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Hedging malting barley

- maximizing expected utility considering price, yield and quality risk

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Torgil Andersson

Abstract

Farmers are faced with situations with uncertain outcomes on a daily basis. Production risks stem from uncertainty about the performance of crops and the unpredictable nature of weather. Also, the markets for inputs and agricultural commodities affect the farm to a high degree. Market prices are largely determined by factors which the farmer cannot control and market risks are often significant. Farming is an activity which takes place in an environment characterized by risk and uncertainty to a high degree. Hedging is a risk management tool which is used to reduce price risk exposure. Through hedging, risk is transferred from the producer to investors/speculators who seek risk for the return. Farmers can hedge grain using futures contracts as a method of reducing their income variance. The focus of this study is to evaluate hedging strategies of malting barley when quality risk is considered in addition to yield and price risk.

The aim of this study is to investigate how future contracts can be used by Swedish grain producers to maximize their expected utility. The study accounts for yield, price and quality risk exposure. Several different marketing strategies are investigated. The study aims to find the cost of quality risk for malting barley and the expected utility of hedging malting barley for various levels of risk aversion. An applied quadratic risk programming model and mathematical optimization is used to derive expected utility maximizing hedging strategies and crop portfolios. Using crop yield data from two case farms in Uppland and Östergötland and variable costing calculations from Agriwise the covariance matrices of gross margins are developed. The information is used to model fictitious case farms using quadratic risk programming. The optimization problem is solved using a non-linear solving algorithm. Historical price data is Swedish spot and Matif and Liffe futures prices from the time period 2009-2017 and are used to examine the different hedging strategies.

The results of this study indicate that a risk averse farmer may reduce his price risk exposure significantly through the practice of hedging malting barley and that the cost of quality risk is no reason not to hedge malting barley. The crop rotations do not change significantly between the almost risk neutral farmer and the extremely risk-averse farmer. The major conclusion of this study is that hedging malting barley is an effective way to maximize expected utility for a risk averse farmer. For a large-scale crop farmer in the mid-Sweden plains areas who is rather risk averse, the value of hedging malting barley is around 2-3 % of total revenue. The cost of quality risk is only 0,2-0,4 % of total revenue in comparison.

Sammanfattning

Lantbrukare står dagligen inför val med osäkra utfall. Produktionsrisker uppkommer från osäkerhet om skördeutfallet och oförutsägbart väder. Dessutom påverkar marknadspriserna för spannmål och insatsvaror gården i hög grad. Marknadspriser av faktorer utanför lantbrukarens kontroll och marknadsrisker är ofta betydande. Växtodling är därför en aktivitet som karaktäriseras av risk och osäkerhet. Växtodlare kan använda sig av terminskontrakt för prissäkring av spannmål som en metod för att minska deras inkomstvariation. Terminskontrakt är ett verktyg för riskhantering som används för att minska prisriskexponering. Genom terminskontrakt överförs risk från spannmålsodlare till investerare/spekulanter som vill köpa risk för avkastningen. Fokus i denna studie är att utvärdera prissäkringsstrategier för maltkorn med beaktande av kvalitetsrisk utöver avkastning och prisrisk.

Syftet med denna studie är att undersöka hur terminskontrakt kan användas av spannmålsproducenter i slättområdena i mellersta Sverige i syfte att maximera deras förväntade nytta. Studien beaktar kvantitet-, pris- och kvalitets-riskexponering. Flera olika prissäkringsstrategier undersöks. Studien syftar till att finna kostnaden av kvalitetsrisk för maltkorn och den förväntade nyttan av att prissäkra maltkorn genom terminskontrakt för olika grader av riskaversion. En applicerad kvadratisk-riskprogrammerings modell och matematisk optimering används för att utvärdera nytto-maximerande prissäkringsstrategier och grödrotationer. Odlingsdata från två fallgårdar i Uppland och Östergötland används tillsammans med bidragskalkyler från Agriwise för att beräkna kovariansmatriser för brutto-vinsten för de olika grödorna. Informationen används för att modellera fiktiva fallgårdar med kvadratisk-riskprogrammering. Optimeringsproblemet löses med en icke-linjär lösningsalgoritm. Historiska prisdata är svenska spot-priser och Matif- och Liffe-terminspriser från perioden 2009–2017 och används för att utvärdera de olika prissäkringsstrategierna.

Resultaten av denna studie indikerar att en riskavert spannmålsodlare kan reducera sin prisriskexponering betydligt genom att prissäkra maltkorn och att kvalitetsrisk inte är ett skäl att inte prissäkra maltkorn. Grödfördelningen förändras inte avsevärt mellan den producent som är riskneutral till den som är extremt riskavert. Främsta slutsatsen av denna studie är att prissäkring av maltkorn är ett effektivt sätt att maximera förväntad nytta för riskaverta spannmålsodlare. För en storskalig spannmålsgård i mellersta Sveriges slättbygder som är ganska riskavert är värdet av att prissäkra maltkorn 2-3 % av totala intäkter. Kostnaden för kvalitetsrisk är i jämförelse 0,2-0,4 % av totala intäkter.

Abbreviations

CAP	Common Agricultural Policy
CE	Certainty equivalent
Gns	the production area Götalands norra slättbygder
ICE	Intercontinental Exchange
Liffe	London International Financial Futures and Options Exchange
Matif	Marché à Terme International de France
MB	Malting barley
MOTAD	Minimization of Total Absolute Deviations
OHR	Optimal hedge ratio
QRP	Quadratic risk programming
RRAC	Relative risk aversion coefficient
SJV	Swedish Board of Agriculture
Ss	the production area Svealands slättbygder
UEP	Utility efficient programming

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1 Introduction

Farmers all over the world understand the existence of risk and adjust to in the way they operate their farms (Hardaker *et al.*, 2015). Farming is an activity that is inherently linked to nature (Debertin, 2012). It may rain too much or too little. Insects and crop diseases may damage a crop (Debertin, 2012). The production volumes are largely influenced by local weather, and the world market largely influence the local price. Production risks are expected to increase due to changes in climatic conditions and price volatility is expected to increase due to market liberalization (Finger, 2012). Farmers will face increased exposure to competitive markets than has been their experience and enjoy less predictable consequences (Hardaker *et al.*, 2015). Therefore, risk management in agriculture is expected to gain importance in the coming decades (Finger, 2012).

Due to free trade policies and agricultural policy reforms the price risk has become a more immediate issue for farmers in the European Union (Pennings, 1998). As agricultural markets become more liberalized, commodity prices become increasingly volatile (Pennings, 1998). In order to cope with increasing risk exposure farmers have financial risk management tools but also on-farm risk reduction measures that will play an even bigger role in the future (Finger, 2012).

Farmers have a number of tools to transfer price risk. Forward and futures contracting have traditionally been the fundamental methods of price risk management (Rolfo, 1980; Lidfeldt & Andersson, 1994). Other methods include price support programs, crop insurance and off-farm income (Shapiro & Wade Brorsen, 1988), and also diversification of the crop rotation (Pannell *et al.*, 2008). Previous research has shown that relatively few producers take advantage of these tools (Simmons, 2002; Pannell *et al.*, 2008).

Futures markets are financial markets that exist parallel to the physical markets. Futures markets offer hedging and speculation services to those who seek to transfer price risk. Hedgers seek to reduce their exposure against price volatility and speculators seek to buy risk in the hope of turning a profit. The futures exchanges allow hedgers to transfer risk to speculators (Rolfo, 1980; Pennings, 1998).

Commodity futures contracts are standardized and traded on exchanges such as Marché à Terme International de France (Matif) and London International Financial Futures and Options Exchange (Liffe) (table 1). Futures trading has been available for a long time but has only in the recent years become an increasingly popular way to hedge against price volatility (Iwarson, 2012)

Table 1. Examples of international exchanges where agricultural commodities are traded (own rendering).

Commodity exchange	**Abbrevation**	**Location**	**Currency**
Australian Securities Exchange	ASX	Australia	AUD
Liffe / NYSE Liffe	NYSE Euronext	England	GBP
Matif / Paris Euronext	NYSE Euronext	France	EUR
Chicago Board of Trade	CBOT	Illinois, USA	USD
Chicago Mercantile Exchange	CME	Illinois, USA	USD
Kansas City Board of Trade	KCBT	Missouri, USA	USD
Intercontinental Exchange	ICE	Atlanta, USA	CAD

Malting barley is one of Sweden's most important grain exports. Malting barley is used to produce beer and whisky and has traditionally been an important crop for producers in the plains areas of mid-Sweden. Farmers may also grow feed barley varieties but typically malting varieties are planted. If the malting variety is rejected due to quality, the farmer would sell it as feed barley at a price which is lower (Wilson *et al.*, 2009). The price difference is becoming an increasing problem as maltsters are placing more emphasis on quality (Wilson *et al.*, 2009).

Malting barley is primarily exported to Germany where it is used in the beer brewing industry. Lantmännen Lantbruk sell about 400 kilo tonnes of malting barley each year (1, Lantmännen Lantbruk, 2018). To be accepted by the malting industry malting barley has to fullfil strict quality demands. The barley produced must be of the malting variety, the germination needs to be high, the shell needs to be undamaged and the protein content needs to be just right and preferably even (Pettersson, 2006). A too high protein content in malting barley gives the beer a haze (Iwarson, 2012). The protein content is highly dependent on the fertilization method used and can vary between years. The fertilization method is the most problematic part about adhering to the strict quality demands of malting barley (Pettersson, 2006).

1.1 Problem background

In the European Union the EU's intervention price on wheat and barley was for a long time set at 101 EUR per ton, which was above the world market price (Iwarson, 2012). This meant that all transactions were made at EU's fixed floor price. Thus, the price has been constant over the years. Focus has therefore been on maximizing production quantity and quality. Any income variation between years has been due to production risk (Iwarson, 2012). In 2006 the world market price rose above the EU's intervention price, which introduced price risk as a source of income variation (Iwarson, 2012).

The fundamental risk management approaches has traditionally been forward contracts and hedging using the futures markets (Lidfeldt & Andersson, 1994). But European/Swedish producers show little interest in managing price risk using the futures markets (Iwarson, 2012). This could be due to the fact that futures markets emerged in the United States. Still the main futures exchanges are located in the United States but currency exchange risk discourage the use by European/Swedish producers (Lidfeldt & Andersson, 1994). Hedgers are assumed to seek to stabilize their income in local currency rather than in the United States dollar (Thompson & Bond, 1987).

The situation becomes more complex once production uncertainty is introduced (Rolfo, 1980). Risk is a result of variability in quantity, price and quality (Wilson *et al.*, 2009). The harvest yields vary from year to year. Market prices vary from day to day and can fluctuate significantly. Lastly, the harvested crops have quality demands they must meet. If the quality demands are not met the crops might be rejected or subject to price reductions (Wilson *et al.*, 2009). The spot market price fluctuations of grain in Sweden and the aggregate harvest yields of winter wheat over the past decade (figure 1).

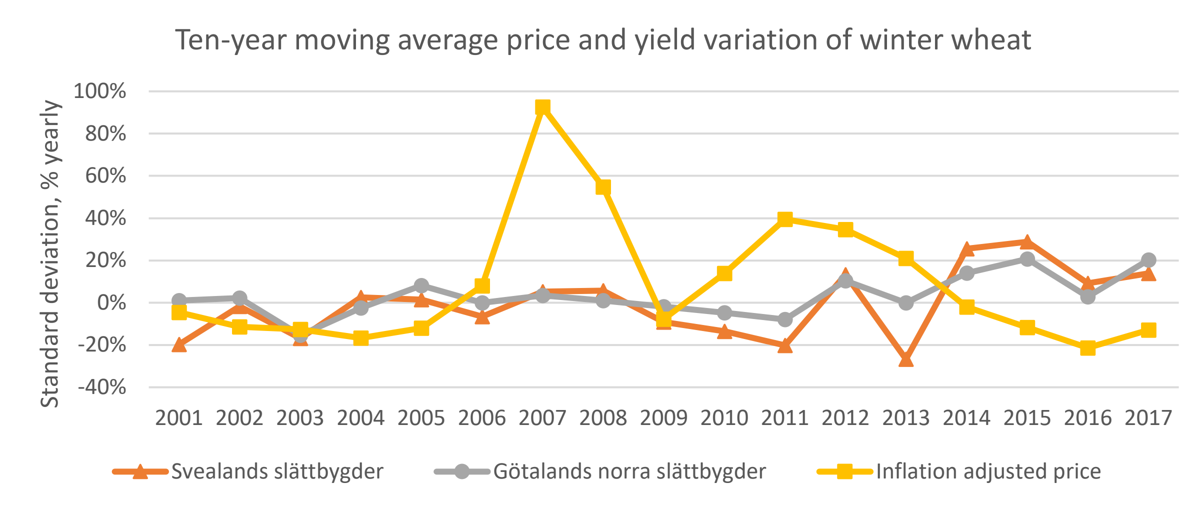

Figure 1. The variation in milling wheat price and regional variation in harvested yield in Gns and Ss (1, SCB, 2018; 1, Agriwise, 2018) (own rendering).

Price variation is the largest source of income variability (Iwarson, 2012), as shown by figure 1. The market can change quickly. The large price movements in 2007 were caused by the United States' policy changes in regards to ethanol production. Price variation is separate to harvest yield variation and therefore need to be dealt with seperately (Iwarson, 2012). Price risk management with respect to the world market price and the production risk on the farm are two separate issues on the farm (Iwarson, 2012).

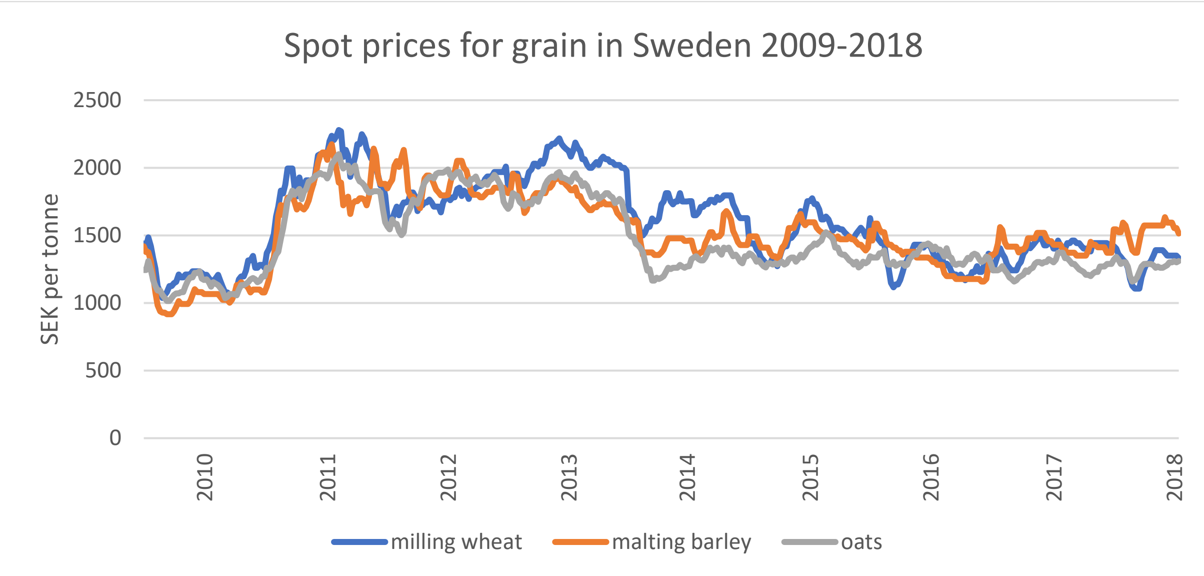

Figure 2. Historical grain spot prices in Sweden for the period 2009-2018 (pers. comm., Johnson, 2018) (own rendering).

The grain prices have been in a steady declining trend since 2011 as illustrated in figure 2.

