the rapeseed is restricted to 16,67% of the total amount of land, the same as in Ugander et al. (2012) and Andersson (2018). The change of restrictions for rapeseed compared to the other grains is because of the risk for diseases. The risk for diseases is larger if it is grown more often than 4-6 years in the same field (Fogelfors 2015). In this study, growing rapeseed on the same piece of land is restricted to every sixth year meaning a total of 16.67% of the total area can be grown with rapeseed. Sugar beet should only be grown every fifth year if rapeseed is part of the crop rotation and is therefore restricted to 20% and this is due to the risk of diseases (Fogelfors 2015). The shares are created to reflect a realistic farm plan for conventional farmers and the shares of certain crops on their farms and are later used in the optimization model restrictions. Table 4 summarizes the maximum share of land for each crop.

Table 4. Crop restrictions on the maximum share of land.

Crop	Maximum share of land
Wheat	40%
Barley	40%
Rapeseed	16,67%
Oats	40%
Sugar beet	20%

Storage is necessary to conduct any type of hedging activity because you do not sell the grains immediately when they are being harvested. In this study is the assumption made that the farms have the capacity to dry and store the total amount of grains produced on the farm. Therefore storage is not a limiting factor for the decisions made about the farm plan and neither the marketing decisions. No restriction is made on the availability of storage making it non-binding in the model.

The amount of grain being hedged is 50% of the total expected yield for wheat, rapeseed, and malting barley. The remaining 50% of the total yield is sold using the spots strategy. The hedge ratio is either 50% or zero. Table 5 gives an example of a hedge ratio.

Table 5. Explanation of hedge ratio.

Expected total yield	Hedge ratio	Amount sold using a hedging strategy	Amount sold using the spot market
1500 tons	50%	750 tons	750 tons

4.2 Mathematical optimization

To be able to maximize the certainty equivalents (CE) based on the quadratic risk programming (QRP) model is a mathematical optimization suitable. The efficiency frontier is maximized for a certain level of risk aversion and the level of risk aversion varies from zero to infinity and the model calculates the maximal utility given a determined level of risk. The model is designed to take into consideration the different crops expected returns given different hedging or marketing strategies. The result from the mathematical optimization intends to show the optimal farm plan when the expected utility is maximized. The EF in the graphs is calculated from variance to standard deviation because the interpretation from variance is difficult for big numbers and the standard deviation is calculated in the same unit as the mean making it easier to interpret (Hardaker et al. 2015).

$$\max CE = \left[\sum_{j=1}^{n}\sum_{s=1}^{o} x_{js}\,\overline{ER}_{js} - 0{,}5r_a \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{s=1}^{o} x_{is}x_{js}cov_{is,js}(ER_{is}, ER_{js})\right] \tag{18}$$

restriction:

$$\sum_{j=1}^{m}\sum_{s=1}^{o} x_{js}a_{ij} \leq b_i, \qquad i = 1 \dots m$$

$$x_{js} \geq 0, \qquad j = 1 \dots n, \qquad s = 1 \dots o$$

where:
x_{js} = land used for crop j using strategy s
a_{ij} = usage of resources r for crop j
b_i = availability of resources r

4.3 Research strategy

When conducting a study different research approaches can be used, two of the most common are quantitative and qualitative (Bryman & Bell 2017). The two research approaches are methodologically different in how they collect empirical data and later how the analysis is conducted. In this study, a quantitative approach is used because it is suitable for research that focuses on objective, observable, and reliable numerical facts (Bryman & Bell 2017). The goal of the quantitative method is also to gather enough data and observations so that assumptions can be made about the population (Bryman & Bell 2017). Collecting objective data that be measured and conducting numerical analysis using the data is the strength of the quantitative method. A deductive approach has been used for this paper and therefore the theories play a central role in developing the strategy and towards the observation and results (Bryman & Bell 2017).

In research there are different philosophical positions, one is ontology, and the other is epistemology (Bryman & Bell 2017). The epistemological position is about what is considered acceptable knowledge within a field of study and the ontological position emphasizes the importance of social values in understanding reality (Bryman & Bell 2017). Quantitative research has often an epistemological orientation and a positivistic perspective. The positivistic perspective states that methods from natural sciences can be used to interpret and analyze the social reality given that the researcher is purely objective and independent (Bryman & Bell 2017). The epistemological perspective this study leans towards is critical realism. This form of realism acknowledges the natural order and the events of the social realities and discourses. Critical realist admits and accepts that the categories they use to explain and understand the world are probably temporary and provisional (Bryman & Bell 2017). The critical realist unlike the positivist is fine with including theoretical terms that cannot directly be observed. As a result of this is the hypothetical entities explanation of regularities in both the natural and social order is fully accepted by the realist but not the positivist. In this study, the critical realistic approach can be shown for example from the attitude of the decision maker regarding risk aversion and how it helps to model the mathematical optimization problem and where the goal of this optimization is the maximation of the expected utility of the farmer for different levels of risk and strategies.

Every strategy has its differences and pros and cons, a researcher has to decide how to take a stand in this regard because the different strategies follow slightly different logic in how empirical material is collected and analyzed (Yin 2007). In this study is an exploratory case study chosen because the strategy is suitable for when the research question is of a “what” type. To answer the “what” question of what the outcome and consequences of a scenario might be can surveys or studying historical economic data be used to find an explanation or answer (Yin 2007). A case study is a research design that in its essence has an in-depth and detailed study of a single case and not others (Bryman & Bell 2017). A case study design investigates a phenomenon within a real defined context when the boundaries between the phenomenon and its context are not clearly defined (Yin 2007). The case study design is often associated with qualitative research. However, it can also be used for quantitative research. The strength of the case study is that it can utilize a variety of empirical materials in order to answer the research question (Yin 2007). Case studies and their units of analysis can be similar to previous work to make a comparison between prior work easier and create more values when results can be compared (Yin 2007). This study has been inspired by previous studies in the field of hedging (Peck 1975; Lidfeldt & Andersson 1994; Pannell et al. 2008; Ugander et al. 2012; Andersson 2018) and has provided the inspiration to use fictive case farms.

Drawing a conclusion from a single case about a population is harder to do scientifically and stirs up the discussion about external validity and generalization however very interesting results can be obtained from a single case and could have some degree of theoretical generalizing and explain other similar cases (Bryman & Bell 2017). Another piece of criticism regarding the case study design is that case studies lack or do not follow systematic procedures, having provided ambiguous or questionable evidence and letting personal bias affect the results or conclusion (Yin 2007). Therefore, is it important to make sure that the empirical material is truthful, and it is done to a high degree of scientific rigor (Yin 2007).

4.4 Research design

The research design creates the framework for the collection and analysis of the empirical data (Bryman & Bell 2017) and finally the conclusion drawn from the initial research question (Yin 2007). The design reflects the stance taken regarding the priorities of the research process and the emphasize that is put on for example, generalizing to a larger group than studied, assessment of different social phenomena, or the understanding of different behavior in special situations (Bryman & Bell 2017).

By using previous work done on this field or in a similar field can the empirical result be produced in formats that make a comparison possible (Yin 2007). Using a narrative literature review creates a good sense of understanding of the field and detects its limitations (Bryman & Bell 2017, p.125). The literature is also helpful when deciding upon the research question (Yin 2007). Since case studies don´t have a clearly defined strategy (Yin 2007) previous studies may provide a framework to design the case study (Bryman & Bell 2017). Previous work and studies on the subject covered in the literature review have been helpful in developing several parts of this study such as the optimization model and how to design cases.

The fictitious case farms used in the model are based on empirical data collected from two large farms situated in SS and GSS. Both farms only produce crops to sell on the market and no crops are used internally for livestock feed or similar purposes. The sizes of the farms are around 1000 hectares. A more extensive background of the fictitious case farms constructed from the data provided by the farms is presented in a later chapter. Because two fictitious case farms are used in this study is it therefore a multiple-case study (Bryman & Bell 2017). The farms chosen to investigate are intended to be similar and representative of the population the study is trying to explain. The are strengths and weaknesses of a multiple-case study compared to a single-case case study (Yin 2007). However, the results and evidence from multiple case studies are often regarded as more convincing, and therefore is the overall case study results considered more robust and stronger (Yin 2007). The data can also be analyzed within each case and across them, which would not be possible with a single case. The results degree of generalization is considerably higher for a two-case case study than the results have been from a single case study (Yin 2007).

4.5 Narrative literature review

For this study, a narrative literature review approach is used. This approach is based around that the researcher reads and presents the findings of some key articles and sources from the field of study by major researchers (Bryman & Bell 2017). The purpose is to broaden and create a better understanding of the subject being researched to be able to formulate good research questions and create an insightful study (Bryman & Bell 2017).

The search for literature was made by using search engines such as SLU Primo, Google Scholar and Web of Science. Searches were done using keywords such as: cross-hedg*, hedg* utility, risk management, grains, futures, risk aversion, strategy. Literature was also found in the references of literature that were found from searches or by recommendation from supervisor.

The reason behind doing the literature review is that the link between the research question is clear, learn about different theoretical and methodological approaches in the scientific field, be able to interpret the results from the insight of previous work and create credibility in the study, and show the contribution to the field (Bryman & Bell 2017).

4.6 Validity and reliability

A study should meet certain quality criteria to ensure that the work is trustworthy and legitimate (Bryman & Bell 2017). Two of these criteria that can be discussed are the validity and reliability of the study. When conducting a case study these quality criteria can further be categorized into 1) construct validity, 2) internal validity, 3) external validity, 4) reliability, and are important to work with when designing high-quality research (Yin 2007).