1.2 Problem statement

Malting barley is a risky crop to grow and producers receive a premium if quality specifications are met (Wilson *et al.*, 2009). In addition to unpredictable weather and market price risk, farmers risk having malting barley rejected if the quality specifications in the contract are not met (Wilson *et al.*, 2009). The leading causes of rejection are protein content and germination rates (Pettersson, 2006; Wilson *et al.*, 2009). The protein content may range between 9,5-11,5 % for European malting barley (Pettersson, 2006). A simultaneous germination is a key factor for high quality beer and variation is germination rates reduce the quality of the malt (Pettersson, 2006).

Malting barley futures contracts are introduced on Matif, part of the global NYSE Euronext, in 2010. The contracts are bought and sold in Euro per metric ton. The contract specifies a volume of 50 tons. The delivery months are January, March, August and November (Iwarson, 2012). The futures contract specifies the acceptable varieties of malting barley. The germination rate must be 95 %, water content maximum 14,5 %, and the protein content maximum 11,5 %.

There is no trading activity of Liffe malting barley contracts at the time of writing this essay. Since of April 2015 the futures contract for malting barley were suspended on the Liffe derivates exchange (1, Euronext, 2015). There is no other malting barley contract availible on any another international commodity exchange either (table 2). This means that European and Swedish farmers can no longer hedge their malting barley on a European derivates exchange.

Cross hedging is a hedging strategy that involves taking a futures position on a different commodity with similar price movements (Brorsen *et al.*, 1998). All hedges are to some degree cross hedges due to differences in quality, location and delivery time (Brorsen *et al.*, 1998). A cross hedge can be an effective price risk management strategy to hedge a commodity for which there is no futures contract availible. For malting barley a cross hedge could be in feed barley. However, the feed barley contract on Liffe was discontinued in 2002 (1, AHDB, 2018). Thus, there is no way to cross-hedge malting barley in feed barley on a local European commodity exchange. However, the Canadian ICE (Intercontinental Exchange) and ASX (Australian Securities Exchange) have feed barley contracts availible. This is a possible way to cross hedge in feed barley, but this type of cross hedge on different exchanges introduces further currecy exchange risk. Using local commodity exchanges is a more efficient risk management strategy (Guo *et al.*, 2013). Thus, hedging malting barley with the ICE contract will be less effective than hedging with a Liffe contract (Brorsen *et al.*, 1998). This study does not deal specifically with currency exchange risk.

Table 2. The different malting and feed barley futures contracts available at the time of writing this study.

Commodity	**Exchange**	**Country**	**Status**
Malting barley	Liffe (NYSE Euronext)	England	suspended
Feed barley	ICE	Canada	active
Feed barley	ASX	Australia	active

The empirical problem of this study is how Swedish crop farmers can manage their increasing risk exposure in order to reduce income variance between years. Before harvest, price and production to be realized are uncertain (Rolfo, 1980). The farm has a number of tools to manage risk. Futures and forward contracts are the traditional methods (Iwarson, 2012). The crop rotation and the way the farmer plans his farm is another one (Pannell *et al.*, 2008). No previous study examines how Swedish malting barley producers can maximize their expected utility using the risk management tools available to them.

The theoretical problem of this study is that no previous study has investigated the expected utility of hedging malting barley using futures contracts considering quality risk. Karlsson and Skog (2016) propose that further research on the topic of hedging strategies for malting barley is needed. One reason for this is likely the short period of time the malting barley futures contracts were available on Matif and then later Liffe, the period 2010-2015. This study uses the gap-spotting method and attempts to fill a gap in existing knowledge where a topic has not been fully explored, misunderstood or ignored (Bryman & Bell, 2015). The quality risk problem of malting barley has been handled theoretically by Pettersson (2006), Wilson *et al.* (2009) and Ugander *et al.* (2012), but none of these studies relate to the topic of hedging. There are no previous studies, to the best of my knowledge, which analyses hedging strategies for malting barley considering quality risk. Hence, it is of interest to further investigate this gap in the literature.

1.3 Aim and research questions

The aim of this study is to investigate how future contracts can be used by Swedish grain producers to maximize their expected utility. The study accounts for yield, price and quality risk exposure. Several different marketing strategies and a variety of crops in the cropping system are investigated. The study aims to find the cost of quality risk for malting barley and the expected utility of hedging malting barley for various levels of risk aversion. To achieve the aim, the research questions are answered:

1. What is the expected utility of hedging malting barley?

2. What is the cost of quality risk of malting barley when hedging?

This study is based on previous studies on hedging agricultural commodities and portfolio theory. The study contributes to existing literature with a normative model for optimal hedging strategies for malting barley producers in Sweden. An optimization model is developed and an applied non-linear programming model is used to find the utility maximizing portfolios and optimal hedging strategies for two fictitious case farms. The research questions are answered using the applied optimization model.

1.4 Delimitations

As this study investigates the expected utility of grain farms it requires fictitious farms with primarily grain production. The major crop producing areas in Sweden are the plains areas Götalands norra slättbygder (Gns), Götalands södra slättbygder (Gss) and Svealands slättbygder (Ss) (1, SCB, 2018). Gss is characterized by a considerable share of seed and specialty crop production (1, SCB, 2018), and differs markedly from the other two plains areas. Therefore, this study only considers the production areas Gns and Ss as these are the major crop producing plains areas in middle Sweden.

The fictitious case farms are assumed to produce crops for commercial purpose rather than use by the grower. Investigated crops and possible crop rotations are therefore limited to the major cash crops: wheat, barley, rapeseed and oats. Feed production, specialty crop production and seed production are not considered in this study. No livestock production is assumed to take place on the case farms. The harvested grain is marketed and not used as inputs in other activities on the farm. Farms with livestock production spread manure on their fields as fertilizer. It is problematic to regulate the fertilizer level when spreading manure which often leads to over- and under-fertilization. If malting barley is not evenly fertilized the quality risk increases significantly (Pettersson, 2006).

Hedging strategies for oats are not considered in this study. It is possible to hedge oats but it is not common among Swedish producers. The considered hedging strategies are therefore limited to include milling wheat, malting barley and rapeseed.

Small and mid-sized farms are not considered in the study as diversification and off farm income significantly reduces the incentive for farmers to hedge (Pannell *et al.*, 2008). The fictitious farms are assumed to be the main source of income and the full-time work for the farmers. For both production areas, Ss and Gns, large-scale case farms of 500 hectares of crop land are developed. A total of two fictitious farms are investigated in this study.

The case farms are assumed to use conventional farming methods as there are no futures contracts available for alternative farming methods. Therefore, alternative farming methods with certified cultivation are not considered in this study.

Hedging currency exchange risk is not considered in this study. The exchange rate uncertainty can substantially effect optimal hedging behavior of offshore hedgers (Thompson & Bond, 1987). It is assumed that the offshore hedger seeks to stabilize returns in the domestic currency (SEK), and exchange rate movements are therefore relevant. This study does not deal directly with the currency exchange risk, but it is implicit in the data as the futures prices are converted into SEK using historical exchange rates. Therefore, this study only considers futures contracts traded on the European derivates exchanges Liffe and Matif (NYSE Euronext). Farmers can hedge using international exchanges outside of Europe such as CBOT (Chicago Board of Trade) and ICE, however the aspect of currency risk is further increased.

Transaction costs are not considered in this study. The direct transaction costs are not significant and the indirect transaction costs are problematic to estimate. The direct transaction costs are the trader fees of the futures exchange. Euronext's trading fees for commodity futures contracts are 0,25 EUR per lot size (2, Euronext, 2018). Which is less than 0,1 % of the value of the contracts (1, AHDB, 2018). The indirect costs of hedging is a controversial topic as they are notoriously difficult to estimate (Pannell *et al.*, 2008). Pannell *et al.*, (2008) estimated the indirect costs of hedging to be 2 % of the value of the contracts.

2 Literature review

The objective of this chapter is to provide an historical background to earlier studies within the research field of futures contracts in the agricultural sector (table 3). Moreover, this chapter provides a fundamental understanding of the existing research within the topic of this study.

2.1 Earlier studies of hedging strategies

There are several scientific articles and books about hedging of agricultural commodities, both international and Swedish. Previous research on hedging focus on economic and technical aspects of hedging.

2.1.1 International studies

Peck (1975) uses portfolio analysis to investigate how an egg producer in Illinois can utilize a hedging strategy to reduce price risk. The results shows that a hedging strategy in the egg market can significantly reduce a producer's price risk exposure (Peck, 1975). Peck (1975) finds that the optimal hedge ratio for a producer is between 75-95 % of expected production volume. Peck's analysis does not consider production risk. Peck (1975) concludes that futures market can be a useful tool to reduce income variability for producers.

Ederington (1979) outlines the three major theories of hedging: the traditional theory, the theories of Holbrook Working, and portfolio theory. Traditional hedging theory emphasizes the risk avoidance potential of futures markets. Hedgers are envisioned as taking futures market positions equal in magnitude but of opposite sign to their position in the cash market. Working argues that hedgers are profit maximisers and since hedger hold positions in both the physical and financial market they are concerned with relative and not absolute price changes. Hedging is undertaken in expectation of a change in the spot-futures price relation Working argues (Ederington, 1979). Ederington (1979) shows that it is possible to use portfolio theory as a way to integrate risk avoidance of the traditional hedging theory with Working's expected profit maximization. The application of portfolio theory can explain why hedgers hold positions both in the physical and financial markets (Ederington, 1979). Ederington (1979) defines hedge effectiveness as the percentage reduction in portfolio variance, a measure which is used in this study.

Robison & Brake (1979) find that portfolio theory and quadratic programming is a useful method to find the optimal farm plan and an improvement over previous linear programming models. Robison & Brake (1979) use a mean-variance framework to derive efficient frontiers to illustrate the set of optimal portfolio choices and they argue that movement along the curve is not a costless transition from one portfolio to another. The movement along the efficient frontier is costly due to investment decisions and asset illiquidity (Robison & Brake, 1979).

Sarris and Freebairn (1983) show that world market prices are affected by national politics and market intervention to a high degree. National policy can create instability of both domestic and international markets (Sarris & Freebairn, 1983). Such volatility in world market prices create uncertainty for all market participants and short and long term planning becomes more difficult (Sarris & Freebairn, 1983). Sarris (2009) analyses the worlds commodity markets in a more recent study and hypothesizes that volatility is likely to continue and possibly increase in the future. Staple food commodity price volatility is a major concern to those countries which are net importers and dependent (Sarris, 2009).

McKinnel *et al.* (1990) show how optimal marketing strategies for soybean producers vary between three different soybean producing states in the USA and find the most efficient risk-return hedging strategies for each of the different areas. It is found that the optimal marketing strategy varies between geographical areas and thus that it is problematic to generalize findings from one study to other areas (McKinnell *et al.*, 1990). Harvest yields and production costs are different across the soybean producing regions (McKinnell *et al.*, 1990). Therefore, the income variance associated with a marketing strategy is expected to be different across regions and the optimal risk-reducing strategies are different (McKinnell *et al.*, 1990).

Anderson and Dillon (1992) propose a classification of degrees of risk aversion which is based on the relative risk aversion with respect to wealth (equation 2). The relative risk aversion coefficient (RRAC) ranges from 0,5 (hardly risk averse at all) to 4 (extremely risk averse) (Anderson & Dillon, 1992). 1 (somewhat risk averse) is considered normal (Anderson & Dillon, 1992). The classification and range of degrees of risk aversion suggested by Anderson and Dillon (1992) is used by later researchers to make comparison between studies easier.

Brorsen *et al.* (1998) use a utility efficient programming (UEP) method to incorporate the hedger's level of risk aversion, which affects the choice of hedging strategy. Brorsen *et al.* (1998) uses a relative risk aversion coefficient ranging from 0 to 3. Brorsen *et al.* (1998) shows that the more risk averse producers are more likely to hedge and benefit more from hedging, whereas the less risk averse producers prefer to sell in the spot market. Brorsen *et al.* (1998) compares the utility of hedging hard red wheat on Chicago Board of Trade with Kansas City Board of Trade and concludes that transaction costs are a negligible factor in the optimal hedging choice.

Pennings (1998) recognize that the way in which a producer handles price risk is dependent on their risk preference. Pennings (1998) argues that decision makers are influenced by their own subjective assessment of the futures market in terms of performance and reliability. Pennings (1998) suggests that futures contracts do not remove all price risk but introduce risk themselves to hedgers.

Pannell and Nordblom (1998) study risk management in Syrian agriculture and the impact of farm size and risk aversion. Pannell and Nordblom (1998) uses a Direct Expected utility maximizing Mathematical Programming (DEMP) and UEP method. Syria is famously know for extraordinarily variability in cereal grain production, mostly due to highly variable rainfall, and risk management is an important aspect of farming (Pannell & Nordblom, 1998). The more risk averse farmers are shown to prefer more diversified crop portfolios (Pannell & Nordblom, 1998). Farm acreage is found to be an important factor influencing the optimal farm plan under risk aversion as the optimal farm plan varies significantly between the 16 hectares and the 64 hectares farms investigated. Farm-based storage is identified as a valuable strategy to manage risk.

Lien and Hardaker (2001) investigate how an optimal farm plan is affected by the degree of risk aversion and choice of utility function. Lien and Hardaker (2001) uses an UEP method to derive the optimal farm plan for farms in Norway. The results indicate that an extremely risk averse farmer would choose the same optimal farm plan as a hardly risk averse at all farmer (Lien & Hardaker, 2001). Lien and Hardaker (2001) also find that the form of the farmer's utility function has little effect on the optimal farm plan. Variability in gross margin between years for the studied crops is identified to be mostly due to variability in yield and quality.

Guo *et al.* (2013) investigates the hedge effectiveness of futures contracts of wheat, barley and canola for farmers in Western Australia. The results show that hedging on the Australian Securities Exchange (ASX) is more efficient in terms of risk reduction and utility maximization compared to hedging on Chicago Board of Trade (CBOT) and Intercontinental Exchange (ICE) (Guo *et al.*, 2013). The findings of the study by Guo *et al.* (2013) show that local exchanges are more efficient in reducing risk.

2.1.2 Swedish studies

Lidfeldt and Andersson (1994) show the benefit of using futures market to reduce risk exposure to Swedish farmers in the plains areas. Lidfeldt and Andersson (1994) accounts for production, price and currency exchange risk. The report shows that the absolute risk reduction of using hedging strategies are between 3 and 29 %. The value of the risk reduction when using hedging is between 41-85 SEK per ton (Lidfeldt & Andersson, 1994). The study finds that a combination of both futures and spot positions are most efficient in reducing risk. The optimal hedge ratio is estimated to be about 60-100 %. The result of the study by Lidfeldt and Andersson (1994) fit well with the results of previous American studies.

Ugander *et al.* (2012) study different aspects of investing in farm-based grain handling facilities. Ugander *et al.* (2012) use a QRP model to examine quantity, price and quality risk under the assumption that farmers are risk averse and seek to reduce risk. Ugander *et al.* (2012) introduces quality uncertainty and develops a method to approximate the quality risk for crop producers in the plains areas producing malting barley, milling wheat and oats. The authors use mathematical programming, qualitative interviews and analyze existing data. The probability of achieving the premium quality demands for the various cereal grains are found by interviewing knowledgeable people and crop advisors in the industry.

2.1.3 Swedish student works

Andersson and Grunér (2015) use quadratic risk programming (QRP) to find utility maximizing crop portfolios when new policy restrictions are introduced. Andersson and Grunér (2015) find that the economic result of the farm is reduced under the CAP-reform especially for the risk neutral farmers. However, Andersson and Grunér (2015) show that an optimal crop portfolio can limit the effects of the new policy restricts effect on the economic result significantly. They develop covariance matrices to model crop rotation effects using historical growing data from case farms in the plains areas Gns and Ss which have recorded their harvested yields every year. Andersson and Grunér (2015) use a method for filling in missing data on the farm level using modified regional statistical data (Andersson & Grunér, 2015).

Karlsson and Skog (2016) investigate how different hedging strategies affect the optimal crop portfolio and the economic results. They use quadradic risk programming to model crop farms in Gns and Ss and derive efficient frontiers for different hedging strategies as suggested by Iwarson (2012). It is shown that utility maximizing farmers can benefit from using hedging strategies over a spot strategy (Karlsson & Skog, 2016). Karlsson and Skog (2016) do not investigate crop rotations with malting barley nor do they consider quality risk.

2.2 Summary of literature review

The summary of the literature review's most important studies is presented in table 3. The table shows the topic, research method, geographical location and commodity. The literature review displays the width and depth of the area of research and reveals the under-researched topic of the utility of hedging malting barley under quality risk in a Swedish context.

Table 3. Overview of earlier studies within the research field of hedging agricultural commodities using futures contracts and their research methods.

Article	Topic	Method	Location	Commodity
Peck, 1975	Optimal hedge ratio	Portfolio analysis	Illinois	Egg
Ederington, 1979	Hedge effectiveness	Econometrics	USA	Treasury bill
Rolfo, 1980	Optimal hedge ratio, production risk	MOTAD programming	Ghana, Nigeria, Ivory Coast and Brazil	Cocoa
Thompson & Bond, 1987	Optimal hedge ratio, currency exchange risk	Simulation model	US and Australia	
Myers & Thompson, 1989	Optimal hedge ratio	Econometrics	USA	Winter wheat
McKinnell *et al.*, 1990	Hedging strategies	MOTAD programming	Arkansas, Illinois and South Carolina	Soybean
Myers, 1991	Optimal hedge ratio	GARCH		
Lidfeldt & Andersson, 1994	Hedge effectiveness	QRP	Europe and Sweden	Winter wheat
Brorsen et al., 1998	Cross hedging	UEP	USA	Winter wheat
Pannell & Nordblom, 1998	Risk management	DEMP/UEP	Syria	Wheat, barley, lentil, vetch and sheep
Pennings, 1998	Hedging risks			
Lien & Hardaker, 2001	Farm planning under uncertainty	UEP	Norway	Dairy, forage and grain
Ugander *et al.*, 2012	Quantity, price, and quality risk	QRP	Sweden	Grain and rapeseed
Guo et al., 2013	Hedge effectiveness	UEP	Western Australia	Wheat, barley and rapeseed

The literature review of this study outlines the research on the topic of hedging agricultural commodities using futures contracts. The literature focus on both technical and economic aspects of hedging. The literature review deals with different ways to select and evaluate hedging strategies. The technical aspects of hedging are linked to weather and the course of nature. The economic aspects of hedging mainly relate to the correlation between spot and future market prices, the hedge ratio, price risk, and production risk. The technical and economic aspects are both important when developing the theoretical framework of this study.

This study is similar to previous studies, particularly (Lidfeldt & Andersson, 1994; Ugander *et al.*, 2012; Andersson & Grunér, 2015; Karlsson & Skog, 2016). Foremost, the fundamental microeconomic calculations are similar to the earlier works. What differentiates this study from earlier works is the focus of hedging malting barley and quality risk. Non-linear programming is often used to find the optimal farm plan where expected utility is maximized for different levels or risk aversion. Earlier studies provide a deeper understanding of the empirical problem as well as providing the theoretical framework in which the results are analyzed and compared to earlier studies.

3 Theoretical framework

In this chapter the theoretical framework of the study is presented. The theories used in this study regard production economics, optimization and risk theory. The theories are used to develop the optimization model used in this study.

3.1 Applied microeconomics: Agricultural production economics

The theoretical foundation of this study is based on classical microeconomic theory (Pindyck & Rubinfeld, 2013). Microeconomics is concerned with the behavior of individual economic entities (Pindyck & Rubinfeld, 2013). Production economics is a more applied and specific area of economics and different from other areas of study. Production economics describe the complex relationships concerning biology, technology and economy, and how scarce resources are optimally utilized to achieve economic goals (Olhager, 1999).

The individual producer typically attempts to maximize profits on their farm as a means of achieving utility or satisfaction, but they may also have other goals (Debertin, 2012). Producers maximize profits given resource constraints such as land, labor and farm machinery, which limits their production function (Hardaker *et al.*, 2015). The motivation for the producer to maximize profits is that the profits can be used to purchase goods and services which provides the farmer with utility and satisfaction (Debertin, 2012). Farmers may maximize other aspects, such as the acreage of the farm as a means to achieve utility (Shapiro & Wade Brorsen, 1988).

In order for a firm to compete in the market the business strategy, products and processes, but also planning and governing must constantly be improved and developed (Olhager, 1999). To achieve a profitable business strategic, tactical and operative decisions that are congruent with each other must be made (Olhager, 1999). By evaluating different production alternatives it is possible to make decisions of which should be chosen (Edlund *et al.*, 1999).

Farmers are faced with situations with uncertain outcomes on a daily basis. Production risks stem from uncertainty about the performance of crops or livestock and the unpredictable nature of weather (Hardaker *et al.*, 2015). Crops can be damaged by hail, pests or crop disease. Thus, farming is an activity which follows the path of nature (Debertin, 2012). Also, the markets for inputs and agricultural commodities affect the farm to a high degree (Debertin, 2012). Prices on inputs and outputs are seldom known for certain at the time a farmer must make decisions about which inputs and how much to use or what and how much output to produce (Hardaker *et al.*, 2015). Market prices are largely determined by factors which the farmer cannot control and market risks are often significant (Hardaker *et al.*, 2015). Farming is thus an activity which takes place in an environment characterized by risk and uncertainty to a high degree (Debertin, 2012).

3.2 Risk theory

There are two major concepts within risk theory, risk and uncertainty. The concept of risk is fundamentally different from uncertainty. When the probability of different possible outcomes are known, the event is risky (Hardaker *et al.*, 2015). When uncertainty exists, the probabilities of the different possible outcome to occur are not known (Hardaker *et al.*, 2015). Risk and uncertainty originate from several different sources (Hansson & Lagerkvist, 2012). Agricultural decisions never have certain outcomes (Dillon, 1979).

One of the problems in dealing with risk and uncertainty is that individuals vary significantly in their willingness to assume risk (Debertin, 2012). Farmers with different personal values perceive and respond differently to risk (Dillon, 1979; Hansson & Lagerkvist, 2012). Numerous empirical studies show that most farmers are risk-averse regarding decisions affecting income and wealth (Hazell & Norton, 1986; Hardaker *et al.*, 2015). Therefore, farmers often favor farm plans which provide satisfactory levels of certainty even if this means expected income is lower on average (Hazell & Norton, 1986). If this risk-averse tendencies were to be ignored in farm planning models, the resulting farm plans would likely be unacceptable to the farmer (Hazell & Norton, 1986).

A farmer's willingness to accept risk is linked to his psychic makeup (Debertin, 2012). Hansson and Lagerkvist (2012) show that there is a significant correlation between a farmer's risk preference and the variance of income for the farm. The crucial variables affecting decision making is consumption and the accumulation of net worth or wealth (Lien & Hardaker, 2001). Both of these variables are difficult to measure for agricultural households (Pope *et al.*, 2011). The maximization of utility subject to constraints for a given level of wealth is the ultimate goal of anyone, including the farmer (Debertin, 2012).

A utility function is a mathematical function which ranks different alternatives by their utility of satisfaction to an individual (Dillon, 1979). Maximization of the utility function is the criterion by which the farmer makes decisions (Debertin, 2012). The phenomenon of risk aversion means that analysis of risky decisions and their average expected results will not always identify the course of action which will be most preferred by the individual (Hansson & Lagerkvist, 2012).

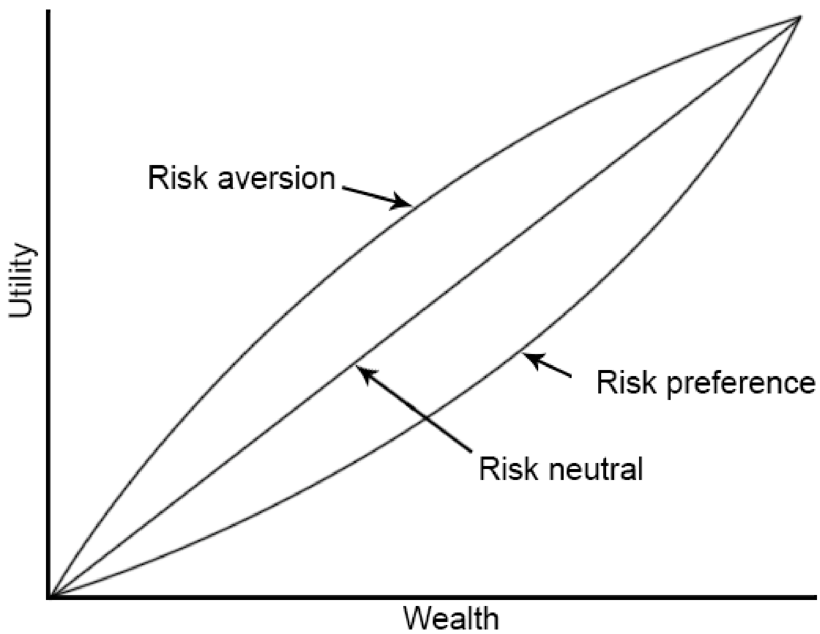

Figure 3. Risk attitudes and the shape of the utility function (Hardaker et al., 2015) (own rendering).

The utility function of a risk neutral individual has a constant slope (figure 3). The utility function of a risk averse farmer increases at a decreasing rate as income rises as it is assumed that higher expected income can only be achieved by taking on greater risks or uncertainty

(Debertin, 2012). The risk preferrer has a utility function which increases at an increasing rate as income rises (Debertin, 2012).

To calculate an individual's risk preferences their utility function (U) needs to be studied. A constant absolute risk aversion (CARA) utility function is assumed and the individuals risk preference is found (Hardaker *et al.*, 2015):

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

The relative risk aversion coefficient $\left(r_r(w)\right)$ is a product of the wealth (w) and the absolute risk aversion coefficient $\left(r_a(w)\right)$. An individual with the same absolute risk aversion coefficient as someone else will have a different relative risk aversion coefficient if their level of wealth differs. The relative risk aversion coefficient is derived when equation 1 is multiplied with the wealth (Hardaker *et al.*, 2015):

$$\mathrm{r}_r(w) = w * r_a(w) \tag{2}$$

The interpretation of the relative risk aversion coefficients are described as such (Anderson & Dillon, 1992):

$r_r(w) \approx$ 0,5 hardly risk averse at all
$r_r(w) \approx$ 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

3.3 Portfolio theory

Portfolio theory is an efficiency criterion that minimizes the expected income variance for different investment plans (Brealey *et al.*, 2017). Portfolio theory was originally intended to describe why investors diversify their portfolios of financial assets and how capital pricing is determined (Robison & Brake, 1979). Portfolio theory now has a wider application and can be used to study resource allocation, growth and financing in the agricultural sector (Robison & Brake, 1979). The decision maker can find his expected utility-maximizing solution for any given level of wealth (Robison & Brake, 1979; Hardaker *et al.*, 2015).

The allocation of resources to specific production activities is significantly influenced by risk factors (Pope *et al.*, 2011). Risk is generally modelled using variances and covariances (Brealey *et al.*, 2017). An increase in the variance of price or revenue in a crop often leads to a reduction in the acreage allocated to that specific crop (Pope *et al.*, 2011). This effect is the result of risk aversion.

The process of selecting a crop portfolio can be divided into two stages. The first stage of selecting a portfolio is to look at historical data and available information to make predictions about future performances of the different assets (Brealey *et al.*, 2017). The second stage is to choose a portfolio based on the beliefs and predictions derived from the first step (Brealey *et al.*, 2017). The general rule is that expected return is a desirable thing while variance of expected return something undesirable to the investor (Markowitz, 1952). Through choosing a diversified portfolio an investor can find a better portfolio to all non-diversified portfolios (Markowitz, 1952). It is important to note that most farmers begin decision periods having already allocated most of their resources already (Robison & Brake, 1979).

Covariance is a measure of the degree two activities covary (Brealey *et al.*, 2017). It is expected that related stocks have a positive covariance (Markowitz, 1952). If the prospects of two activities were unrelated the covariance would be zero, and if the activities were to move in opposite directions the covariance would be negative (Brealey *et al.*, 2017). The covariance of expected return is defined as (Brealey *et al.*, 2017):

$$cov(x_i, x_j) = \sum[(\tilde{x}_i - \overline{x}_j)(\tilde{x}_j - \overline{x}_j)] \quad (3)$$

The risk of a portfolio with two or more assets can be calculated with respect to the covariance of the assets. Say that a farmer produces two outputs, x_i and x_j, and both outputs have income variability due to price and production risk. The income variability of x_i is $x_i^2\sigma_i^2$ and the income variability of x_j is $x_j^2\sigma_j^2$. The income variability of one output is affected by the other output by the properties of covariance. The interaction term from covariance to income variability is $2(x_i x_j cov_{ij}\sigma_i\sigma_j)$ (Debertin, 2012; Brealey *et al.*, 2017). The income variability (δ) of a two-asset portfolio is found by (Brealey *et al.*, 2017):

$$\delta = x_i^2\sigma_i^2 + x_j^2\sigma_j^2 + 2(x_i x_j cov_{ij}\sigma_i\sigma_j) \quad (4)$$

This method for calculating portfolio variance can be extended to portfolios of three or more assets (Brealey *et al.*, 2017). The weight of an asset (σ_j^2) is square of the proportion invested in that specific asset (Brealey *et al.*, 2017).

Diversification has been used by farmers for a long time as a strategy to manage uncertainty arising from both price and production uncertainty (Debertin, 2012). A diversification strategy is based on the idea that profits from one activity within the enterprise can offset losses in another activity within the same enterprise. Diversification may have the additional effect of utilizing labor and fixed capital more efficiently over the course of the year, and thus increasing income (Debertin, 2012). To effectively deal with income variability, the enterprise must diversify into activities which move opposite to each other (Debertin, 2012).

3.3.1 Mean-variance analysis

A mean-variance analysis is a mathematical framework for combining portfolios of assets so that the expected return is maximized for any given level of risk. The expected return-variation criterion assumes that the farmer's optimal choice of possible crop portfolios consists of expected return (E) and variance of expected return (V). This is referred to as the mean-variance decision rule and is calculated as follows (Hazell & Norton, 1986):

$$E = \sum_{j=1}^{n} x_j \overline{ER}_{jf} \quad (5)$$

$$V = \sum_{i=1}^{m}\sum_{ij=1}^{n} x_i x_j cov_{ijf}(ER_{jf}, ER_{if}) \quad (6)$$

A mean-variance analysis can be used to measure yield variation for different crops or the expected return of hedging strategies (Hardaker *et al.*, 2015). To model a selected hedging strategy both the expected return and variance of expected return needs to be included in the objective function (Thompson & Bond, 1987). A mean-variance framework is therefore suitable when evaluating different possible hedging strategies (Thompson & Bond, 1987). It is more convenient to determine the set of mean-variance efficient portfolios than it is to find the individuals preferred portfolio which maximizes his utility (Hardaker *et al.*, 2015). It is assumed that a point on the mean-variance efficient frontier can yield the maximum expected utility. Expected return $\left(E(R_j)\right)$ and variance of expected return$\left(var\left(R_j\right)\right)$ of a crop j can be calculated using historical data over a number of time periods (Wahlin, 2011):

$$E(R_j) = \frac{\sum_{j=1}^{n} R_j}{\text{n}} \tag{7}$$

$$var\left(R_j\right) = \sigma_j^2 = \frac{\sum_{j=1}^{n}\left[(\tilde{R}_j - \overline{R}_j)^2\right]}{n-1} \tag{8}$$

The major disadvantage of a mean-variance framework is that it assumes that a producer has constant absolute risk aversion and only makes decision based on expected return and variance of expected return (Rolfo, 1980). These assumption are criticized for being unrealistic (Rolfo, 1980; Lien & Hardaker, 2001). A realistic farm planning model ought to account for an individual farmer' subjective beliefs about the probabilities of uncertain events and for the risk preferences regarding those events, reflecting the farmer's degree of risk aversion (Lien & Hardaker, 2001). However, Lien and Hardaker (2001) find the form of the farmer's utility function to have little effect to the optimal farm plan. Therefore, a mean-variance analysis is a good alternative to UEP with a utility function characterized by decreasing absolute risk aversion. Another limitation of the mean-variance analysis is that not all decision makers can find their preferred farm plan in the efficient mean-variance set (Robison & Brake, 1979).