Construct validity or theoretical validity is about measuring the correct things that the study has aimed to explain (Bryman & Bell 2017). In this study is the expected utility of different hedging strategies with respect to different levels of risk aversion. Mean-variance analysis is used together with quadratic risk programming in order to derive the efficient frontier. This type of method is suitable to study expected returns and variance in expected returns (Hardaker et al. 2015). Similar methods and theoretical frameworks have been used by previous studies studying similar subjects within an agricultural context (Peck 1975; Rolfo 1980; Lidfeldt & Andersson 1994; Nilsson 2001; Ugander et al. 2012) and some student work has used a similar method and theoretical framework (Andersson & Grunér 2015; Karlsson & Skog 2016; Andersson 2018).

Internal validity addresses the question of whether there is a causal relationship between the variables that are being studied and a correlation between theories, observations, and developed models (Bryman & Bell 2017). In this study, the internal validity could be if the use of expected utility is the best or well-adapted measurement to compare and analyze how the different hedging strategies affect the expected utility of the farmer for different levels of risk. The theory of expected utility is used instead of profit maximization because it reflects the reality better (Hardaker et al. 2015).

External validity addresses however the result can be generalized. Can the results from the study be applied to a larger population and be generalized for areas outside the research context (Bryman & Bell 2017). Depending on the number of cases used in a study might the results not be suitable to be used to generalize a population or be used in a larger context (Yin 2007). In this study with numbers based on two cases is the risk that the results are not representative of the population and are flawed (Yin 2007).

Reliability is the question of whether the research could be replicated and whether the results would be the same as when it was conducted in the first place or whether was it affected by random or temporary errors, to summarize, how trustworthy is the study (Bryman & Bell 2017). This study is based on historical numerical data and this secondary information can be collected from different independent sources and can therefore be considered to have a high degree of reliability. Another researcher should be able by using the method, data, and procedures used in the original study arrive at the same results and conclusions (Yin 2007).

4.7 Ethical consideration

Ethical issues can be actualized during different stages of a research project. This is important to have in consideration during the work (Bryman & Bell 2017). The researcher should be honest with what the purpose of the collected empirical data is and how it is used and later presented. This is in order so people who participate are fully aware of the intention (Bryman & Bell 2017). The researchers should also be aware of their own biases and reflect on how this could affect the research questions and the work as a whole and make an effort to minimize the effect on the study (Bryman & Bell 2017). All external experts who were asked for data, opinions, or knowledge were given an introduction to what the study was about and how their given information was going to be used. The initial contact was done through telephone or email. The data received was only used in the frame of this work. Throughout the work of this study has the effect of the researcher been reflected upon and how a more objective approach could be made.

5. Background to the empirical study

5.1 Case farms

This study uses fictive case farms in order to model a farm in the grain-producing regions of Sweden. The regions the farms are placed in SS and GSS and are proportionally larger farms. The size was 1000 hectares on the fictive farms. In Sweden there are around 6700 agricultural businesses with a size of 100 hectares or more of the total 58 700 businesses and these larger farms with 100 hectares or more cultivate 60% of the total arable land in Sweden (SJV 2022).

When designing the farms and certain attributes regarding the farm several different sources of secondary data were used. Data was collected to model the expected yield, expected quality, production costs, market prices, cost of storage, and income. The yield data comes from the farm's own records for the period of 2014-2022.

The Net farm income is used in the calculation and in the optimization model as the wealth/income factor similar to Lien and Hardaker (2001). The Net farm income is derived from data collected from FADN (Farm Accountancy Data Network). The years used to calculate the average were 2019-2022 (FADN 2024) because it was the most recent years with a normal level of income, the result was adjusted from EUR to SEK using historical exchange rates (Sveriges Riksbank 2024), and the results are based on the largest crop farms in the plains of Sweden. The average Net farm income was 2 200 000 SEK for the time period and the same Net farm income is used for both GSS and SS.

All prices and costs in the model have been adjusted for inflation. These adjustments have been made so they represent the price level of 2022. This was made using historical data on the level of inflation from SCB (SCB 2024). This adjustment is done so that a comparison over time can be made that reflects the actual changes in prices and not the inflation effects on the prices (Kumaranayake 2000).

5.2 Quantity risk

The risk of quantity is the consequence of a variety of different things that could happen that make the yields to be lower than expected. It could be bad weather, pests, diseases, and even technology (Hohl 2019). Farmers possibility to forecast their crop yields is difficult even though all production decisions have been made (Rolfo 1980). The farmer´s expectation of the yield is largely based on past experience growing a particular crop and after the harvest all the quantity risk is resolved (Debertin 2012). To take into account the quality risk in the model were historical yield data from cases farms used to create an ex-ante distribution. Historical yield recordings between 2014-2022 were used from the case farms and made it possible to calculate the expected harvest yield, the variance of the expected yield, and the covariance of gross margin between different crops in the covariance matrix (Andersson 2018). The covariance is also used to be able to calculate the variance of different crop portfolios.

Historical yield data was collected from two different sources. For the different case farms data was collected from different farms' own harvest statistics as well as data from the SCB on aggregated yield levels for different areas of production. This was done to fill out any gaps that might exist in the data concerning the historical yields on the case farms for certain years and crops. These gaps in the data can be because some years certain crops are not grown on the farm or the yield was not been recorded.

These gaps in the data need to be managed because they will cause problems when estimating the covariance matrix for the case farms. There are some issues with using the aggregated yield levels for a production area and applying it to farm level this is because the yield variability is lower on the aggregated level than on the farm level (Cooper et al. 2009). Therefore, a compensating factor is applied to the aggregated data when filling the gaps in farm data. The compensating factor (δ^{FP}) is used by Cooper et al. (2009) as well as by Karlsson & Skog (2016) and Andersson (2018) when they are dealing with the same problem of missing data. The compensating factor is the ratio of standard deviation (σ) of farm level yield to aggregated production area yield levels (Cooper et al. 2009).

The calculations are done by subtracting the mean from the yearly aggregated data from SCB. This way is the variance calculated to a mean of zero. These values are then adjusted with the compensating factor which gives a more correct variance on the farm level (Cooper et al. 2009).

$$\delta^{FP} = \frac{1}{N}\sum_{i=1}^{N}\frac{\sigma(Y_i^F)}{\sigma(Y_i^P)} \tag{19}$$

where:
$i = 1, \ldots, N =$ the number of farms in the selection producing crop
Y_i^F = the vector (T* 1) of yields of crop I on farm F
Y_i^P = the vector of yields crop I in production area P

By then applying the factor to the average yield of the farm creates a closer to the reality yield than if the average yield on an aggregated level was used (Cooper et al. 2009). The method is not flawless and can possibly create some degree of error. Still, it is better than using the aggregated levels straight up because it accounts for the different levels of standard deviation (Cooper et al. 2009). The farm in GSS was the compensating factor used for oats only and on the farm in SS was the factor used for adjusting wheat, rapeseed, barley, and oats.

Preceding crop values are important to consider because they can have large effects on the yields of certain crops and should be taken into consideration when deciding on a crop rotation (Fogelfors 2015). The effect is a combination of several factors improved by implementing a crop rotation such as nutrition, soil structure, pests, crop disease, and weeds. Having a preceding crop in grain production that is not the same or belongs to the same grass family can have an increase in yield by 300-1000 kg/ha (Fogelfors 2015). Some crops are better than others in this regard and in this study, the preceding crop value is limited to fallow, oats, rapeseed, and sugar beet if grown. The fallow, oats, and rapeseed have yield-increasing effects on winter wheat and sugar beet has yield-increasing effects on barley. The increase in yield is presented in Table 6.

Table 6. Crops yield increasing effects (kg/hectare)(Andersson et al. 2023)

Preceding crop	**Increase in yield (kg/hectare)**
Sugar beet	500
Rapeseed	1200
Fallow	500
Oats	700

These effects were programmed in the optimization model as the monetary value of the increased yield of the following crop.

$$PCV_i = IY_y * p_y - AC_y \tag{20}$$

PCV_i = Preceding crop value for crop i
IY_y = Increase in yield for crop y
p_y = Price for crop y
AC_y = Associated cost with increase in yield crop y

These values were added to the preceding crops creating these positive effects of the increase in yield and improving the preceding crops expected return. For example, sugar beet increases the yield of barley by 500kg/hectare and the net return of 500kg of barley is added to the sugar beet calculation to value the proceeding crop effect.

5.3 Quality risk

When growing crops there is always a production risk and one risk is that the crops do not meet the quality requirements (Hohl 2019). Previous studies (Ugander et al. 2012; Andersson, 2018) have used an estimated probability of reaching the quality requirement are 0,8 for milling wheat and 0,7 for oats. These numbers are used in this study as well when not finding more updated information except for malting barley. In this study is the achievement of quality for beer malting barley for beer based on yearly data from Lantmännens facilities in the different regions between 2014-2022. For the southern region is the acceptance rate between 31-86% between 2014-2022 and for the northern region is the acceptance rate between 26-84%. The probability of meeting whisky barley quality requirements is assumed to be 0,9 and this assumption is the same for both GSS and SS (per. comm., Gerhardsson, 2024). If the wheat, barley, or oats do not fulfill the quality requirements the premium will not be received and a lower price will be paid because it is no longer suitable for malting or milling and becomes classified as feed (Lantmännen 2023).

Whisky malt prices have a price premium on average of 200 SEK / ton over beer malting barley and are used to calculate the whisky barley price (per. comm., Gerhardsson, 2024). This is one limitation of this study because it means that it is not possible to capture the true variance in the whisky price which affects the risk associated with it.