An optimal hedge ratio is defined as the proportion of a cash position that should be covered with an opposite futures position (Myers, 1991). An optimal hedging ratio can be anywhere between 0-100 % (Peck, 1975; Rolfo, 1980; Lidfeldt & Andersson, 1994). The OHR-formula is perhaps the most common method used to estimate the optimal hedge ratio. Historical spot market prices are compared to future market prices (Myers, 1991). The optimal hedge ratio (h^*) when production risk is considered is found by (Andersson & Lidfeldt, 1994):

$$\max h \left[\bar{P}_{s1} * \bar{Q}_1 + h\left(P_{f_0} - \bar{P}_{f_{t1}}\right)\right] - \frac{r_a}{2}\begin{bmatrix} var(\bar{P}_{s1} * \bar{Q}_1) + h^2 * var\left(\bar{P}_{f_1}\right) \\ -2 * h * cov\left(\bar{P}_{s1} * \bar{Q}_1, \bar{P}_{f_{t1}}\right) \end{bmatrix} \tag{9}$$

$$h^* = \frac{cov\left(P_{s1} * Q_1, P_{f1}\right)}{var(P_{f1})} + \frac{P_{f0} - P_{f1}^e}{r_a * var\left(P_{f1}\right)} \tag{10}$$

where:
h = expected harvest quantity sold in the futures market
h^* = optimal hedge ratio as a percentage of expected harvest quantity
P_{s1} = spot market price at time of sales $t = 0$
Q_1 = quantity for delivery in spot market
P_{f0} = 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 $t = 1$
$var(\bar{P}_{f_1})$ = variance of futures market price
$var(P_{s1})$ = variance of spot market price
$cov(P_{s1} * Q_1, P_{f1})$ = covariance of expected return and futures market prices at time $t = 1$

On a market where everyone has the same information the second term of equation 10 equals zero as no one can predict the futures price at time $(t = 1)$ better than anyone else. Thus, $(P_{f0} - P_{f1}^{e})$ equals zero. The optimal hedge ratio is therefore calculated by dividing the covariance between spot market and futures market prices $\left(cov(P_{s1} * Q_1, P_{f1})\right)$ with the variance of the futures market prices $\left(var(\bar{P}_{f_1})\right)$. The quantity to be delivered in the spot market (Q_1) is unknown at the time $(t = 1)$ when futures contracts are sold, signifying the production risk. The optimal hedge ration when production risk is considered is therefore calculated as follows:

$$h^* = \frac{cov(P_{s1} * Q_1, P_{f1})}{var(P_{f1})} \tag{11}$$

The implications of using the OHR-formula or other similar formulas is that is none of them is a good general rule except for in special circumstances (Myers & Thompson, 1989). The hedging ratio ought to be estimated with respect to the type of problem facing the decision maker (Myers & Thompson, 1989) In the case of agricultural commodities the OHR-method fails to consider production and quality risk (Rolfo, 1980; Lidfeldt & Andersson, 1994).

The futures markets' risk reduction potential can be measured using portfolio theory (Ederington, 1979). Hedge effectiveness is measured by comparing the risk of an unhedged portfolio with the minimum risk that can be obtained of a portfolio containing both spot and futures contracts (Ederington, 1979):

$$\theta = 1 - \frac{\text{var}(P_f)}{\text{var}(P_s)} \tag{12}$$

where:
(θ) = the percentage reduction in the variance of income

3.4 Quadratic risk programming: the efficient frontier

A common application of mean-variance analysis is to make normative decisions about a combination of risky assets, such as an investor's stock portfolio or a farmer's farm plan (Brealey *et al.*, 2017). With one or more constraints on the objective function, such as land, labor and capital constraints on a farm plan (and if the possible levels of the components of the portfolio are continuous), the set of feasible farm plans forms a convex set in the mean-variance space (figure 4). The optimal farm plan is found on the efficient mean-variance boundary in point P where the iso-utility curve (U_2) meet the efficient frontier.

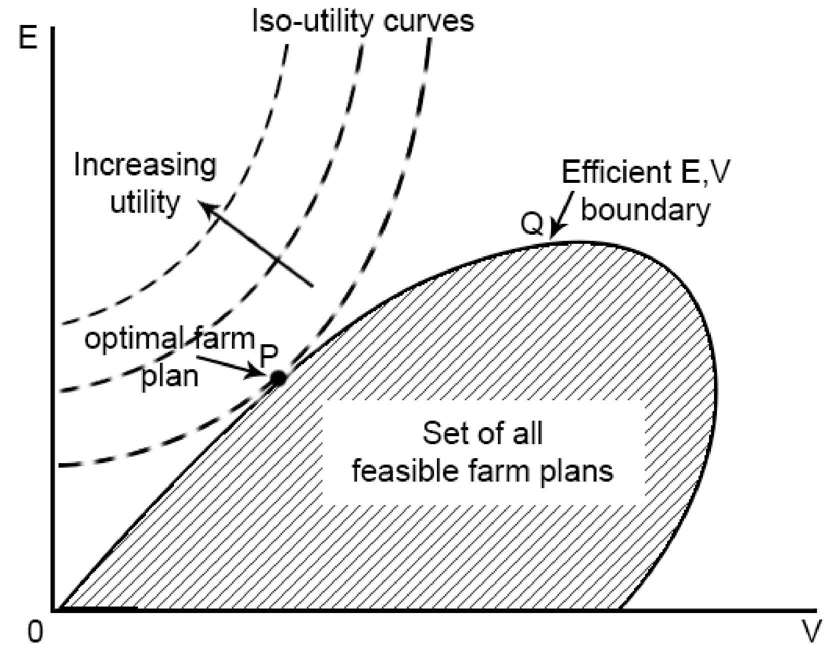

Figure 4. The efficient mean-variance boundary and optimal farm plan (Hazell & Norton, 1986) (own rendering).

The efficient frontier comprises the mean-variance efficient set and can be calculated using quadratic risk programming (QRP) (Hardaker *et al.*, 2015). QRP is a form of non-linear programming (Hardaker *et al.*, 2015). QRP in this study is used to maximize the certainty equivalent (CE). The certainty equivalent is defined as the certain income that a person would be indifferent to accept for his uncertain income (Hardaker *et al.*, 2015). The certainty equivalent can be found using QRP (Hardaker *et al.*, 2015):

$$CE = E - 0{,}5 r_a V \quad (13)$$

Efficient frontiers are derived using the core principles of a mean-variance analysis. The decision maker is assumed to have a CARA utility function and stochastic variables are assumed to be multi-normally distributed unless otherwise stated.

All farm plans are subject to risk and uncertainty and no farm plan has a known income (Hazell & Norton, 1986). In the mathematical optimization context, the actual outcome depends on the realized values of all the crops in the portfolio (Hazell & Norton, 1986). The farmers decision making problem lies in the need to rank all possible farm plans based on their expected return distribution, and thereafter select the farm plan that best meets his goals (Hazell & Norton, 1986). For any two alternative farm plans put before him, he needs to be able to determine which one of the two which he prefers (Dillon, 1979).

3.5 Motivation of theories

The purpose of this study is to find the expected utility of hedging malting barley using futures contracts and the cost of quality risk for different levels of risk aversion. There are many alternative programming models for farm planning under risk (Lien & Hardaker, 2001). MOTAD (Minimization of Total Absolute Deviations) model is a method for including risk in the objective function (Hardaker *et al.*, 2015). The MOTAD method is a simplified version of QRP and uses linear programming (McKinnell *et al.*, 1990). Previous studies have used this method (Rolfo, 1980; McKinnell *et al.*, 1990). In MOTAD programming the variance restriction of the QRP model is substituted for a restriction on the mean absolute income variance (Hardaker *et al.*, 2015). This allows the objective function to be solved using linear programming instead of non-linear programming. However, the profit target is problematic to decide which can negatively affect the optimization (Hardaker *et al.*, 2015). Quadratic programming models are more useful when determining the optimal farm plan as production is often non-linear and harvest yield variance is at least as important as price variance (Robison & Brake, 1979). Since MOTAD is a simplification of QRP and requires the target to be defined it is not as well suited as the QRP method for the purposes of this study.

The utility-efficient programming (UEP) model could have been used if the subjective utility function of the farmers was known. UEP is an approach used in similar studies (Brorsen *et al.*, 1998; Pannell & Nordblom, 1998; Lien & Hardaker, 2001; Guo *et al.*, 2013). This model is suitable to use given a programming problem under risk and knowledge about the decision makers risk attitude and utility function (Hardaker *et al.*, 2015). Each farmer's subjective probabilities about risky choices and uncertain outcomes ought to be accounted for when planning a realistic farm plan (Dillon, 1979; Lien & Hardaker, 2001). As the nature of the farmers true utility function in study is unknown UEP modelling is not appropriate to use in this study.

The hedge effectiveness measure by Ederington (1979) allows for measurement of risk exposure when hedging different crops at certain hedge ratios. The QRP model allows for measurement of the cost of risk and comparison to be made for the different investigated strategies (McKinnell *et al.*, 1990). The QRP model can additionally be used to find the optimal crop rotations for the different marketing strategies for various levels of risk aversion, and thus the expected utility maximizing crop rotational effects can be studied.

4 Method

This chapter describes the chosen research strategy and design of this study. A literature review was conducted in order to determine relevant theories and narrow down the methodological alternatives. Finally, the decisions leading up to the chosen methodology are explained and motivated.

4.1 Research strategy

When choosing research approach there are traditionally two options, quantitative and qualitative (Bryman & Bell, 2015). These two different methodological approaches regard how the empirical data collection is devised and the analyses implemented. In the quantitative approach the quantification in the collection and analysis of data is emphasized (Bryman & Bell, 2015). The hope is that many observations of a sample can be used to find out what is true for the entire population (Bryman & Bell, 2015). The quantitative method is suitable for objective measurements and the numerical analysis of data. The goal of quantitative studies is to determine the relationship between independent variables and another dependent variable within a population (Stake, 1995). Quantitative research designs can be descriptive or experimental. A descriptive study only establishes a relationship between variables whereas an experimental study determines the causality (Stake, 1995). The objective of this study is to analyze secondary numerical data using computational techniques. The study uses a quantitative method with an experimental design and a deductive approach (Bryman & Bell, 2015).

Ontology and epistemology are two different aspects of a research philosophy. Ontology is the study of what is, while epistemology is the theory of knowledge (Bryman & Bell, 2015). Quantitative methodology is a research strategy that mainly has an epistemological orientation that is from the natural sciences, particularly positivistic, and an ontological orientation that is mainly from objectivism (Bryman & Bell, 2015). In the positivist approach the researcher believes himself to be purely objective and independent of the research. The epistemological position of this study leans more towards critical realism. Critical realism recognizes the reality of the natural order and the events of discourses of the social world (Bryman & Bell, 2015). Critical realists accept that categories they use to understand reality are likely to be temporary and provisional (Bryman & Bell, 2015). Critical realists, unlike positivists, include theoretical terms that are not directly amenable to observation (Bryman & Bell, 2015). As a result, hypothetical entities to account for regularities in the natural or social orders are admissible for realists, but not for positivists (Bryman & Bell, 2015). The critical realist approach in this study can for example be seen in the fact that psychic makeup of the decision maker through subjective beliefs and attitudes towards risk are the foundation of the objective function which maximizes expected utility and not expected profit.

The most important condition for differentiating between various research strategies is identifying the type of research questions which are being asked (Yin, 2009). The exploratory case study is a research strategy which is suitable if the research question is of the “what?” nature. When we want to find “what” the possible outcomes of a scenario are, this can be done either by performing a survey or examining economic data (Yin, 2009).

A case study is a research design which 1) investigates a phenomenon within its real-life empirical context, when 2) the phenomenon and its context have no clearly distinguishable boundaries (Yin, 2009). The objective of a case study design is to reveal the nature of its kind (Bryman & Bell, 2015). Case studies primarily aim to understand the particular case and do not aim to understand other cases (Stake, 1995). A typical or representative case may work well when we want to understand other cases as well (Stake, 1995). This study uses fictitious case farms which are designed to be typical for the respective production area and farm size. The case study research design can be used to explore situations in which the factor being evaluated does not have a clear set of outcomes (Yin, 2009). When there is a need for a general understanding and studying a particular case may provide insight into the question being studied. The case study is instrumental to understand other cases than the particular case being examined (Stake, 1995). Some examples of previous case studies within the field of hedging is (Peck, 1975; Lidfeldt & Andersson, 1994; Pannell & Nordblom, 1998; Lien & Hardaker, 2001; Ugander *et al.*, 2012).

The case study strategy is criticized by several researchers (Stake, 1995; Yin, 2009). The greatest concerns relate to the scientific rigor and the external validity of the case study (Yin, 2009). Case study research investigators have been criticized for allowing biased views and misleading evidence to influence the findings (Yin, 2009). It is therefore important that the case study researcher works hard to report all empirical result in a fair and unbiased way in order to achieve scientific rigor (Yin, 2009). The second common concern is the external validity or generalizability of case study research (Yin, 2009; Bryman & Bell, 2015). Case studies of single cases are problematic to apply to other cases (Bryman & Bell, 2015), and are only generalizable to the theoretical proposition (Yin, 2009). Some writers on case study research give plenty of attention to addressing these issues, like Yin (2009), while other writers like Stake (1995) barely mention them (Bryman & Bell, 2015).

4.2 Research design

The research design is the logical sequence that connects the empirical data collected in the study to the initial research questions, and ultimately the conclusions which can be drawn from the study (Yin, 2009). The research design dictates the generalizability of the study and defines if the results are generalizable to a larger population or different situations.

Previous studies are used as a framework for this study (Lidfeldt & Andersson, 1994; Pannell & Nordblom, 1998; Lien & Hardaker, 2001; Ugander *et al.*, 2012; Karlsson & Skog, 2016). Researchers often want to obtain empirical results in a format which allows for comparison to previous research (Yin, 2009). Thus, earlier studies may provide a rich theoretical framework and can be used to design a the case study and define the unit of analysis (Yin, 2009). This is why this study uses a narrative literature review and identifies similar previous studies as a basis from which to design the cases and to develop the optimization model. The theoretical framework resulting from the literature review is used to empirically evaluate the simulations performed using the historical market data. The purpose of this study is to investigate how future contracts can be used by Swedish grain producers to maximize their utility with consideration to degrees of risk aversion.

Fictitious case farms are modelled based on empirical data collected from the crop advisory firms Lovang Lantbrukskonsult and Växtråd. The case farms from which the data is collected by the crop advisory firms are large-scale crop farms with cereal grain and oilseed production.

The case farms are located in the mid-Sweden plains areas which are production areas with mostly crop production and limited livestock production. The case farms have no livestock production. One case farm is located in the production area Gns and one in Ss. Both case farms have an acreage of around 500 hectares. An in-depth background to the fictitious case farms based on the data provided by Lovang Lantbrukskonsult and Växtråd is provided in chapter 5.

In a study with a multiple-case study design the generalizability of the results is higher since the study is based on multiple cases (Bryman & Bell, 2015). If a pattern of results are found for the multiple cases this would provide more substantial support for theoretical replication (Yin, 2009). This study only investigates two fictitious cases with the purpose of evaluating how hedging strategies and quality risk affect the utility of these two fictitious case farms based on choice of hedging strategy, crop portfolio and level of risk aversion. One justification for selecting a two-case design over a multiple-case design is that the two cases represents the critical test of a significant theory (Yin, 2009). The two cases investigated in this study are intended to be typical and representative for the populations.

4.3 Narrative literature review

This study's literature review uses a narrative approach. The narrative literature review means that the researcher reads and presents the key articles and books by some of the major researchers within the field (Bryman & Bell, 2015). The purpose of the narrative literature review is to provide the researcher with a deeper understanding of the subject and develop sharp and insightful questions about the topic (Yin, 2009).

The literature search is conducted using the search engines Google Scholar, SLU's Primo and Web of Science. The literature search is based on the key words: hedg*, malting barley, optimal hedge ratio, risk, strateg*, utility. Literature is additionally found through being referenced in articles which are of particular interest.

The purpose of the literature review is to link the research questions, findings and analysis and discussion to the previous literature as a way of demonstrating the credibility of this study and show the contribution which is attempts to make (Bryman & Bell, 2015). The literature review of this study also serves to validate the empirical findings of the optimization model.

4.4 Applied quadratic risk programming

4.4.1 Optimization process

The optimization process consists of numerous steps (figure 5) in order to analyze a problem formulation of a decision making problem in a given situation (Lundgren *et al.*, 2001). Firstly, the empirical problem is identified from reality as an optimization problem (Lundgren *et al.*, 2001). Secondly, the problem is formulated. The problem is formulated mathematically in an optimization model (Lundgren *et al.*, 2001). Thirdly, the problem is solved using a solving algorithm. Finally, the results are interpreted and evaluated.

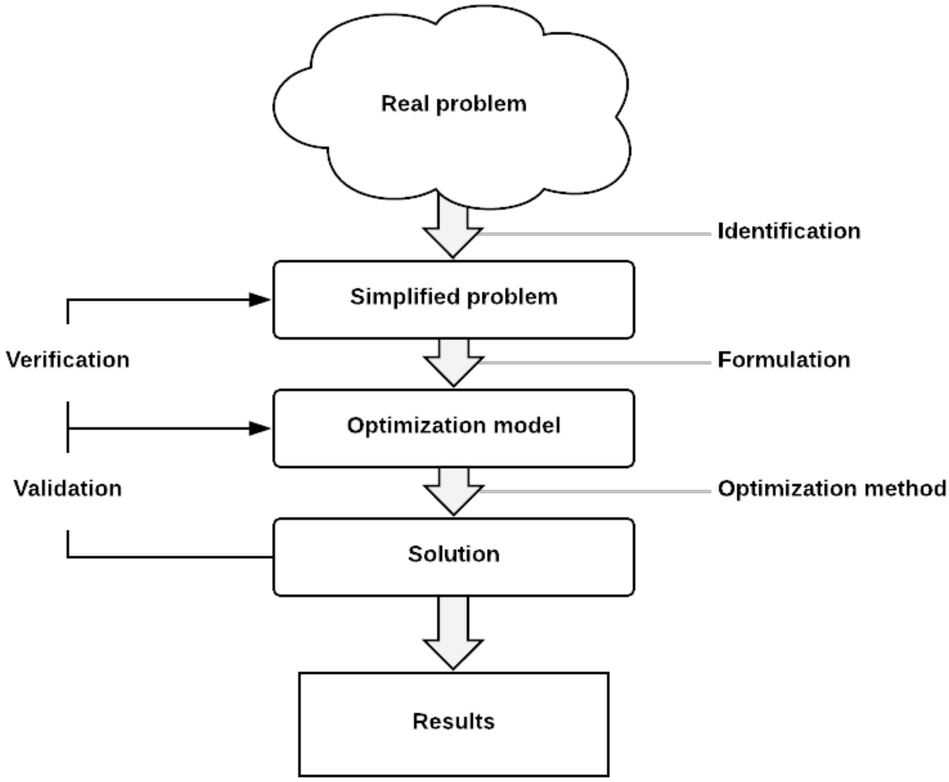

Figure 5. Schematic illustration of the optimization process (Lundgren et al., 2001) (own rendering).

The empirical problem is often characterized by a high level of complexity and contains a number of factors which are not possible or desired to include in the model (Lundgren *et al.*, 2001). The optimization problem is a simplified form of the empirical problem (Lundgren *et al.*, 2001). The simplified problem is formulated as a mathematical problem in an optimization model. Even after the mathematical problem has been formulated it may be necessary to make further delimitations and simplifications in the optimization model (Lundgren *et al.*, 2001). The solution must be validated and verified before it is used as normative information in a decision making progress (Lundgren *et al.*, 2001). The results of a study can be validated by comparing them to earlier studies and by interviewing knowledgeable individuals in the industry.

The efficient set of crop portfolios for different marketing strategies and different levels of risk aversion can be found using quadratic programming when expected return, variance of expected return and covariance of expected returns between crops are known (Hardaker *et al.*, 2015). The target function is solved using an algorithm. The algorithm used in this study is the generalized reduced gradient method which tracks and finds optimum points where the slope of the partial derivative is equal to zero. These are global maximum points where the optimal solutions are found. The results are confirmed and validated through comparison to existing theory and previous studies (Lidfeldt & Andersson, 1994; Lien & Hardaker, 2001; Ugander *et al.*, 2012; Hardaker *et al.*, 2015).

4.4.2 Restrictions

General conditions are developed and adapted to empirical use in the optimization model from the available data (Pope *et al.*, 2011). The restrictions in the model are of four categories. Land specific, crop rotation specific, storage specific and marketing strategy specific (figure 6).

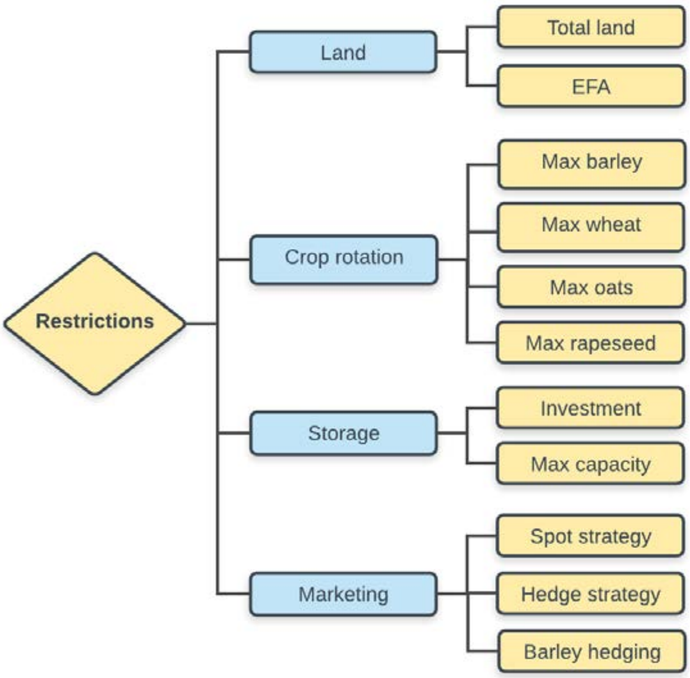

Figure 6. Schematic illustration of the restrictions used in the optimization model (own rendering).

The first category of restriction relates to land. The total acreage of the farms (500 ha) is the maximum land restriction. A minimum share of 5 % of total land (25 ha) is required to be ecological focus area in order to qualify for greening payments (1, SJV, 2018). The ecological focus area in this model is defined as fallow land.

The second category of restrictions is concerned with the crop rotation (table 4). The crop rotational restrictions used in this model are devised to illustrate actual conditions of Swedish crop production (Fogelfors, 2015). The restrictions define the maximum share of cultivated land which can be dedicated to: spring barley, winter wheat and rapeseed. Oats and fallow land are not subject to restrictions. It is assumed that winter wheat is restricted to 40 % of total land due to the time aspects of fall planting (Fogelfors, 2015). Spring barley is restricted to 40 % of total land. The crop rotation restrictions of winter wheat and spring barley in this study are the same as Ugander *et al.* (2012) used to make comparison easier. Rapeseed is restricted to $16,\overline{6}$ % of total land. If rapeseed is grown more often than every 4-6 years on the same field the risk of crop diseases significantly increases (Fogelfors, 2015).

Table 4. Crop rotational restrictions, maximum allowable share of total land for each cash crop.

Crop	Maximum share of total land
Winter wheat	40 %
Spring barley	40 %
Rapeseed	$16,\overline{6}$ %

The share of cereal grains should preferably not exceed the share of on non-cereal grains in the cropping system, which is often not realistic (Fogelfors, 2015). The fictitious case farms are therefore characterized by some monoculture much like actual crop farms in these production areas.

The third category of restrictions are related to storage. The maximum capacity of the farm-based grain storage facility limits the volume of grain that can be stored on the farm. This restriction is non-binding as the modelled farm-based storage facility has a maximum capacity that exceeds the expected total yield. The fourth category relates to the marketing strategy restrictions. These restrictions are used to define the marketing strategies with different hedging ratios.

4.4.3 Mathematical optimization

Mathematical optimization is used to maximize the utility function of the applied quadratic risk programming model. Optimal hedging strategies are simulated under varying levels of risk aversion in the model. The economic result of the farm is weighed against the associated risk through a utility function with respect to the risk preferences of the decision maker to obtain the certainty equivalent maximum. The results yield the expected return and standard deviation of expected return which are used to plot the efficient frontiers. The efficient frontiers show the optimal farm plans for when the farmer maximizes expected utility.

Quadratic function of certainty equivalent which is maximized:

$$max\ CE = \left[\sum_{j=1}^{n}\sum_{s=1}^{o} x_{js}\overline{ER}_{js} - 0{,}5r_a \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{s=1}^{o} x_{is}x_{js}cov_{is,js}\left(ER_{is}, ER_{js}\right)\right] \qquad (14)$$

subject to restrictions:

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

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

where:
x_{js} = acreage of crop j using marketing strategy s
$\overline{ER}_{js}$ = expected return of crop j using marketing strategy s
$cov_{is,js}\left(ER_{is}, ER_{js}\right)$ = covariance of expected return of crop j and crop i using marketing strategy s
a_{ij} = usage of resource r for crop j
b_i = availability of resource r

4.5 Validity and reliability

In order for a study to be legitimate and trustworthy it is important with quality assurance Bryman & Bell, 2015). This can in part be done by evaluating and discussing the validity and reliability of the study. Sveral authors have discussed these concepts (Stake, 1995; Yin, 2009). Generalizability, personal views of the research investigator and the case studies verifiability are some common criticisms (Bryman & Bell, 2015). Yin (2009) argues that the scientific rigor and bias of case studies is a common problem and proposes a wide range of preventative actions to handle these shortcomings in the case study research design.

In a case study the investigator must maximize the quality of the research design in three aspects, 1) construct validity, 2) external validity and 3) reliability (Yin, 2009). Theoretical validity is about measuring the correct thing in an empirical study (Bryman & Bell, 2015). In this study the expected utility of different marketing strategies is compared with consideration of different risk sources depending on the level of risk aversion. This study uses a mean-variance framework and QRP to derive the efficient frontiers. This method is suitable to measure expected return and the variance of the expected return (Hardaker *et al.*, 2015). Earlier studies have used the same method and theoretical framework to analyze risk sources in agriculture (McKinnell *et al.*, 1990; Lidfeldt & Andersson, 1994; Ugander *et al.*, 2012), as well as in some student works (Andersson & Grunér, 2015; Karlsson & Skog, 2016).

Internal and external validity are the two aspects of validity. Internal validity is concerned with if there is a strong correlation between the researcher's observation and the theoretical ideas and models the researcher develops (Bryman & Bell, 2015). The internal validity of this study concerns if expected utility maximization actually measures how the different hedging strategies affects the expected utility or satisfaction of the individual farmer. Expected utility theory is used instead of profit maximization to better reflect reality.

Generalizability, also referred to as external validity, is concerned with whether the results of a study can be generalized beyond the specific research context and applied to the larger population (Bryman & Bell, 2015). When conducting a case study with relatively few cases there is a risk of the results not being representative for the population and the results may be misleading. The results of this study are based on only two cases and are therefore problematic or difficult to generalize to other cases or situations (Yin, 2009).

Reliability is how trustworthy a study is considered to be (Bryman & Bell, 2015), if the same study is repeated by another researcher the same results should be found (Stake, 1995; Yin, 2009). The goal of reliability is to minimize the risk of biases and errors occurring in a study (Yin, 2009). The reliability of this study should be considered high as the collected secondary data is historical numerical data available from many independent sources. Hence, if subsequent researchers follow exactly the same procedures as described and conduct the same case study once again, the latter researchers will arrive at the same findings and conclusions (Yin, 2009). Additionally, the historical harvest data recorded by the crop advisors are more likely to be accurate than if the farmers themselves reported their harvest yields (Murphy *et al.*, 1991). Farmer's estimates are fairly accurate but requires supervision as sometimes farmers deliberately overestimate or underestimate field and farm level harvest yields (Murphy *et al.*, 1991).

4.6 Ethical considerations

Consideration of ethical aspects is of importance when doing a research project (Yin, 2009). It is important for researchers to be truthful with how empirical data is used and how findings are presented (Bryman & Bell, 2015). The researcher should be aware of the problem of allowing his or her own personal views and feelings affect the research and make an effort to minimize this problem (Bryman & Bell, 2015). It is a problem presented to all researchers to some degree. The researcher cannot be completely objective as he or she choose the research question(s), what analysis is conducted, the sample, how the results are measured, and most importantly what results to report (Bryman & Bell, 2015). Nevertheless, it is important to not let private opinions or norms influence the interpretation of the results (Yin, 2009).

This study relies on data from experts within the industry. The experts are initially contacted via telephone. The experts are given a short background to the study and a description of the data which the study needs from them and asked if they want to contribute. If the participants choose to contribute with data they are subsequently sent a comprehensive project description of the study. All contacted experts chose to contribute to this study. The data provided by the participants is not shared with anyone.

5 Background to the empirical study

In this chapter information concerning the background to the empirical study is presented. The purpose of this chapter is to provide an understanding of the choices made to simplify the empirical problem and build the optimization model.

5.1 Case farms

The fictitious case farms are parameterized to reflect typical growers in the malting barley producing regions. The fictitious case farms are designed to be representative for large-scale crop farms in the production areas Gns and Ss.

Secondary data from a wide range of sources are used to design the fictitious case farms. Data is collected to model the fictitious case farms, the farm specific yield risk, market price risk, quality risk, farm-based grain storage investment cost, production cost and marketing strategies.

The fictitious case farms are largely based on data collected from the crop advisor consultant firms. The crop advisors keep record of the crops yields of the farms consistently over the time period for this study. Växtråd provide data for Ss (pers. comm., Lagerholm, 2018) and Lovang Lantbrukskonsult the data for Gns (pers. comm., Lovang, 2018).

The fictitious case farms are assumed to be large-scale crop farms and the main source of income for the farmer. To statistically analyze the population of crop farms in the examined production areas a set of requirements are defined and statistical data is requested from the Swedish Board of Agriculture. 1) crop farming is the full-time job and the main source of income for the farmer, 2) the farm has no significant livestock production. 3) A minimum of 150 hectare cereal grain and rapeseed is grown. At least 75 % of the total acreage is allocated to cereal grains and oilseeds. The acreage distribution of the farm meeting the defined requirements are shown in figure 7 (pers. comm., Olsson, 2018).

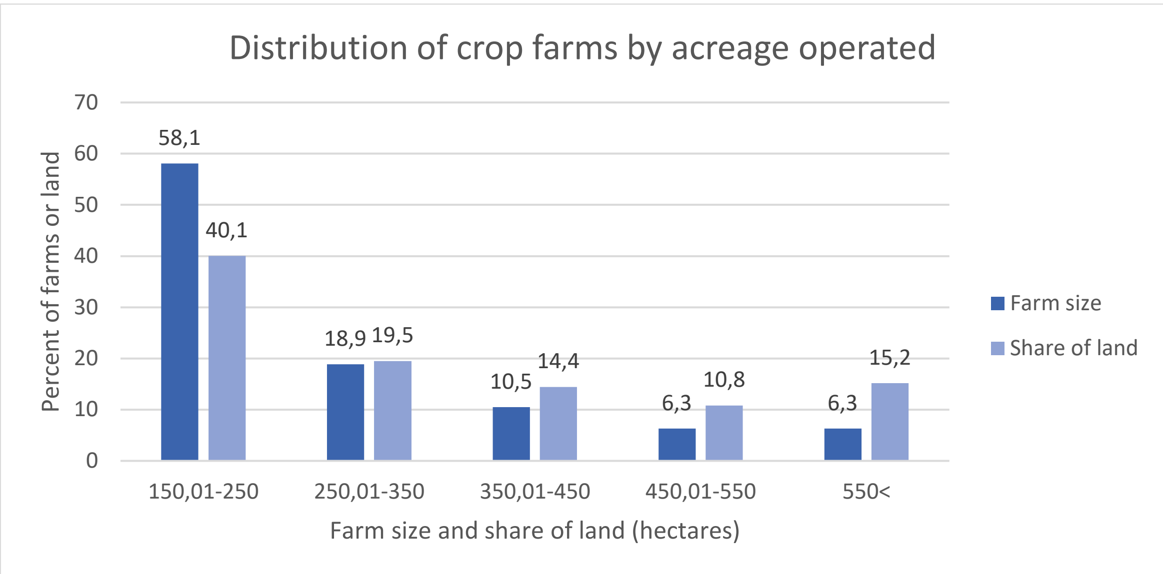

Figure 7. Distribution of crop farms by farm size and acreage operated (pers. comm., Olsson, 2018) (own rendering).