Quality risk is calculated in this study as either the wheat and oats fulfilled the quality or it didn't and therefore binary just as it is done in Ugander et al. (2012) and Andersson (2018). Barley is treated differently where the quality risk is a part of the price. If 70% of the yield was accepted 70% gets the price premium and the following 30% gets the lower feed price. This reflects the price received under quality risk for barley when accounting for the individual years difference in achieving the quality requirements.

$$P_s^e = (q^t * P^g) + \left((1 - q^t) * P^f\right) \tag{21}$$

P_s^e = effective price with respect to quality a certain year
q^t = share of accepted crop fulfilling quality requirements

P^g = Price of accepted crop fulfilling quality
P^f = Price of feed barley

The share of the crop that fulfills the quality requirements varies from year to year and differs from GSS and SS (per. comm., Gerhardsson, 2024). To calculate the cost of quality risk two different prices are used. One price is when the quality is taken account for the different acceptance ration variation between years (P_s^e). The other price assumes that all of the crop produced will fulfilled the quality requirements and receive the price premium. The objective function is solved with both prices, one at the time and the difference in results is the cost of quality risk.

5.4 Price risk

In order to be able to make an empirical analysis of marketing strategies is it necessary to have historical prices on the futures and spot market (Lidfeldt & Andersson 1994). The prices for different grains in this study are provided by Lantmännen (per. comm., Gerhardsson, 2024). Spot prices for milling and feed wheat, malting and feed barley, oats for human consumption and feed oats, and rapeseed are Lantmännens own historical prices and from their records. The future prices for wheat and rapeseed were also provided by Lantmännen and were collected from the historical records of Euronext. Both spot and future prices were presented in SEK even if Euronext is traded in EURO daily exchange rates were used to transfer it to SEK. The data was presented by daily price but the calculation used in this study is a weekly average used on the first trading week of the month. The timeframe used in this study is for data between 2014-2022. Growing sugar beet is based on contracts between the grower association and the sugar industry and the price is negotiated between the growers and the industry (Fogelfors 2015). Since 2017 is the sugar beet market in EU is not regulated by a quota system (EU 2017).

5.5 Marketing strategies

Farmers have different options when they have grains to sell on the market (Peterson 2018). Farmers that produce grains have a physical long position on the grain market and to be able to hedge against prices dropping are they going short on the futures market. Farmers selling grains are naturally long and farmers that will buy grains, for example, cattle or pork producers are naturally short on grains and will take a long position on the futures market to protect from rising prices (Peterson 2018).

The optimal hedge ratio has been shown in previous studies to be between 0 - 100% (Peck 1975; Rolfo 1980; Lidfeldt & Andersson 1994). However, it is not recommended to hedge 100% of the expected yield due to the production risk (Rolfo 1980). Nilsson (2001) showed that Swedish farmers' optimal hedging ratio was between 38 - 62 % when trading on the European future market exchanges and in the work of Andersson (2018) was a 50% hedge ratio used and Anderson and Skog (2016) have ratios of 40% and 60% been used. Therefore, the hedging ratio was chosen to be 50% in this study to make comparisons between studies more solid and that hedging half of the grains is an easy role of thumb.

The farmer can deliver in the harvest at a spot price or choose to store the grains and deliver at a later date at a spot price (Iwarson 2012). They can also choose to sell the grain on the futures market at what time can vary and it can be done before planting or after harvest and all the time in between all depending on the farmers' strategy (Iwarson 2012). Future contracts traded on an exchange are standardized with the volume and quality of the commodity specified (Peterson 2018). The size for rapeseed and milling wheat contrasts on Euronext is 50 tons, in this study the size of the contract is regarded as a continuous variable and not binary.

The are more advanced strategies and more simple guidelines for when and how much to sell or buy (Iwarson 2012). Both Andersson and Skog (2016) and Andersson (2018) used strategies given by example by Iwarsson (2012). In this study, four different strategies were chosen, and these are not very complex strategies and can be viewed as rules of thumb, the strategies are the same as Andersson (2018).

5.5.1 Net price received using a hedge

When a producer wants to have downward protection on the price received for grains can the future market be used to mitigate the price risk (Peterson 2018). However, when the farmer has sold futures contracts the price can go up or down, is no certainty that it will be to any benefit for the farmer depending on the movement of the market, the farmer can gain or lose money on the futures (Peterson 2018). What is important is what the final net price received becomes and that is a result of when the future is sold, when the future contracts are bought back and what the spot price is in this instance this depends on what the strategy was. The traditional hedge is lifted when the physical commodity is sold and in the same instance is the future contract bought back (Peterson 2018).

$$P_{is} = P_{f1} - P_{f2} + P_{s2} \qquad (22)$$

P_{f1} = Price of the future contract at t=1
P_{f2} = Price of the future contract at t=2
P_{s2} = Price of the spot/cash market at t=2

5.5.2 Spot

The spot strategy is that all output is sold on the spot market. In this study, the sale and delivery are done in December so the grains have been in storage since the harvest. This is not a hedging strategy but more of a marketing strategy because it doesn't involve futures (Iwarsson 2012).

5.5.3 Static

This is the simplest of the hedging strategies. In this strategy, the future contracts are sold before planting and harvest in February and are bought back in December when the output is sold on the spot market and delivered (Iwarsson 2012).

5.5.4 Average

The future contracts sales are done in equal large portions during between one harvest and the next years crop. In this study the months chosen are December, February, and April and the contracts are bought back in December before expiring and the physical commodity is sold on the spot market and delivered (Iwarsson 2012).

5.5.5 Staircase

The staircase strategy is based on evening out the income variance between years and not generating the highest price received (Iwarsson 2012). The strategy is based on that a part of the future expected harvest is sold on the future market over several years. If the horizon was three years then the farmer would sell one-third of the future market year t= -1, one-third year t=0, and one-third of year t=1. If this is done will the received price be the average of the three last year's prices. The strategy can be used with more or fewer years (at least two years horizon) and in this study is three years used. The contracts were sold in February and bought back in December.

5.6 Production cost

The production cost must be calculated and subtracted from the revenues. To be able to calculate the gross margin for the specific area and crops. The cost of production is not the same from year to year due to the changes in various inputs-goods prices. The production cost was found and calculated by using Agriwise´s contribution margin calculations (Agriwise 2024). An example of the gross margin matrix for both areas of production can be seen in Appendix 2. This matrix changes depending on the area, crops, and marketing strategies however it indicates roughly what the gross margin was used in this study. From Agriwise was the contribution II used for the different crops, area, and year. The contribution calculation was adjusted according to the fictitious farm yields, the costs associated with the size of the harvest were adjusted and the revenue associated with the size of the yield was also adjusted to make a fair assessment of the gross margin and revenue. The amount of fertilizer and the size of the yields for malting barley intended for whisky were adjusted in the production cost calculations because of the slight difference there is between them and beer malting barley and because there are no margin calculations for barley used for whisky. The amount of fertilizer used was 30kg/ha greater for whisky barley than for malting barley intended for beer (Yara n.d.) and the yield is 95% of those yields when growing feed or malting barley varieties (per. comm., Pettersson, 2024).

Storage is essential to be able to do any hedging. In this study, the fictive case farms are assumed to have adequate and sufficient storage and drying capacity to take care of the total amount of the crop produced on the farm and one growing season. The cost per kg for grain storage and drying is assumed to be between 0,29 - 0,51 SEK /kg (Kolm & Sjöberg 2022). The number is based on real investments done between 2017 - 2022 in the grain plains of Sweden. The farm sizes were between 130 - 620 hectares with grain production. This is the most recent estimate when writing this study of the investment cost of grain storage and drying facilities on Swedish farms (Kolm & Sjöberg 2022). In the optimization model, the cost is assumed to be 0,4SEK /kg with no difference between different storable crops.

6. Results

6.1 Efficient frontier

The efficient frontiers are being presented in the coming figures. The figures show the region, beer, and whisky separately. In the figures are the different strategies plotted both with cross-hedge for barley and a non cross-hedge and the spot strategy. Strategies are plotted for the fictitious farms in GSS and SS and create the efficient frontier. On the x-axis is the standard deviation per hectare and on the y-axis is the expected return per hectare. The best strategies are ones that have a high expected return and a low standard deviation because that will ensure a more stable return. Strategies can achieve the same expected return on different levels of standard deviation and the other way around works as well, strategies can have the same standard deviation but have different expected returns.

In Table 7 below are the strategies expected return at a RRAC = 0 shown. The choice of using this risk level is to compare the strategies when the maximum amount of barley for beer or whisky is grown. For higher levels of risk aversion are other grains given bigger portions of crop portfolio but in this study the interest is in the malting barley intended for beer or whisky, not feed.

Table 7. The expected return/hectare for different strategies at RRAC=0

Expected return (SEK)/hectare RRAC=0				
	Area of production			
	GSS	SS	GSS	SS
	Variety of barley			
Strategy	Beer	Beer	Whisky	Whisky
Spot	3647	3958	3775	4362
Static	3237	3965	3439	4289
Staircase	3125	3769	3330	4100
Average	3330	4115	3530	4433
Static: non cross-hedge	3441	4196	3633	4509
Staircase: non cross-hedge	3388	4050	3579	4367
Average: non cross-hedge	3490	4310	3682	4618

6.1.1 Götalands södra slättbygder

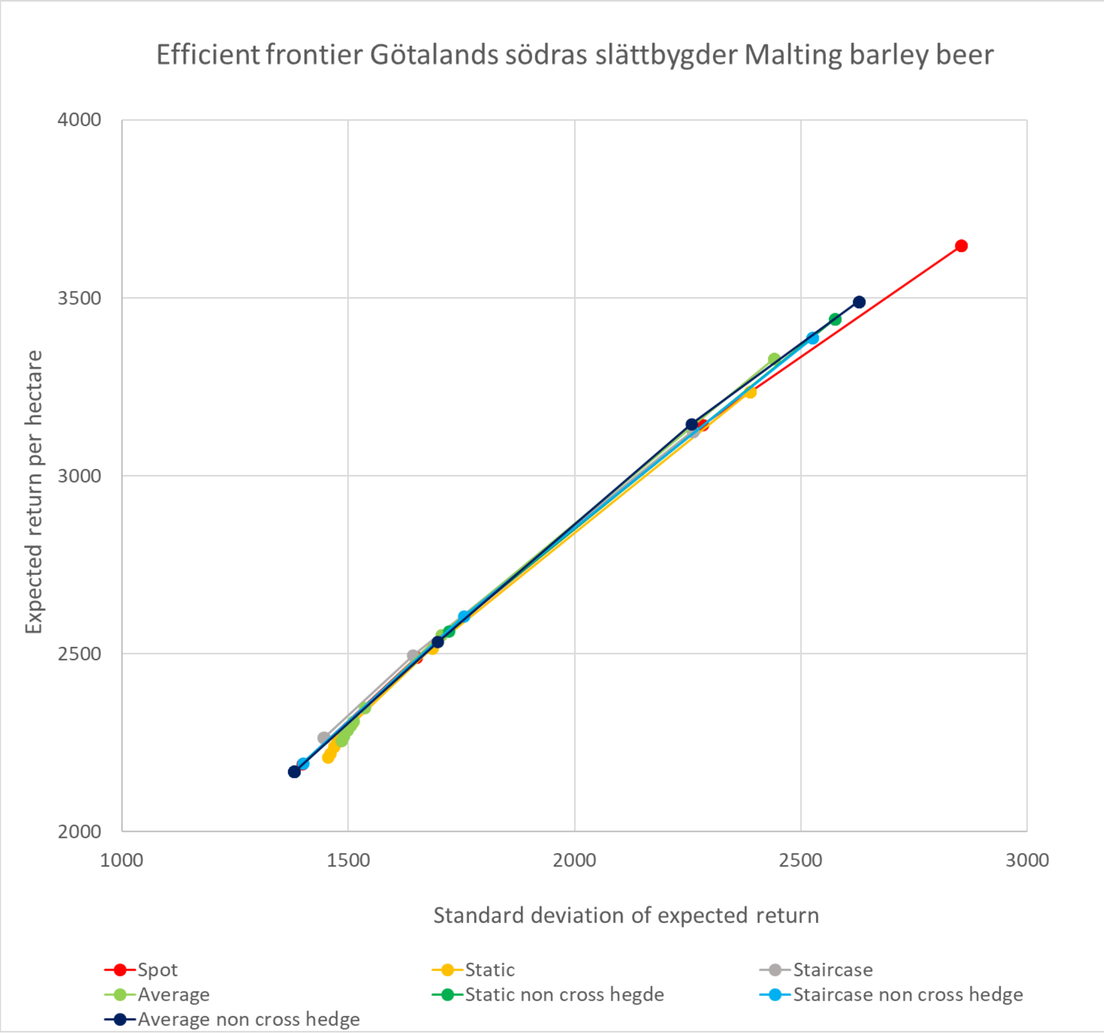

Figure 9. Efficient frontier Götalands södras slättbygder Malting barley beer

As shown in Figure 9 the EF is very similar for all of the different strategies regarding beer barley. One conclusion that can be made is that the spot strategy has the highest expected return and standard deviation. The strategies with no cross-hedge have a higher expected return and standard deviation than the cross-hedged strategies. The crop portfolio that also is responsible for the results can be viewed in Appendix 3. The crop portfolio shows that growing barley for beer is only done on the lowest levels of risk aversion. At higher levels of risk aversion, the less risky crops are chosen, therefor is it of interest to look at this graph on the data point to the right because they are the ones reflecting a crop portfolio that contains beer barley. When studying the point down in the left corner of the graph this reflects the growing of less risky crops such as feed barley and oats.

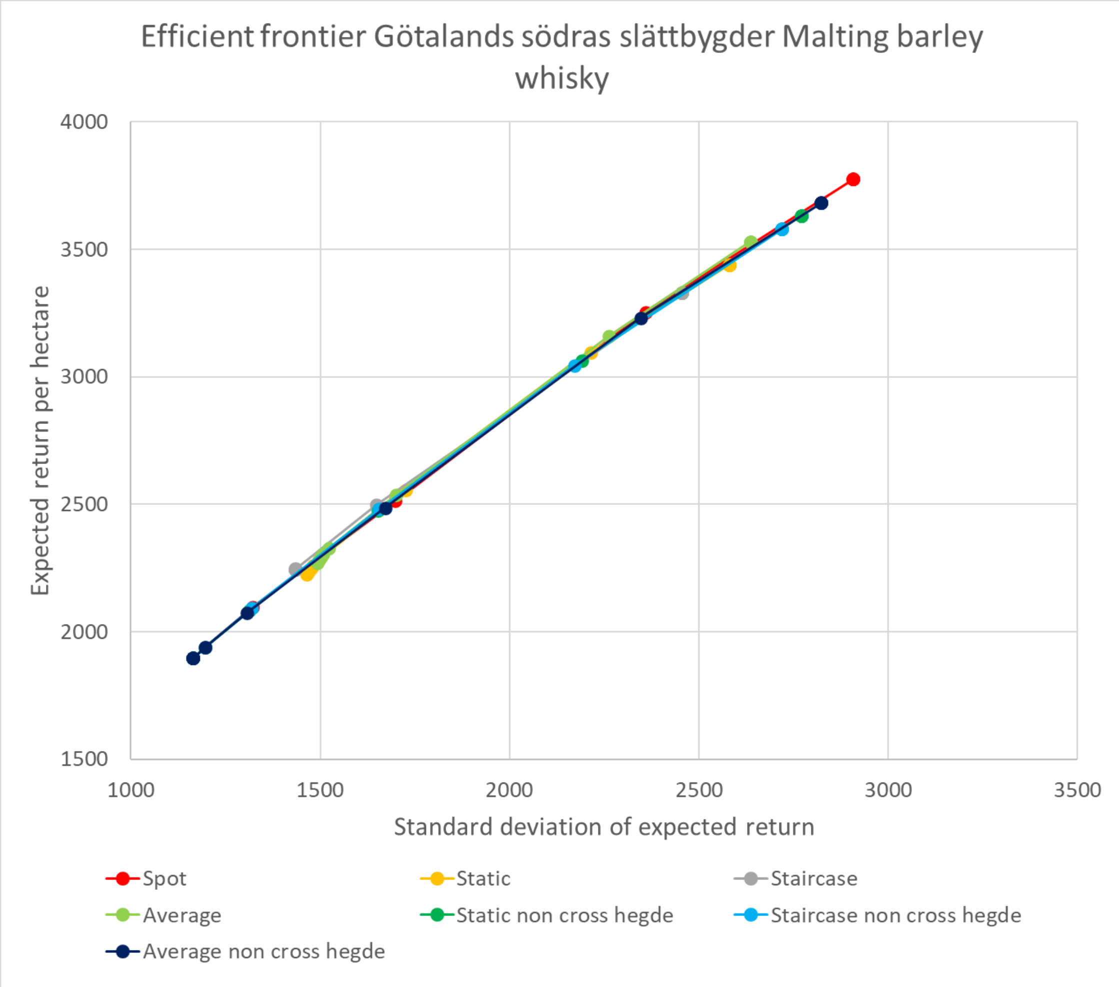

Figure 10. Efficient frontier Götalands södras slättbygder Malting barley whisky

Figure 10 above represents the strategies for whisky barley in GSS. In this, as the previous Figure 9 the difference between the strategies are very small and hard to make out. Similar to the beer is the spot strategy the one that has the highest expected return and standard deviation and the strategies without a cross-hedge have a higher expected return and standard deviation than the strategies that cross-hedged the barley. Similarly to beer is whisky still risky to grow and can be seen in Appendix 4 is whisky barley only grown during low levels of risk aversion therefore should the focus be on the points in the top right corner of the graph.