The acreage of the fictitious farms is chosen by examining the statistics (figure 8) and studying the literature. Westlin *et al.* (2006) describe the economies of scale effects to be significant for farms between 100-500 ha, and more limited between 500-1000 hectares. The crop farms which are larger than 450 hectares represent 12,6 % of the population and operate 26,0 % of the cropland in the population (figure 8). Considering that we want to investigate large-scale farms and 500 hectares is in the span where economies of scale are achieved and this is also the size of the case farms. A 500 hectare farm can also be representative for larger farms. Therefore, the fictitious case farms are defined as an acreage of 500 hectare.

The farm wealth factor is derived by analyzing data from the annual *Farm Economics Survey* (2009-2016) reports from the Swedish Board of Agriculture for the years 2009 through 2016 (SJV, 2018). A Norwegian study by Lien and Hardaker (2001) use farm equity as a measure of wealth. The average farm equity in the plains areas for mid Sweden is approximated to be 1 260 000 SEK using the method by Lien and Hardaker (2001) and assuming that 50 % of the land is rented. The wealth factor is assumed to be the same for both case farms.

5.2 Quantity risk

Quantity risk is a farm-specific phenomenon which is caused by myriad of factors such as pests, crop disease and weather (Pennings, 1998). To forecast the size of the harvest is an impossible task to the farmer (Dillon, 1979; Rolfo, 1980). During the preharvest period the yield to be realized is assumed to be unknown (Rolfo, 1980). After harvest all uncertainty is resolved (Debertin, 2012).

Quantity risk is modelled by analyzing *ex ante* distributions of harvest yield from the case farms. Historical data from the case farms is analyzed for the time period 2009-2017 and used to determine the expected harvest yield, the variance of the expected yield and also the covariance of the gross margins of the different crops in a covariance matrix (appendix 1). The correlation coefficient matrix is used to calculate the portfolio variances for various possible crop rotations.

Historical harvest data is collected from two sources: the case farms, and aggregate regional data. The case farms data is provided by crop advisors consultant firms. Aggregate data from Statistics Sweden are used as the aggregate regional data (1, SCB, 2018). The historical growing data from the case farms is mostly complete but there are some gaps. Missing data can be indicative of that it is not applicable (Bryman & Bell, 2015). In the case of farm harvest yield historical data, some crops are not grown or recorded every year.

An important issue when managing data is how to handle missing data (Bryman & Bell, 2015). Missing data creates a problem when deriving the covariance matrices for the fictitious case farms. Where there are gaps additional data from an aggregate level has been used to fill the gaps. The gaps are filled using aggregate growing data for the production areas (1, SCB, 2018). The aggregate data is used to substitute missing values using a compensating factor. The compensating factor (δ^{FP}) is calculated by applying the method used by Cooper *et al.* (2009). The method is used to find the ratio of standard deviation of farm level yield to production area level yield (Cooper *et al.*, 2009). This is because yield variability is lower at aggregate levels, due to the so called aggregation bias (Finger, 2012).

The aggregate data from Statistics Sweden is standardized by subtracting the average yield from the yearly observations (Cooper *et al.*, 2009). The resulting series show the variation in yield with the average of zero. The standard deviation can then be adjusted with the compensation factor (Cooper *et al.*, 2009). The compensation factor (δ^{FP}) between the farm level and production area level standard deviations of yields (σ) are calculated below:

$$\delta^{FP} = \frac{1}{N}\sum_{i=1}^{N}\frac{\sigma(Y_i^F)}{\sigma(Y_i^P)} \tag{15}$$

where:
$i = 1, \dots, N$ = 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 of crop i in production area P

The average yield of crops for the case farm can then be applied on adjusted and standardized aggregate regional data from Statistics Sweden and imputed into the incomplete series of case farm data and thus fill the gaps and create complete data sets. The problems of using the method by Cooper *et al.* (2009) is that it creates the possibility of error. The adjusted and standardized data are more suitable than using the aggregate data directly, as it accounts for the standard deviation difference levels (Cooper *et al.*, 2009).

Preceding crop value is not always considered when deciding the crop rotation. It is therefore important to include the preceding crop value when modelling crop portfolio to more accurately represents the contribution of less profitable crops like oats to the crop rotation. A cropping system is a plan in which crops are cultivated on a piece of land over a period of time. The cropping system aims to maintain and improve the productivity of the land through proper soil management (Fogelfors, 2015). A cropping system is also an important tool to manage pests, weeds and crop diseases (Fogelfors, 2015).

Preceding crop value of growing nitrogen fixating crops like rapeseed, oats and fallow are found by estimating the value of the additional yield to the following crop. The estimated additional yield is found using previous work by Fogelfors (2015) and Agriwise (1, Agriwise, 2018). The value of the extra yield is found using Lantmännen Lantbruk's spot prices (pers. comm., Johnson, 2018).

It is important to accurately model preceding crop values when deriving optimal crop rotations. However, it is a rather extensive procedure to model all possible combinations of preceding and following crop pairs. In a scenario where the crop rotations are characterized by monoculture and dominated by cereal grains, the preceding crop values are limited to the acreage of crop with positive crop rotational effects, like oats, rapeseed and fallow. In this scenario, it is easier to add the nominal expected value of the preceding crop to the crop with the positive crop rotational effect. This method reduces the complexity of the objective function, reduces the computation time of the solving algorithm and increases the reliability of the solutions.

The prices and yields are both assumed to be multivariate normally distributed. Yield and price is known to move be negatively correlated as more supply leads to lower prices and vice versa. This is what is known as the natural hedge as it stabilizes the income of the farm between years to some degree. The natural hedge is the negative correlation between price and yield levels (Finger, 2012). Larger farms have a stronger natural hedge than smaller farms (Finger, 2012).

Therefore, yield and price risk are dependent variables and the variance is calculated for both price and yield risk simultaneously.

Many authors have pointed out the complex relationship between malting barley harvest yield and protein content (Le Bail & Meynard, 2003). If environmental factors are removed, there exists an inverse relation between harvest yield and protein content for malting barley (Le Bail & Meynard, 2003). Late planting typically reduces harvest yield and increases protein content (Le Bail & Meynard, 2003). Increasing the nitrogen application rate generally increases the yield and protein content (Le Bail & Meynard, 2003). In this study there is no information about quality outcome of each production year. There is also no information about the nitrogen application rate, or the date of planting. In this study quality outcome is assumed to be an independent variable and the variance is therefore added to the yield and price risk, as can be seen in equation (19).

5.3 Price risk

To conduct an empirical analysis of marketing strategies price data of future and spot prices are needed (Lidfeldt & Andersson, 1994). Spot price data is provided by Lantmännen Lantbruk (pers. comm., Åkerblom, 2018). Spot prices for malting barley, milling wheat, oats and rapeseed are used from a nine-year period (pers. comm., Johnson, 2018). Spot price data is in local currency (SEK) and futures price data is in GBP. The futures prices are adjusted to local currency using historical exchange rates.

The spot prices are observed on a daily basis, and the end of day or settle price is logged into a record Lantmännen Lantbruk keeps for internal purposes. The futures prices used in this study are presented on a weekly average basis. To compare this data to the spot prices, the end of day prices of the Wednesday is used for comparison. When Wednesday is not a trading day due to a holiday, the next or previous day is used.

Futures contract prices for milling wheat and rapeseed are collected for a nine-year period from AHDB, a British statutory levy board. AHDB keep an open-access record of futures contract price information (1, AHDB, 2018). For malting barley futures contract prices are collected for the six-year period when they were traded on Matif and Liffe (NYSE Euronext) from Lantmännen Lantbruk (pers. comm., Johnson, 2018).

5.4 Quality risk

Grain is priced according to a set of quality parameters. Sampling and testing is performed upon delivery of the grain to the elevators. The sample is tested and reveals the quality of the grain in the delivered load and thus the final price.

Quality requirements for malting barley, milling wheat and oats are not achieved every year. Wilson *et al.* (2009) approximate the probability of achieving the premium malting barley quality for producers in Illinois to be 0.90. This study is problematic to apply to a Swedish context. A Swedish study by Ugander *et al.* (2012) approximate the probability of reaching the premium quality to be 0.80 for milling wheat, 0.60 for malting barley and 0.70 for oats. The approximations are made for both production areas Ss and Gns and based on interviews with crop advisors and other knowledgeable professionals within the industry (Ugander *et al.*, 2012).

The only previous studies to estimate the quality risk of cereal grains grown in Sweden is the study by Ugander *et al.* (2012) to the best of my knowledge at the time of writing this study. Using these approximations by Ugander *et al.* (2012) as a basis the probability of achieving the premium level quality were re-evaluated and adjusted. Crop advisors comment on the report by Ugander *et al.* (2012) in light of the past production years 2009-2018 and the *ex ante* harvest outcome (pers. comm., Lagerholm, 2018).

Quality risk is calculated based on the assumption that the quality outcome each of the years in the studied time period is binary. Each year quality demands are either achieved $(X = 1)$ or not achieved $(X = 0)$, therefore the data is assumed to follow the Bernoulli distribution (Wahlin, 2011).

The price penalty if the premium quality demands are not met can be expressed as the price difference between premium quality and feed quality. The price difference is approximated using historical price data for both qualities. For barley data from Lantmännen Lantbruk is used for the December month spot price (pers. comm., Johnson, 2018). For wheat Lantmännen Lantbruk's Pool-price 1 and 2 for the period 2009 to 2017 are used (1, Agriwise, 2018). For each year the price difference is calculated. The price difference for barley (P_i^1) is on average a reduction of 225 SEK per ton or -17,6 % compared to the premium quality (P_i^0). The price difference for wheat is on average a reduction of 230 SEK per ton or -14,5 %.

As we have found the probabilities and the expected price differences, we can use this information to find the expected revenue per hectare for each crop i with quality risk:

$$E(q_i) = P_i^0 * Pr(X = 1) + P_i^1 * Pr(X = 0) \tag{16}$$

where:
$Pr(X = 1)$ = the probability that the outcome is premium quality
$Pr(X = 0)$ = the probability that the outcome is feed quality

The quality variance of a crop i is found using the method of the Bernoulli distribution (Wahlin, 2011):

$$\sigma_{q_i}^2 = Pr(X = 1) * Pr(X = 0) \tag{17}$$

The quality yield component used in the objective function in this study is the expected revenue $\big(E(\pi_i)\big)$ minus the expected revenue under quality risk multiplied with the standard deviation of the quality outcome:

$$\big(E(\pi_i) - E(q_i)\big)\sigma_{q_i} \tag{18}$$

The standard deviation of total revenue for crop i per hectare when yield, price and quality risk is considered is given by:

$$\sigma_{TR_i} = E(TR_i)\left(\frac{\sigma_{py_i}}{E(py_i)}\right) + E(q_i)\sigma_{q_i} \tag{19}$$

where:
$E(TR_i)$ = the expected total revenue of crop i
σ_{yp_i} = the standard deviation of yield times price for crop i
$E(yp_i)$ = the expected yield times price for crop i

5.5 Marketing strategies

The traditional recommendation and general rule amongst farmers is to hedge half of the expected yield (Ederington, 1979; Rolfo, 1980). An established long position in the physical market is protected with a short position of equal magnitude in the financial futures market (Rolfo, 1980). This assumption is used to define the static hedge ratio to 50 % of the expected harvest yields. Preliminary calculation shows that the OHR is close to 100 %, but this level of hedging is unrealistic in practice due to both yield and quality risk. A full hedge is not recommended when the expected output is subject to production variation (Rolfo, 1980).

Producers can sell their grain in the spot or futures market. They can sell in the spot market at harvest or delivery any time thereafter. They can also sell futures contracts prior to planting, at planting or any time during the growing season or after harvest when it is being stored (McKinnell *et al.*, 1990). This analysis considers only a limited number of the existing marketing strategies that grain and rapeseed producers can use. It is assumed that futures contracts are infinitely divisible. The milling wheat future contract is traded in standardized quantities of 50 tons. For simplicity sake the number of contracts is assumed a continuous variable and not discrete.

Seven different hedging strategies are proposed and defined by Iwarson (2012). Four of these strategies are simpler rule-of-thumb strategies, but Iwarson (2012) also suggest more advanced strategies involving technical analysis. Iwarson (2012) conclude that the simpler rule-of-thumb strategies perform equally or better than the more advanced technical analysis strategies. Therefore, this study examines the four simpler strategies. An overview of the strategies is given in figure 8.

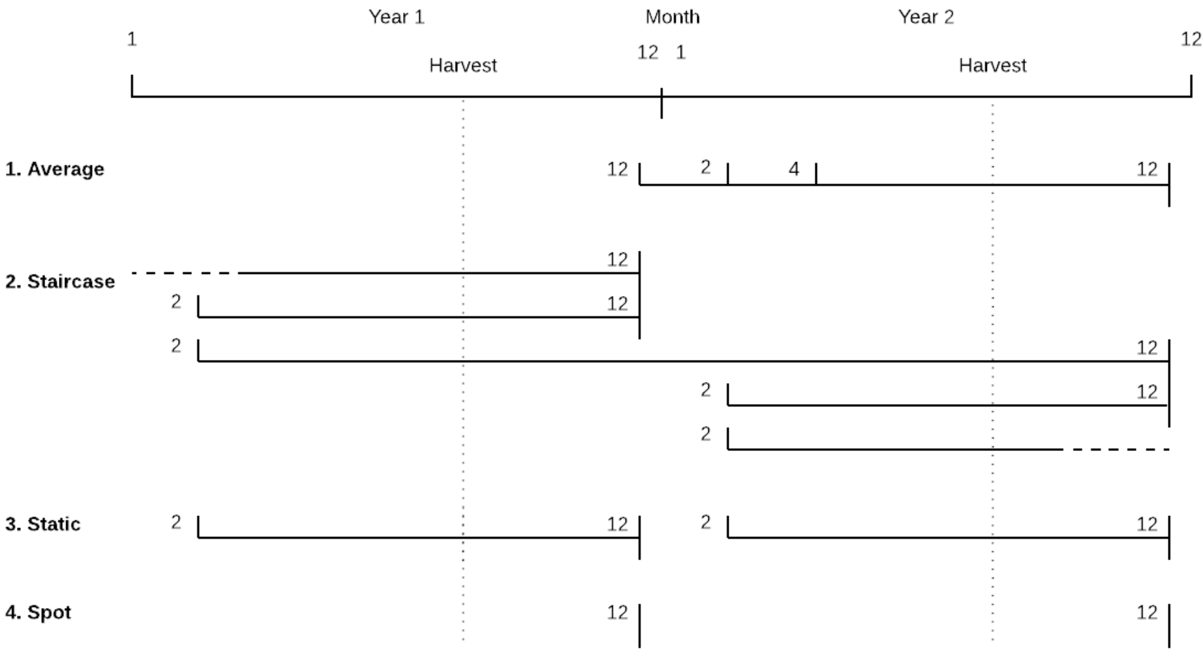

Figure 8. Schematic view of the different hedging strategies of times when futures contracts are bought and sold (own rendering).