6.1.2 Svealands slättbygder

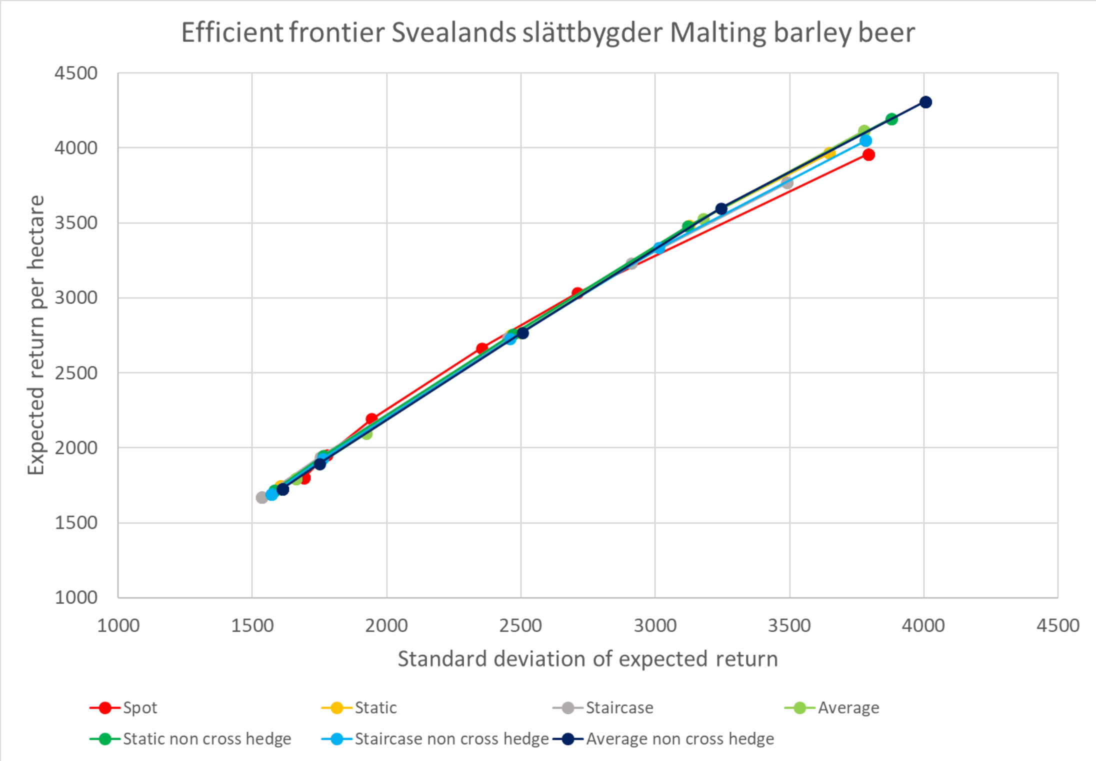

Figure 11. Efficient frontier Svealands slättbygder Malting barley beer

The results for SS shown in Figure 11 are similar to the results for GSS. There are no significant differences between the strategies except for the ones where malting barley is not hedged have a higher expected return and standard deviation than strategies that cross-hedge the barley. The spot strategy did not have the highest expected return and standard deviation in this case. As can be seen in the Appendix 5 of the crop portfolio is it similar to the results from GSS that only low levels of risk aversion grow barley and grains for human consumption.

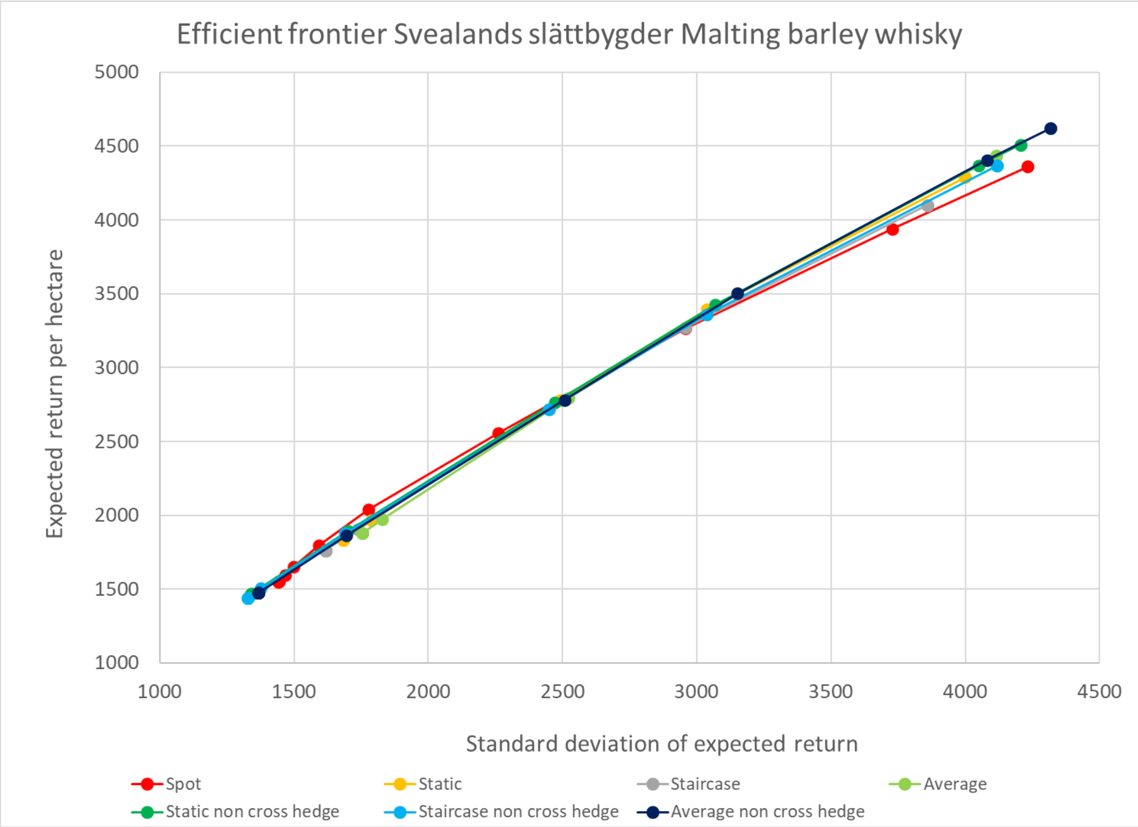

Figure 12. Efficient frontier Svealands slättbygder Malting barley whisky

As for whisky is the results as shown in Figure 12 similar to previous results. No significant difference between the strategies except that the non cross-hedge strategies have a higher expected return and standard deviation than the cross-hedge strategies and the spot strategy. The crop portfolio can be seen in Appendix 6.

6.2 Hedge effectiveness

Table 8. Hedge effectiveness of different strategies and crops for GSS and SS

Hegde effectiveness				
Strategy	**Crop**			
	Wheat	Rapeseed	Whisky Barley	Beer Barley
Static	37%	28%	40%	40%
Staircase	41%	4%	42%	43%
Average	24%	9%	29%	28%

As shown in Table 8 above is all the different strategies efficient in lowering the variability of the price. The hedging strategies are compared to the spot price received in December. There are no differences in hedge effectiveness between GSS and SS because the prices they receive are the same. For wheat was the result a reduction in variability between 24 - 41%. For rapeseed was a reduction between 9 - 40%. In the case with a cross-hedge for malting barley in wheat, both beer and whisky barley had similar results and the reduction was between 28 - 43%. For all of the grains was staircase the best strategy for hedge effectiveness.

6.3 Cost of quality risk

The cost of quality risk was the difference between objective function in the model when quality risk was present with variation between years and when the quality requirements of the barley were met every year. The comparison was made for the spot strategy so no hedging influenced the results. The results can be seen in Table 9 below. The results are for RRAC 0-0,25 because as shown in the crop portfolio is only malting barley chosen at the absolute lowest level of risk aversion. The cost of quality risk for whisky is similar for both regions. GSS has a cost of 135 SEK and SS has a cost of 131 SEK, making it only a 4 SEK difference. The difference is more significant for malting barley intended for beer. The cost of quality risk for beer barley is 334 SEK in SS and 61 SEK in GSS which makes a difference between the regions of 273 SEK per hectare.

Table 9. Cost of quality risk in GSS and SS

Cost of quality risk (SEK/hectare)	**GSS**	**SS**
Whisky	135	131
Beer	61	334

7. Analysis and discussion

7.1 Hedging

The strategy with the highest expected utility when cross hedging malting barley was the average strategy at RRAC=0. However to not cross hedge malting barley but using the average strategy gave a higher expected utility with a difference between 152 - 195 SEK/hectare depending on beer or whisky and the region. The average strategy was also the one strategy providing the highest expected utility in Andersson (2018) for risk averse producers.

Hedge effectiveness shown in this study was between 24 - 41% for wheat, 9 - 40% for rapeseed, and for a cross-hedge in wheat for malting barley both beer and whisky were the result of a 28 - 43% reduction in variability. All strategies are effective in lowering the variance of expected income. The wheat and barley hedge effectiveness is similar because the barley was cross-hedged using wheat, therefore, is the result as expected.

The result from Nilsson (2001) on hedge effectiveness is higher than in this study with a hedge effectiveness between 40 - 72% for wheat. However, these results were for the time period 1989-1999 and the hedge effectiveness is highly influenced by the price movement of the selected time period studied and the strategies were not the same. However. it still shows that hedging is effective for wheat in lowering the variability. The hedge effectiveness for a cross-hedging malting barely was 17 - 21% (Nilsson 2001). The results from this study show that a cross-hedge in wheat for malting barley is more effective than cross-hedging in feed barley was on a European exchange 1989-1999.

The hedge effectiveness of different wheat strategies is also similar to Andersson (2018) found from 2009-2017 of 23 - 36% so there has been not much change from the time period of 2014-2022. For rapeseed is the difference between Andersson (2018) larger compared to the findings of this study, Andersson (2018) hedge effectiveness was 29 - 34%. The average strategy for rapeseed stands with only a hedge effectiveness of 9% this could be a result of big changes in the futures prices and spot prices during 2014-2022.

Lidfeldt and Andersson (1994) showed an absolute risk reduction of between 3 - 29% when taking into account production risk and using an optimal hedge ratio. This is slightly lower than the results from this study but can be a result of this study's choice of strategies, hedge ratio, and the time period studied.

The hedge effectiveness on the total farm of using a cross-hedge is a risk reduction of 11 - 17%. However, using a cross-hedge for malting barley either for beer or whisky was never beneficial for the highest expected return/ hectare of the aggregated farm compared to the same non cross-hedge strategy. The difference between strategies that cross-hedge barely and those that did not cross-hedge was between 152 – 281 SEK/hectare. This equals 61 000 – 112 000 SEK less in expected return on the aggregated farm level if growing the maximum of 400 hectares with a hedging ratio of 50% and hedging 200 of them.

Therefore it is better to not cross-hedge the barley in wheat future contracts than to cross-hedge with respect to achieving the highest possible expected return. The spot strategy delivers the highest expected return in both beer and whisky in GSS. For SS was the static and staircase cross-hedge strategy worse then the spot strategy for whisky but for beer was staircase the worst then spot. The best strategy in SS was average non cross-hedge for both beer and whisky. There is a difference between the benefits of using hedging strategies between the areas of production. These results can also be seen in previous studies (Lidfeldt & Andersson 1994; Karlsson & Skog 2016; Andersson 2018).

Andersson (2018) found that for a risk-averse farmer are there is a significant utility in hedging malting barley between 65 000 – 155 000 SEK depending on strategy and production area on a farm of 500 hectares. This is the opposite of the results of this study but there are several differences that do not make a direct comparison correct for example the use of futures contracts for malting barley specifically. This could however indicate that it previously existed better possibilities to manage risk for malting barley for beer on the futures markets.

The results are for the most part not in favor of using a cross-hedge as a satisfying way of handling the risk of barley production. This can be a combination of the low correlation between wheat futures prices and spot barley prices and the effect of the time series of data shows both high prices and low yield which can affect the outcome of the model, and in a time of rising prices is it not favorable to use the futures market but when facing declining prices it is (Iwarsson 2012).

7.2 Cost of quality risk

From the results, it is clear that there is a quality risk with growing malting barley for the production of beer or whisky. The cost of quality risk for whisky is similar either if it is in the southern part of Sweden in GSS or in the northern in SS. This is what to expect because of the assumption that 9 times out of 10 are the barley within the quality requirements in both of the production areas and the barley can be sold as the whisky malting barley and receiving a price premium. The cost is 131-135 SEK/hectare and that is equal to 1% of the total value of the barley crop and it is equal to 3% of the gross margin of the crop. The cost of quality risk when growing 400 hectares of barley is a total of 52 000 – 54 000 SEK.

The differences in quality risk for growing malting barley for beer are greater between both areas of production. In GSS is the cost of quality risk as low as 61 SEK/hectare but in SS is it as high as 334 SEK/hectare. In GSS is the cost of quality risk equal to 0,5% of the total value of the crop in SS it is 2,7% and 1,6% of the gross margin per hectare and 9% for SS. For the scenario when the farms grow the maximum amount of barley (400 hectares) is the cost of risk 24 000 SEK in GSS and 134 000 SEK in SS. If growing a maximum of 400 hectares of barley would the cost of quality risk be 110 000 SEK difference on the aggregated farm level between a farm in the GSS and SS.

The results are similar to those in Ugander et al. (2012), not taking the quality risk into account when estimating the earnings will generate higher than expected returns. Further comparisons are not made because the quality risk in Ugander et al. (2012) is made for all the investigated grains and in this study the quality risk is only for malting barley.

Andersson (2018) had a cost of between 3 - 81 SEK/hectare depending on the level of risk and hedging strategy for malting barley intended for beer in SS. Anderssons cost of quality is smaller than this study's result of 334 SEK/hectare however the methods used in the optimization are slightly different when it comes to how the acceptance rate of quality is modeled and also have different time series have been studied which effect the results and making more comparison misleading due to the difference in methods.

7.3 Crop portfolio

The likelihood of achieving the quality requirements in the case of beer barley differs between the areas of production, on average the quality requirements were fulfilled 59% of the volume in SS and 68% in GSS. This creates a large difference between the variability in the expected return from the different production areas which creates these large differences of roughly five times greater cost of quality risk in SS than GSS.

More is risk involved with growing malting barley for beer in SS than in the GSS. This can be seen in the crop portfolio for different levels of risk. In SS is malting barley of any kind only a part of the crop portfolio at very low levels of risk aversion but in GSS is malting barley a part of the portfolio at slightly higher levels of risk aversion (see Appendix 3 - 6). The farmer's risk level will affect the choices of crops he grows.

This is different than what Lien and Hardaker (2001) found, they found that the farmer's attitude toward risk likely does not affect the choices of farm plan, the same type of findings Andersson (2018) had when studying the utility of the combination of different risk levels and hedging strategies for malting barley for beer did not the risk or the strategy have a significant effect the crop portfolio but this is different from what this study shows.

In this study, it is shown that already at low levels of risk aversion are the less risky crops chosen than a riskier higher paying crop. For example, feed barley is prioritized before malting barley of any kind. Similar to the results from Andersson (2018) is the crop portfolio similar regardless of which type of hedging strategy is used, the strategy had little to no effect but the level of risk aversion had more effect. The change in the crop portfolio is due to the level of risk aversion more than the strategy used. This also links to the results of Hansson and Lagerkvist (2012) that there is a significant correlation between farmers' risk preference and farm income volatility. A lower level of risk aversion will lead to more riskier higher paying crops being sowed with more variability, and this will affect how stable the income of the farmer is from year to year.

The attitude of the farmer effect on the crop portfolio is also shown in work done by Anderson and Grunér (2015) and Karlsson and Skog (2016) both show that malting barley gets a larger portion of the acreage when risk levels of the decision maker are low. The farmer's risk aversion level also reflected the amount of diversification made as mentioned in Pannell and Nordblom (1998).

Ugander et al. (2012) could neither sugar beet nor oats be motivated economically to have a part of the crop portfolio when the RRAC=3. In this study is the opposite true, sugar beet is always a part of the crop portfolio and oats are often an increasing part of the portfolio when the risk aversion increases.

8. Conclusion

8.1 Findings and Contributions

The aim of this study was how futures contracts could be utilized for Swedish grain producers to handle risk when growing malting barley and if there was any benefit with cross-hedging the malting barley. This was achieved by applying different marketing strategies, crop portfolios, and levels of risk aversion of the farmer. The other aim of this study was to investigate the cost of quality risk is between barley for beer or whisky production for different levels of risk and areas of production. By using an optimization model could the difference be calculated.

This study finds that the use of hedging strategies does lower the variability of the price received. The utility of using hedging strategies is different from one production area to another. The greatest benefits of hedging were for the grower in SS, and for the farmer in GSS, there were no benefits in hedging at low levels of risk aversion. The best hedging strategy for lowering the price variability was the staircase strategy and the best for the highest utility was the average strategy. The cross-hedge did not yield the highest expected utility, the option of not using a cross-hedging for barley was more efficient on the aggregated farm level than to cross-hedge barley by 152 - 195 SEK/hectare, this was true for both areas of production.

This study also shows that there are considerable differences in the cost of quality risk between beer barley production in the two investigated production areas SS and GSS. The cost of quality risk was 334 SEK/hectare in SS and 61 SEK /hectare when maximizing the share of barley in the crop portfolio and using the spot strategy. The difference in barley production for whisky is smaller. In SS is the cost 131 SEK/hectare and 134 SEK/hectare in GSS.

This study proves that a farmers' choice of crop can therefore affect the risk experienced and that growing malting barley of any kind is considered risky because other varieties of crops were chosen in the portfolio when increasing levels of risk aversion. However, by choosing either barley varieties for beer or whisky can the risk of quality be managed, and the risk is different depending on the location of production.

8.2 Further research

Further research that would be interesting to study is at what level of achieving quality is the threshold of choosing to produce feed quality rather than malting or milling quality grains in different areas of production in Sweden. Making a similar study like this but with the use of individual farms' quality achievements would be interesting. Further research into how different financial instruments could be used in a way to handle risk in agriculture grain production and applying different strategies for different crops during the same year and different ratios.

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Personal messages

Gerhardsson, Per, Spannmålsenheten, Lantmännen Lantbruk. [2024-02-15]

Petterson, CG , Scientific Project Manager, Lantmännen [2024-03-26]

Popular science summary

Farming can be risky sometimes. There is uncertainty in how much to get paid due to world market changes and there is uncertainty how much is produced and if your crop is able to sell for its intended purpose. A difficult crop to grow is barley. The farmer can grow it to feed livestock, malting beer or whisky. Not always does the barley meet the quality requirements for beer or whisky and is forced to be sold as feed at a lower price. One way farmers can handle the price received by using what is called a future contract, which also farmers to lock in a price in advance an allows farmers to handle the risk of decreasing prices on the grain.

The purpose of this study is to compare how much the risk is for not being able to sell everything for it intended purpose and if there is a difference the risk between barley for beer or whisky. The difference between two areas of production is also taken into account. Another purpose is to study what strategy is the best when you should sell the grain using futures.