The market timing decision using futures contracts is an important mechanism that determines the final price. Futures prices change from the time of when they are first sold to when they are bought back on the final sale date (the position in the futures market is cancelled out and the grain is sold in the cash market). The final sales price for crop i using marketing strategy s is determined by:

$$P_{is} = P_{f0} - P_{f1} + P_{s1} \tag{20}$$

where:
P_{f0} = the sales price of the futures contract at time $t = 0$ before planting
P_{f1} = the sales price of the futures contract at time $t = 1$ post harvest
P_{s1} = the sales price in the spot market at time $t = 1$ post harvest

When the hedge placement $(t = 0)$ and final sale date $(t = 1)$ expires is determined by the hedging strategy (figure 8). Common for all outlined strategies is that the futures contracts are only bought back at the point in time when a sale in the cash market takes place. The seller cancels his delivery commitment by buying contracts of the same future before deliver. This is the most common type of hedge (Ederington, 1979).

5.5.1 Average strategy

Using the average hedging strategy futures contracts are sold in three equal increments, in December, February and April with delivery in December (figure 8). The futures contracts are bought back in December before expiration and the farmers position in the futures market is cancelled out. When the position in the futures market is cancelled out the output is then sold in the physical spot market and delivered.

5.5.2 Staircase strategy

The staircase hedging strategy uses incremental hedging over several years. The time horizon is set to two years in this study due to the limited time the malting barley contracts were available, and thus the limited data available. If the volume of grain to be hedged is 200 tons, 100 tons is hedged with delivery the same year, and 100 tons (of next year harvest) with delivery the following year. Futures are sold in February for delivery in December (figure 8). The purpose of the staircase strategy is to even out income variance between years (Iwarson, 2012).

5.5.3 Static strategy

The futures contracts are all sold in February with delivery in December (figure 8). The futures contracts are bought back before expiration in December and the output is sold in the spot market and delivered. This static strategy is the simplest of the investigated hedging methods.

5.5.4 Spot strategy

The spot strategy assumes that all output is sold in the spot market. The sale and delivery occur in December (figure 8). Iwarson (2012) consider the spot strategy to be the least desirable marketing strategy.

5.6 Production cost

The costs of production are found and subtracted from the revenue to find the gross margin for each production area and crop. The costs of production vary between years as input prices for factors of production vary in price. Production costs are found for each year of the period 2009 through 2017 using Agriwise's variable costing calculations (2, Agriwise, 2018). Agriwise's variable costing calculations were used to determine the contribution margin II for each crop, area and year of the time period (2, Agriwise, 2018). No adjustment for inflation is made due to a rather low inflation rate across the period of the study. The variable cost calculations were modified and assumed to produce the average yield from the case farms.

Investing in a farm-based grain storage facility is a considerable investment in farming operations (Westlin *et al.*, 2006). The cost for drying with a farm-based dryer is significantly higher compared to central drying at Lantmännen Lantbruk (Gunnarsson *et al.*, 2012). Farmers often invest in a farm-based grain storage facility and dryer and store their grain after harvest before delivery. During the harvest period there is typically a considerable reduction in spot prices, about 5 %. Spot prices are generally at their lowest right at harvest. Therefore, in order to achieve higher prices for his grain there is a need for storing the grain for a period of time before delivery (Ugander *et al.*, 2012).

The fictitious case farms are assumed to have farm-based grain storage facilities with adequate volume of storage and a drier capacity. The farm-based grain storage facilities are a necessity in order to fulfil their delivery obligations without the need for external storage or drying. Economies of scale effects make it easier for larger farms to justify the investment as they can make better use of it than medium-sized and small farms (Ugander *et al.*, 2012). For a smaller farm the associated cost is higher and it is more difficult to justify the investment.

An investment calculation for the farm-based grain handling facility is developed based on Agriwise's sample investment calculation (2, Agriwise, 2018). The yearly cost is calculated using an interest rate of 3,5 %, a 0,5 % maintenance cost and an amortization period of 25 years for the storage bins and ten years for the dryer.

All marketing strategies involve storage in this study. Storage cost per hectare is calculated by the volume the harvest occupies in the farm-based grain handling facility (McKinnell *et al.*, 1990). The storage cost is deducted from the yearly cost for the farm-based grain storage facility and is included in the gross margins of each crop. Storing the harvest from one hectare of rapeseed is a lot less costly than winter wheat (McKinnell *et al.*, 1990). This more accurately describes the crop rotation decision for the farmer.

6 Results

In this chapter the empirical results of the applied non-linear optimization model are presented. The results are presented per hectare in order to easily compare the results to previous studies.

6.1 Expected utility of hedging malting barley

The certainty equivalents (equation 14) are derived for the expected utility maximizing scenarios in which malting barley is hedged and when malting barley is not hedged. The expected utility of hedging malting barley is defined as the difference between these two scenarios. The expected utility (SEK per hectare whole-farm) when hedging malting barley compared to when malting barley is not hedged is displayed in table 5.

Table 5. The change in CE when malting barley is hedged and the expected utility of hedging malting barley in Ss and Gns per hectare whole-farm.

	Ss			Gns		
	1. Average	2. Staircase	3. Static	1. Average	2. Staircase	3. Static
RRAC = 0,5						
CE hedging MB	2423	2367	2385	3186	3128	3153
CE not hedging MB	2325	2327	2335	3089	3091	3097
Utility of hedging MB	**98**	**40**	**50**	**98**	**37**	**56**
RRAC = 1						
CE hedging MB	2207	2154	2156	2981	2942	2935
CE not hedging MB	2020	2027	2034	2845	2865	2854
Utility of hedging MB	**187**	**127**	**122**	**136**	**77**	**81**
RRAC = 2						
CE hedging MB	1821	1768	1739	2570	2569	2498
CE not hedging MB	1511	1526	1525	2358	2413	2368
Utility of hedging MB	**310**	**242**	**213**	**213**	**156**	**130**
RRAC = 3						
CE hedging MB	1562	1505	1446	2160	2196	2061
CE not hedging MB	1185	1205	1197	1870	1960	1882
Utility of hedging MB	**377**	**301**	**249**	**289**	**235**	**179**
RRAC = 4						
CE hedging MB	1344	1285	1196	1749	1823	1624
CE not hedging MB	906	933	920	1383	1508	1396
Utility of hedging MB	**439**	**352**	**275**	**366**	**315**	**228**

The hedge effectiveness (θ) of the hedging strategies compared to a spot strategy is shown in table 6. The hedge effectiveness is measured as the percentage reduction in income variance between the hedged and unhedged position (equation 12). As both case farms face the same spot and futures market prices the reduction in spot and futures market price variance through hedging are the same for both farms.

Table 6. Hedge effectiveness of the different hedging strategies for the individual crops for both Gns and Ss.

Hedge effectiveness (θ), h*=0,5			
Crop	Strategy		
	Average	Staircase	Static
Barley	13,6%	17,7%	8,1%
Wheat	27,9%	36,0%	22,9%
Rapeseed	29,2%	34,1%	29,0%

The hedge effectiveness of hedging malting barley varies between 8,1-17,7 %, milling wheat between 22,9-36,0 %, and rapeseed between 29,0-34,1 %. Rapeseed and milling wheat are the most effective crops to hedge while malting barley is about half as effective. Additionally, there is a notable difference in hedge effectiveness between the hedging strategies. The staircase strategy is the most effective while the static strategy is the least effective. The overall hedge effectiveness depends on the weights of the different crops in the crop portfolio. The hedge effectiveness measure only accounts for the variance of expected return and not changes to the expected return.

6.2 Cost of quality risk

The cost of the different types of risks for malting barley is defined as the CE when all risks are considered compared to the CE a scenario when yield, price and quality risk is excluded, one at a time. The difference in CE between the scenarios is the cost of the different types of risk in terms of utility to the producers.

The costs of risk for malting barley (SEK per hectare of malting barley) are displayed in table 7. Price and quantity risks are significant for both case farms. Price risk appears to be the most substantial risk source for the farm in Ss while quantity risk is the most substantial risk source for the farm in Gns.

Table 7. Cost of yield, price and quality risk for malting barley for Ss and Gns per hectare of malting barley.

	Ss			Gns		
	1. Average with MB	2. Staircase with MB	3. Static with MB	1. Average with MB	2. Staircase with MB	3. Static with MB
RRAC = 0,5						
Cost of quantity risk	22	23	35	55	48	74
Cost of price risk	29	40	40	45	42	50
Cost of quality risk	**3**	**14**	**18**	**17**	**16**	**20**
RRAC = 1						
Cost of quantity risk	44	48	74	110	96	147
Cost of price risk	59	69	83	90	83	99
Cost of quality risk	**16**	**19**	**23**	**34**	**32**	**40**
RRAC = 2						
Cost of quantity risk	82	86	135	219	191	294
Cost of price risk	110	123	152	180	167	198
Cost of quality risk	**30**	**34**	**43**	**68**	**64**	**80**
RRAC = 3						
Cost of quantity risk	117	121	194	329	287	442
Cost of price risk	156	173	219	269	250	298
Cost of quality risk	**43**	**48**	**62**	**101**	**96**	**120**
RRAC = 4						
Cost of quantity risk	152	156	254	438	383	589
Cost of price risk	203	223	286	359	334	397
Cost of quality risk	**56**	**61**	**81**	**135**	**127**	**160**

The cost of quality risk for malting barley per hectare of malting barley grown is for the hardly risk averse at all farmer is 3-18 SEK while for the extremely risk-averse farmer the cost is 56-81 SEK depending on hedging strategy. For Gns the cost is significantly higher. The hardly risk averse at all farmer faces a cost of quality risk of 16-20 SEK and the extremely risk-averse farmer has a cost of 127-160 SEK.

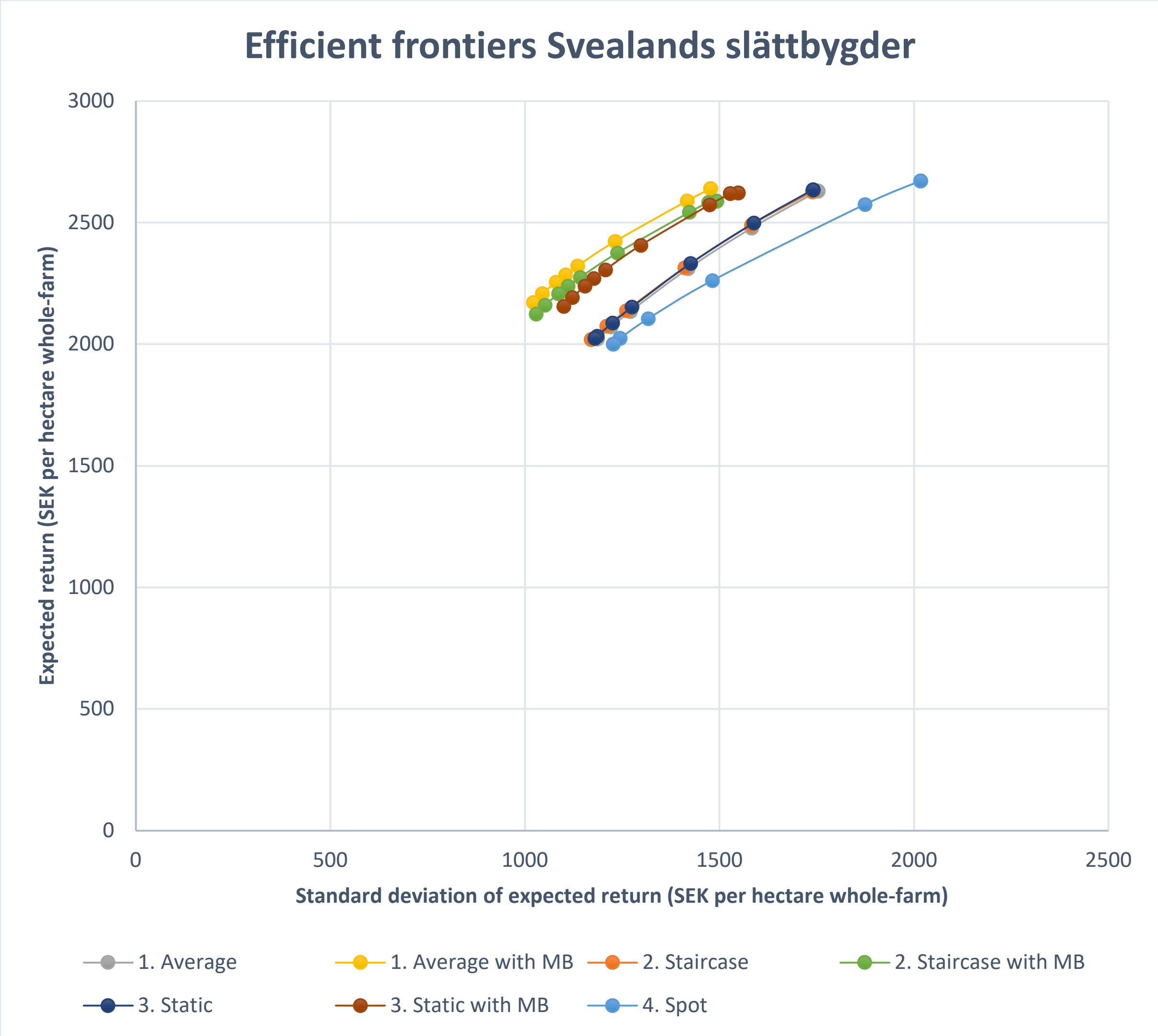

Figure 9. Efficient frontiers of the investigated hedging strategies for the fictitious case farm in Ss.

In figure 9 the efficient frontiers of the different hedging strategies for the farm in Ss are displayed. The efficient frontiers are clearly distinct and grouped according to the crops which are hedged. The most leftward frontiers have the lowest variance of expected return. The hedging strategies with malting barley are more leftward than the same strategies without malting barley. The movement along the efficient frontier is primarily due to the crop portfolio decreasing the share of winter wheat and increasing the share of oats (appendix 2).

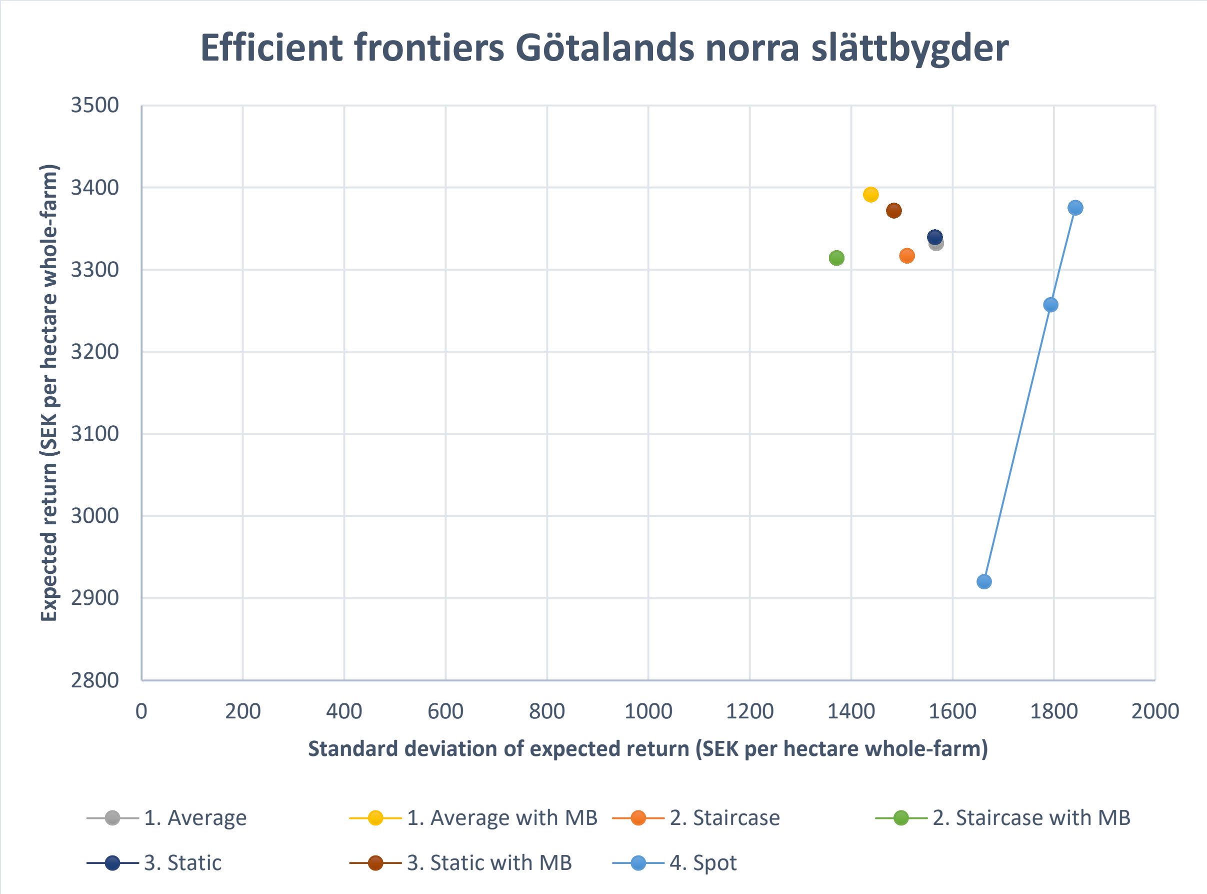

Figure 10. Efficient frontiers of the investigated hedging strategies for the fictitious case farm in Gns

In figure 10 the efficient frontiers of the different hedging strategies for the farm in Gns are displayed. The efficient frontiers in Gns remain unchanged for the hedging strategies. The optimal crop portfolio is the same irrespective of hedging strategy and degree of risk aversion. The optimal crop portfolio for the spot strategy changes slightly but not significantly. For complete crop rotational effects see appendix 2.