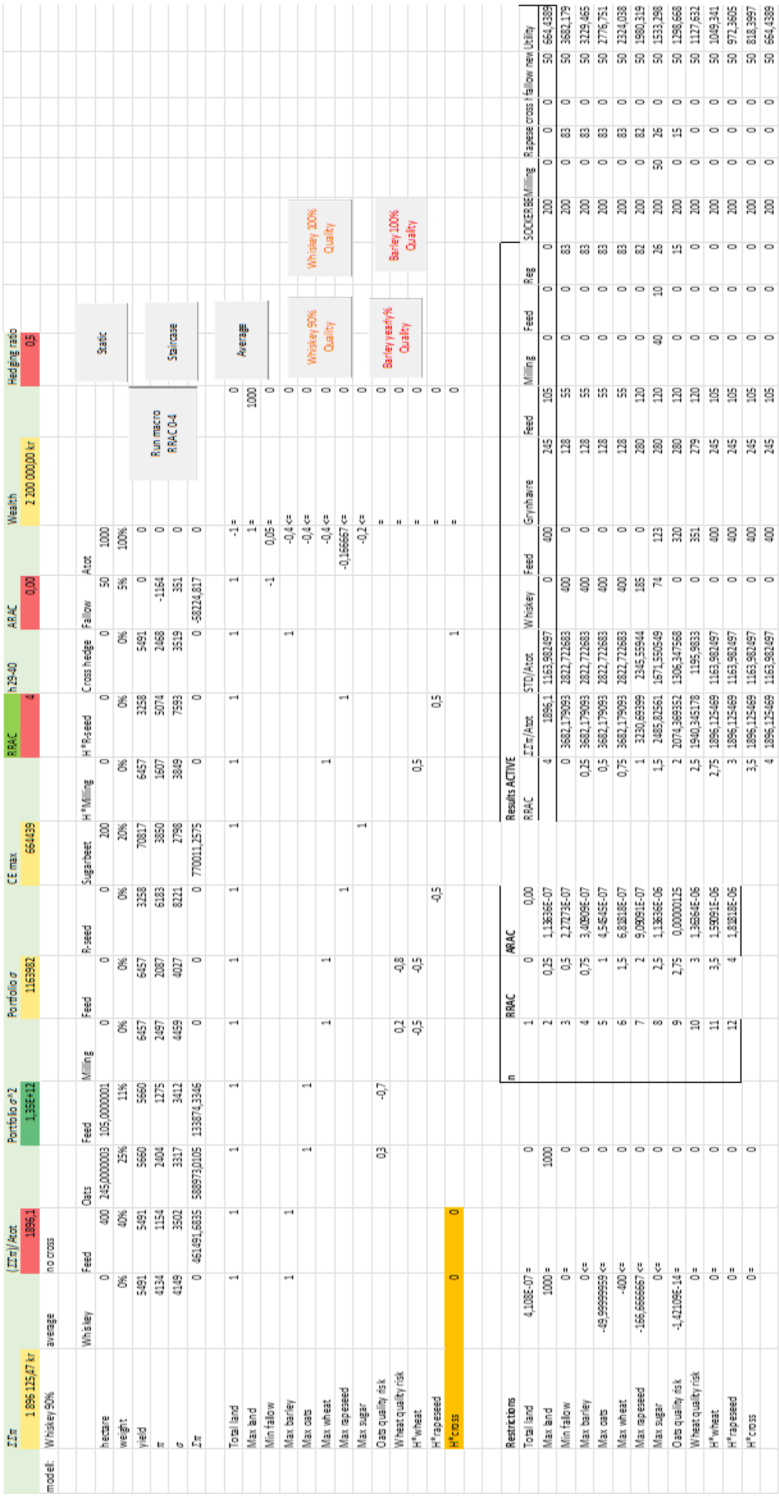
This is achieved by collecting data from farms on the yield of different crops, cost of production calculations, grain prices, and other forms of necessary data to construct a mathematical model that can be solved using a computer program. This model creates the best solution for different combinations of crops for different strategies and depending on how much risk the farmer is willing to take.

The results were that the risk was greater for barley intended for beer in the production area Sveanlands slättbygder, the cost was calculated to be 334SEK/hectare compared to 64SEK/hectare in Götalands södra slättbygder. For whisky was the cost 131SEK/hectare respective 134SEK/hectare. The best strategy varied from the varieties of barley and production area however, there were no benefits for using future contracts for barley if the farmer wanted to receive the highest price.

Acknowledgements

I want to thank my supervisor Hans Andersson for his guidance and support during the time writing this master's thesis. This thesis would not been possible without the help of Per Gerhardsson, I am grateful for all the fast replies and comments. Thanks, CG Pettersson for an interesting discussion about malting barley qualities, and to the two farmers who swiftly shared their data with me, thank you for contributing to science.

Appendix 1: Optimization model in Excel



ΣΣπ		(ΣΣπ)/Atot	Portfolio σ^2	Portfolio σ	CE max	RRAC	h29-40	ARAC	Wealth	Hedging ratio
1 896 125,47 kr		1896,1	1,35E+12	1163982	664439	4		0,00	2 200 000,00 kr	0,5

model:	Whiskey 90%	average	no cross												
		Whiskey	Feed	Oats	Feed	Milling	Feed	R-seed	Sugarbeet	H*Milling	H*R-seed	Cross hedge	Fallow	Atot	
	hectare	0	400	245,0000003	105,0000001	0	0	0	200	0	0	0	50	1000	
	weight	0%	40%	25%	11%	0%	0%	0%	20%	0%	0%	0%	5%	100%	
	yield	5491	5491	5660	5660	6457	6457	3258	70817	6457	3258	5491	0	0	
	π	4134	1154	2404	1275	2497	2087	6183	3850	1607	5074	2468	-1164	0	
	σ	4149	3502	3317	3412	4459	4027	8221	2798	3849	7593	3519	351	0	
	Σπ	0	461491,6835	588973,0105	133874,3346	0	0	0	770011,2575	0	0	0	-58224,817	0	
	Total land	1	1	1	1	1	1	1	1	1	1	1	1	-1 =	0
	Max land													1 =	1000
	Min fallow												-1	0,05 =	0
	Max barley	1	1									1		-0,4 <=	0
	Max oats			1	1									-0,4 <=	0
	Max wheat					1	1			1				-0,4 <=	0
	Max rapeseed							1			1			-0,166667 <=	0
	Max sugar								1					-0,2 <=	0
	Oats quality risk			0,3	-0,7									=	0
	Wheat quality risk					0,2	-0,8							=	0
	H*wheat					-0,5	-0,5			0,5				=	0
	H*rapeseed							-0,5			0,5			=	0
	H*cross	0	0									1		=	0

Restrictions		
Total land	4,108E-07 =	0
Max land	1000 =	1000
Min fallow	0 =	0
Max barley	0 <=	0
Max oats	-49,9999959 <=	0
Max wheat	-400 <=	0
Max rapeseed	-166,6666667 <=	0
Max sugar	0 <=	0
Oats quality risk	-1,42109E-14 =	0
Wheat quality risk	0 =	0
H*wheat	0 =	0
H*rapeseed	0 =	0
H*cross	0 =	0

n	RRAC	ARAC
1	0	0,00
2	0,25	1,13636E-07
3	0,5	2,27273E-07
4	0,75	3,40909E-07
5	1	4,54545E-07
6	1,5	6,81818E-07
7	2	9,09091E-07
8	2,5	1,13636E-06
9	2,75	0,00000125
10	3	1,36364E-06
11	3,5	1,59091E-06
12	4	1,81818E-06

Results ACTIVE

RRAC	ΣΣπ/Atot	STD/Atot	Whiskey	Feed	Grynhavre	Feed	Milling	Feed	Reg	SOCKERBE	Milling	Rapese	cross h	fallow new	Utility
4	1896,1	1163,982497	0	400	245	105	0	0	0	200	0	0	0	50	664,4389
0	3682,179093	2822,722683	400	0	128	55	0	0	83	200	0	83	0	50	3682,179
0,25	3682,179093	2822,722683	400	0	128	55	0	0	83	200	0	83	0	50	3229,465
0,5	3682,179093	2822,722683	400	0	128	55	0	0	83	200	0	83	0	50	2776,751
0,75	3682,179093	2822,722683	400	0	128	55	0	0	83	200	0	83	0	50	2324,038
1	3230,69399	2345,55944	185	0	280	120	0	0	82	200	0	82	0	50	1980,319
1,5	2485,82561	1671,550549	74	123	280	120	40	10	26	200	50	26	0	50	1533,298
2	2074,369352	1306,347568	0	320	280	120	0	0	15	200	0	15	0	50	1298,668
2,5	1940,345178	1195,9833	0	351	279	120	0	0	0	200	0	0	0	50	1127,632
2,75	1896,125469	1163,982497	0	400	245	105	0	0	0	200	0	0	0	50	1049,341
3	1896,125469	1163,982497	0	400	245	105	0	0	0	200	0	0	0	50	972,3605
3,5	1896,125469	1163,982497	0	400	245	105	0	0	0	200	0	0	0	50	818,3997
4	1896,125469	1163,982497	0	400	245	105	0	0	0	200	0	0	0	50	664,4389

Appendix 2: Gross margin matrix for GSS and SS

Gross margin matrix (GSS)

			2014	2015	2016	2017	2018	2019	2020	2021	2022	**mean**	σ
Spot	Barley	Malting	2789	1815	1092	4385	59	2635	2751	8548	13133	4134	4149
		Feed	-753	-781	-1492	125	-1027	142	768	3941	9460	1154	3502
	Oats	Oats	466	1502	-79	309	774	2569	2839	2483	10772	2404	3317
		Feed	-825	-155	-596	-1684	-542	853	579	5091	8753	1275	3412
	Wheat	Milling	1304	238	-1663	131	-2122	2567	2817	7691	11508	2497	4459
		Feed	556	-353	-1601	130	-2096	2620	2786	6521	10216	2087	4027
	Summer rapeseed	Reg	2133	3151	-1382	2602	-4817	10080	7257	20913	15710	6183	8221
		Sugarbeet	7907	4010	5303	2267	629	6720	275	6018	1521	3850	2798
Future		Milling	545	1224	-1768	251	-3485	3404	2235	1823	10234	1607	3849
		Rapeseed	1887	1982	-2709	2866	-5091	8701	7049	11090	19888	5074	7593
	cross	whiskey	1283	1441	185	3431	-1599	2202	1114	3235	10921	2468	3519
		fallow	-1355	-1401	-1431	-1167	-1615	-1122	-1159	-699	-530	-1164	351

Gross margin matrix (SS)

			2014	2015	2016	2017	2018	2019	2020	2021	2022	**mean**	σ
Spot	Barley	Malting	1748	-511	667	1420	1661	639	2650	8770	11182	3136	4022
		Feed	-566	-1278	-713	-557	1460	307	2075	6411	9325	1830	3661
	Oats	Oats	-220	236	-421	59	1858	1412	4241	1039	7024	1692	2459
		Feed	-1265	-971	-1063	-1521	-112	164	1520	2540	5729	558	2367
	Wheat	Milling	2628	1346	286	1368	2505	2893	4450	10687	9712	3986	3719
		Feed	1587	275	3	1473	2508	2959	4309	9220	8561	3433	3366
	Summer rapeseed	Reg	2008	4057	5809	4304	3405	5970	8840	22343	11940	7631	6284
Future		cross/hedge	1106	204	568	1509	191	1235	2035	2580	10024	2161	3055
		Milling	1766	2535	160	1505	608	3770	3717	3231	8600	2877	2504
		Rapeseed	6589	6774	7037	8490	2233	13328	20389	23553	38935	14147	11611
		Fallow	-1425	-1337	-1251	-1094	-933	-1110	-1106	-641	-556	-1050	295

Appendix 3: Crop portfolio in GSS for beer barley

Spot	Barley BEER	Feed Barley	Oats	Feed Oats	Milling Wheat	Feed Wheat	Rapeseed	Sugarbeet	Fallow
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	219	0	280	120	0	0	131	200	50
1,5	68	128	280	120	86	21	46	200	50
2	0	319	280	120	0	0	31	200	50
4	0	400	245	105	0	0	0	200	50
Static									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	400	0	128	55	0	0	167	200	50
1,5	4	283	280	120	0	0	64	200	50
2	0	314	280	120	29	7	0	200	50
4	0	0	280	120	280	70	0	200	50
Staircase									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	400	0	128	55	0	0	167	200	50
1,5	13	262	280	120	0	0	75	200	50
2	0	350	280	120	0	0	0	200	50
4	0	350	280	120	0	0	0	200	50
Average									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	400	0	128	55	0	0	167	200	50
1,5	0	289	280	120	0	0	61	200	50
2	0	339	280	120	9	2	0	200	50
4	0	42	280	120	246	62	0	200	50
Static (non cross hedge)									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	400	0	128	55	0	0	167	200	50
1,5	83	198	280	120	0	0	68	200	50
2	0	350	280	120	0	0	0	200	50
4	0	350	280	120	0	0	0	200	50
Staircase (non cross hedge)									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	400	0	128	55	0	0	167	200	50
1,5	101	171	280	120	0	0	77	200	50
2	0	343	280	120	0	0	7	200	50
4	0	350	280	120	0	0	0	200	50
Average (non cross hedge)									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	183	0	280	120	0	0	167	200	50
1,5	73	217	280	120	0	0	60	200	50
2	0	350	280	120	0	0	0	200	50
4	0	350	280	120	0	0	0	200	50

Appendix 4: Crop portfolio in GSS for whisky barley

Spot	Barley Whiskey	Feed Barley	Oats	Feed Oats	Milling Wheat	Feed Wheat	Rapeseed	Sugarbeet	Fallow
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	219	0	280	120	0	0	131	200	50
1,5	68	128	280	120	86	21	46	200	50
2	0	319	280	120	0	0	31	200	50
4	0	400	245	105	0	0	0	200	50
Static									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	183	0	280	120	0	0	167	200	50
1,5	48	242	280	120	0	0	60	200	50
2	0	314	280	120	28	7	0	200	50
4	0	65	280	120	228	57	0	200	50
Staircase									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	400	0	128	55	0	0	167	200	50
1,5	21	255	280	120	0	0	74	200	50
2	0	350	280	120	0	0	0	200	50
4	0	350	280	120	0	0	0	200	50
Average									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	192	0	278	119	0	0	162	200	50
1,5	14	228	280	120	39	10	59	200	50
2	0	343	280	120	6	1	0	200	50
4	0	111	280	120	191	48	0	200	50
Static (non cross hedge)									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	148	53	267	115	0	0	167	200	50
1,5	68	203	280	120	0	0	79	200	50
2	0	316	280	120	0	0	34	200	50
4	0	400	245	105	0	0	0	200	50
Staircase (non cross hedge)									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	163	50	259	111	0	0	167	200	50
1,5	71	194	280	120	0	0	85	200	50
2	0	311	280	120	0	0	39	200	50
4	0	400	245	105	0	0	0	200	50
Average (non cross hedge)									
0	400	0	128	55	0	0	167	200	50
0,5	400	0	128	55	0	0	167	200	50
0,75	400	0	128	55	0	0	167	200	50
1	185	0	280	120	0	0	165	200	50
1,5	74	123	280	120	40	10	53	200	50
2	0	320	280	120	0	0	30	200	50
4	0	400	245	105	0	0	0	200	50

Appendix 5: Crop portfolio in SS for beer barley

Spot	Barley BEER	Feed Barley	Oats	Feed Oats	Milling Wheat	Feed Wheat	Rapeseed	Fallow
0	400	0	0	0	307	77	167	50
0,5	400	0	0	0	307	77	167	50
0,75	289	0	280	120	75	19	167	50
1	156	228	280	120	0	0	167	50
1,5	0	400	280	120	36	9	105	50
2	0	400	280	120	88	22	40	50
4	0	400	280	120	120	30	0	50
Static								
0	400	0	0	0	306	77	167	50
0,5	400	0	0	0	306	77	167	50
0,75	0	0	280	120	307	77	167	50
1	114	20	280	120	269	67	79	50
1,5	0	258	280	120	234	58	0	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50
Staircase								
0	400	0	0	0	306	77	167	50
0,5	400	0	0	0	306	77	167	50
0,75	148	0	280	120	188	47	167	50
1	280	7	280	120	125	31	107	50
1,5	0	400	280	120	88	22	40	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50
Average								
0	400	0	0	0	306	77	167	50
0,5	400	0	0	0	306	77	167	50
0,75	95	0	280	120	230	58	167	50
1	191	0	280	120	227	57	75	50
1,5	340	0	280	120	168	42	0	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50
Static (non cross hedge)								
0	400	0	0	0	306	77	167	50
0,5	400	0	0	0	306	77	167	50
0,75	36	0	280	120	278	69	167	50
1	77	16	280	120	310	78	69	50
1,5	0	246	280	120	243	61	0	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50
Staircase (non cross hedge)								
0	400	0	0	0	306	77	167	50
0,5	400	0	0	0	306	77	167	50
0,75	151	0	280	120	186	46	167	50
1	115	16	280	120	272	68	79	50
1,5	0	289	280	120	198	50	13	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50
Average (non cross hedge)								
0	400	0	0	0	306	77	167	50
0,5	400	0	0	0	306	77	167	50
0,75	0	0	280	120	307	77	167	50
1	37	46	280	120	320	80	67	50
1,5	0	310	280	120	189	47	4	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50

Appendix 6: Crop portfolio in SS for whisky barley

Spot	Barley Whiskey	Feed Barley	Oats	Feed Oats	Milling Wheat	Feed Wheat	Rapeseed	Fallow
0	400	0	0	0	307	77	167	50
0,5	400	0	117	50	172	43	167	50
0,75	331	26	280	120	21	5	167	50
1	114	269	280	120	0	0	167	50
1,5	0	400	280	120	16	4	130	50
2	0	400	280	120	68	17	66	50
4	0	400	280	120	120	30	0	50
Static								
0	400	0	0	0	307	77	167	50
0,5	400	0	0	0	307	77	167	50
0,75	0	0	280	120	307	77	167	50
1	0	66	280	120	320	80	84	50
1,5	0	288	280	120	209	52	0	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50
Staircase								
0	400	0	0	0	307	77	167	50
0,5	400	0	0	0	307	77	167	50
0,75	66	0	280	120	254	64	167	50
1	13	60	280	120	310	77	91	50
1,5	0	346	280	120	153	38	13	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50
Average								
0	400	0	0	0	307	77	167	50
0,5	400	0	0	0	307	77	167	50
0,75	0	0	280	120	307	77	167	50
1	0	73	280	120	320	80	77	50
1,5	0	318	280	120	186	46	0	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50
Static (non cross hedge)								
0	400	0	0	0	307	77	167	50
0,5	338	0	32	14	320	80	167	50
0,75	37	0	280	120	277	69	167	50
1	13	62	280	120	310	77	89	50
1,5	0	314	280	120	159	40	38	50
2	0	400	280	120	120	30	1	50
4	0	400	280	120	120	30	0	50
Staircase (non cross hedge)								
0	400	0	0	0	307	77	167	50
0,5	400	0	0	0	307	77	167	50
0,75	109	0	280	120	220	55	167	50
1	37	55	280	120	292	73	92	50
1,5	0	400	280	120	63	16	71	50
2	0	400	280	120	112	28	10	50
4	0	400	280	120	120	30	0	50
Average (non cross hedge)								
0	400	0	0	0	307	77	167	50
0,5	311	0	51	22	320	80	167	50
0,75	0	0	280	120	307	77	167	50
1	0	68	280	120	318	80	84	50
1,5	0	400	280	120	75	19	56	50
2	0	400	280	120	120	30	0	50
4	0	400	280	120	120	30	0	50

Publishing and archiving

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