7 Analysis and discussion

This chapter analyses and discusses the empirical results of the optimization model. The analysis is based on previous research within the theoretical framework.

7.1 Summary of results

A short summary of the empirical results presented in the previous chapter is given in table 8.

Table 8. Summary of the empirical results.

	RRAC	**Ss**	**Gns**
Expected utility of hedging malting	0,5	40-98	37-98
barley	1	122-187	77-136
	2	213-310	130-213
(SEK per hectare whole-farm)	3	249-377	179-289
	4	275-439	228-366
Cost of malting barley quality risk	0,5	3-18	16-20
when hedging	1	16-23	42-40
	2	30-43	64-80
(SEK per hectare of malting barley)	3	43-62	96-120
	4	56-81	127-160

Within production economics farm planning and management there are important aspects to consider (Debertin, 2012). The empirical results are the basis of the quantitative prognosis which can be used as normative information in the decision-making processes of future planning of hedging strategies and crop rotations. The results of the empirical analysis should be regarded as illustrative rather than prescriptive.

An example of the optimization model developed and used in this study can be seen in appendix 3 where one scenario of a hedging strategy for the fictitious case farm is Ss is solved. The objective function displayed in equation 14 is maximized under the restrictions outlined in figure 6.

7.2 Expected utility of hedging

After reviewing the measures of production, quality and price risk, the results provide normative information about optimal hedging strategies for Swedish crop farmers in the mid Sweden plains areas that are subject to variability in output yield, price and quality. The results verifies what previous studies show, that hedging through futures markets can significantly reduce farmers risk exposure (Peck, 1975; McKinnell *et al.*, 1990; Guo *et al.*, 2013). The results of this study additionally support the results of Brorsen *et al.* (1998) and shows that the more risk averse producers benefit more from hedging.

This study finds that hedging does not significantly reduce the expected return as expected. Contrary to what the literature suggests (McKinnell *et al.*, 1990; Lidfeldt & Andersson, 1994; Pennings, 1998; Guo *et al.*, 2013), the expected return remains mostly unchanged for all examined hedging strategies in both Ss and Gns in the risk neutral scenario (figure 9 and 10).

This is likely in part due to a steadily declining market for the investigated time period (figure 2). In a rising market, futures contracting is less favorable. In a declining market, futures contracting is more favorable (Iwarson, 2012).

Lidfeldt and Andersson (1994) found that the absolute risk reduction when hedging ranged between 3-29 % when using an optimal hedge ratio with consideration of production risk. This study finds the hedge effectiveness to be slightly higher at around 8,1-17,7 % for malting barley and 22,9-36,0 % for milling wheat, and 29,0-34,1 % for rapeseed for both Ss and Gns. As this study does not use variable optimal hedge ratios the hedge effectiveness is potentially greater than what the results of this study show. The higher effectiveness obtained in this study could be due to increased price risk from the time of the Lidfeldt and Andersson (1994) study as price risk has become a more prominent risk source for Swedish producers in recent years (Iwarson, 2012).

The aggregate whole-farm hedge effectiveness is largely dependent on the ability to hedge malting barley and less dependent on which marketing strategy is used. The ability to hedge malting barley provides an average risk reduction for the entire farm of about 3,23-7,09 % in Ss and Gns compared to when only wheat and rapeseed is hedged. This is because without malting barley only 57 % of the crops are hedged, and when malting barley is hedged a maximum of 95 % of the crops are hedged.

The average hedging strategy provided the highest expected utility to the risk averse producers. The average strategy seeks to reduce price variance when selling the futures contracts before planting by spreading out the points in time when futures contracts are sold (Iwarson, 2012). The average strategy provided the highest expected utility for farmers in both Ss and Gns which can be noted by studying the efficient frontiers. Analyzing the efficient frontiers reveals that for both Ss and Gns, the average strategy provides the most efficient risk-return combinations for the farmers (figure 9 and 10).

The staircase hedging strategy provided the highest hedge effectiveness of all the investigated hedging strategies. The staircase strategy aims to reduce income variance between years through hedging years in advance (Iwarson, 2012). The hedge effectiveness measure does not however account for the change in expected return.

The static hedging strategy did not provide as much of an increase in expected utility as the other strategies. Only in Gns did it provide more expected utility than the staircase strategy for hardly risk averse at all and somewhat risk averse farmer (RRAC=0,5-1). However, considering that the static method was the simplest of all hedging methods and it still performed considerable better than a pure spot strategy one could argue that the static method performed well. Too advanced of hedging strategies face the risk of simply not being implemented due to the high complexity involved (Iwarson, 2012).

Which hedging strategy is best is highly subjective and largely depends on what is meant by best. For farms in different regions the optimal marketing strategies is likely to be different (McKinnell *et al.*, 1990). The historical data used to backtest the performance of the different hedging strategies evaluated in this study have limited ability to accurately make forecasts about the effectiveness of the different investigated strategies in coming years.

7.3 Cost of quality risk

Pennings (1998) suggests that futures contracts do not remove all price risk but introduce risk themselves to hedgers. Quality risk is introduced as malting barley is hedged, thus the utility of a reduction in price risk could be offset by the cost of quality risk. However, this study finds that the cost of quality risk is not very high for the farmer is Ss, but somewhat significant for the farmer in Gns. This is in part due to the farm level variance in harvest yields, which is lower in Gns compared to the case farm in Ss. In all cases the expected utility of hedging is considerably higher than the cost of quality risk. Therefore, quality risk is no reason to not hedging malting barley.

The price penalty if malting barley fails to meet the quality demands and is sold as feed is somewhat substantial (-17,6 %) but the approximated probability of achieving malting barley premium quality is high (70 %). Therefore, as quality risk is not a significant cost to the hedger it is shown to not affect the optimal marketing strategy or crop rotation of the case farms.

This study reveals similarly to McKinnell *et al.* (1990) that the significance of price and yield risk is farm-specific and that it can very between production areas. In Ss yield risk was the costliest risk for all levels of risk aversion as predicted by Iwarson (2012). In Gns the price risk was the costliest source of risk by far. Robison and Brake (1979) find that quantity variance is at least as important as price variance. Therefore, the different types of risk can be assumed to be dependent on the individual farm which is investigated (Robison & Brake, 1979; McKinnell *et al.*, 1990).

The significantly higher cost of quality risk to the farmer in Gns is due to less variation in yields and a higher gross margin. Gns displays no crop rotational effects to offset crop specific risks. In Ss the more risk averse farmers tend to include larger shares of crops with positive crop rotational effects and a lower covariance to reduce overall portfolio risk.

The cost of quality risk for the hedging strategies without malting barley is zero since the quality outcome is known at harvest before the grain is marketed (Debertin, 2012). The risk associated with hedging strategies including malting barley and milling wheat is attributed to the fact that futures contracts are sold as the premium quality before planting, and in the case of the staircase method a year and a half ahead of time, when the harvest quality is an unknown.

The results of the empirical study show that the effects of risk aversion and use of different hedging strategies do not significantly affect the crop portfolio of the fictitious case farms (appendix 2). These results are contrary to some of the previous research (McKinnell *et al.*, 1990). However, Lien and Hardaker (2001) also found that contrary to previous studies, the level of risk aversion has little effect on the optimal crop portfolio. This study investigates large-scale crop farms. Farm acreage is an important factor influencing the optimal farm plan under risk aversion (Pannell & Nordblom, 1998). If small- and mid-sized crop farms were investigated the results are likely to be different. It can be shown that the more risk averse farmers prefers more diversified crop portfolios (Pannell & Nordblom, 1998).

8 Conclusions

This study aims to investigate how future contracts can be used by Swedish grain producers to maximize their expected utility. The study accounts for yield, price and quality risk exposure. Several different marketing strategies and a variety of crops in the cropping system are investigated. The study aims to find the expected utility of hedging malting barley and the cost of quality risk for malting barley for various levels of risk aversion.

This study finds that the expected utility of hedging malting barley is significant for both case farms. The expected utility of hedging malting barley is for the rather risk-averse producer (RRAC=2) 213-310 SEK in Ss and 130-213 SEK in Gns for aggregate whole-farm. For farms of 500 hectares this is worth 106 500-155 000 SEK in Ss and 65 000-106 500 SEK in Gns. The hedge effectiveness of malting barley is found to be around 8,1-17,7 % which is only about half of milling wheat (22,9-36,0 %) and that of rapeseed (29,0-34,1 %).

This study reveals that the cost of quality risk is not a significant cost to the farm in Ss and a somewhat significant cost to the farm in Gns. For a rather risk-averse farmer (RRAC=2) in Ss the cost of quality risk is between 30-43 SEK and for the farm in Gns it is 64-80 SEK. The cost of quality risk is several times less than the value of hedging. Therefore, it can be stated that quality risk is no reason not to hedge malting barley using futures contracts.

To put this in perspective, a grain farmer in mid Sweden's plains areas who has an average harvest yield of 6 000 kg per hectare of malting barley and sells it for an average of 1,50 SEK over the period 2009-2017, the utility of hedging for the rather risk-averse producer (RRAC=2) is worth 2-3 % of total revenue. Hence, there is a significant value to the farmers who use futures markets to hedge their malting barley. On the other hand, the cost of quality risk when 40 % of the crop portfolio consists of malting barley is only worth 0,2-0,4 % of total revenue.

8.1 Further research

Further studies within the field of futures contracts in the agricultural sector are needed. This study could be further developed to include hedging using international commodity exchanges outside of Europe as the trading of malting barley contracts on Liffe at the time of writing this study are still suspended. This study could additionally be developed to include variable optimal hedge ratios for all of the investigated crops instead of the fixed ratio used in this study.

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Appendix

Appendix 1: Covariance of gross margins matrices

SS		Malting barley	Feed barley	Oats	Feed oats	Milling wheat	Feed wheat	Fall rapeseed	Malting barley	Milling wheat	Fall rapeseed	Fallow
Spot prices	Malting barley	4533407	4319824	1226371	1313953	5162572	4982468	1561985	-628311	2141073	556229	78327
	Feed barley	4319824	4133762	1251244	1287962	4990897	4834588	1502052	-525130	1840496	523566	73445
	Oats	1226371	1251244	1483250	1226966	1597946	1759754	1056606	672815	-18393	814259	141183
	Feed oats	1313953	1287962	1226966	1270994	1427544	1512332	1006879	1739159	409574	864013	141818
	Milling wheat	5162572	4990897	1597946	1427544	9358195	9182649	1850030	1439586	5213169	295657	24057
	Feed wheat	4982468	4834588	1759754	1512332	9182649	9136996	1762105	1515674	4997445	405108	45589
	Fall rapeseed	1561985	1502052	1056606	1006879	1850030	1762105	2086776	768798	723298	1342738	157482
Futures prices	Malting barley	-628311	-525130	672815	1739159	1439586	1515674	768798	4673357	1416204	563199	97525
	Milling wheat	2141073	1840496	-18393	409574	5213169	4997445	723298	1416204	7778709	233185	49303
	Fall rapeseed	556229	523566	814259	864013	295657	405108	1342738	563199	233185	1360282	163533
	Fallow	78327	73445	141183	141818	24057	45589	157482	97525	49303	163533	25210

GNS		Malting barley	Feed barley	Oats	Feed oats	Milling wheat	Feed wheat	Summer rapeseed	Malting barley	Milling wheat	Summer rapeseed	Fallow
Spot prices	Malting barley	4916499	4685119	1223176	988438	3243446	3248821	2994909	3035285	2603752	687504	250134
	Feed barley	4685119	4484367	1202586	946193	3204546	3233833	2928554	2904559	2397036	661004	239497
	Oats	1223176	1202586	1890700	1625908	1352200	1453129	876989	1134221	1019681	2542055	182385
	Feed oats	988438	946193	1625908	1505223	1318062	1348875	914346	791719	1073398	2330661	154907
	Milling wheat	3243446	3204546	1352200	1318062	6487109	6461550	6447342	397734	1312351	1247586	227193
	Feed wheat	3248821	3233833	1453129	1348875	6461550	6638493	6375694	793190	1285788	856690	244636
	Summer rapeseed	2994909	2928554	876989	914346	6447342	6375694	7665598	128648	1414912	394360	240019
Futures prices	Malting barley	3035285	2904559	1134221	791719	397734	793190	128648	5151538	4515551	-1219541	291439
	Milling wheat	2603752	2397036	1019681	1073398	1312351	1285788	1414912	4515551	4813860	-6488	233805
	Summer rapeseed	687504	661004	2542055	2330661	1247586	856690	394360	-1219541	-6488	5583782	150863
	Fallow	250134	239497	182385	154907	227193	244636	240019	291439	233805	150863	26870

Appendix 2: Crop rotations

		SS						GNS				
Strategy	RRAC	barley	oats	wheat	rapeseed	fallow		barley	oats	wheat	rapeseed	fallow
1. Average												
	0	200	0	192	83	25		189	0	200	83	28
	0,5	200	0	192	83	25		189	0	200	83	28
	1	200	0	192	83	25		189	0	200	83	28
	2	200	101	91	83	25		189	0	200	83	28
	3	114	200	77	83	25		189	0	200	83	28
	4	119	200	73	83	25		189	0	200	83	28
1. Average with MB												
	0	200	0	192	83	25		189	0	200	83	28
	0,5	200	0	192	83	25		189	0	200	83	28
	1	200	0	192	83	25		189	0	200	83	28
	2	200	68	123	83	25		189	0	200	83	28
	3	200	121	71	83	25		189	0	200	83	28
	4	200	147	44	83	25		189	0	200	83	28
2. Staircase												
	0	192	0	200	83	25		189	0	200	83	28
	0,5	192	0	200	83	25		189	0	200	83	28
	1	192	0	200	83	25		189	0	200	83	28
	2	194	98	99	83	25		189	0	200	83	28
	3	107	200	85	83	25		189	0	200	83	28
	4	111	200	81	83	25		189	0	200	83	28
2. Staircase with MB												
	0	192	0	200	83	25		189	0	200	83	28
	0,5	192	0	200	83	25		189	0	200	83	28
	1	200	0	192	83	25		189	0	200	83	28
	2	200	66	126	83	25		189	0	200	83	28
	3	200	119	73	83	25		189	0	200	83	28
	4	200	145	46	83	25		189	0	200	83	28
3. Static												
	0	200	0	192	83	25		189	0	200	83	28
	0,5	200	0	192	83	25		189	0	200	83	28
	1	200	0	192	83	25		189	0	200	83	28
	2	200	95	97	83	25		189	0	200	83	28
	3	114	197	80	83	25		189	0	200	83	28
	4	116	200	76	83	25		189	0	200	83	28
3. Static with MB												
	0	192	0	200	83	25		189	0	200	83	28
	0,5	192	0	200	83	25		189	0	200	83	28
	1	200	0	192	83	25		189	0	200	83	28
	2	200	67	125	83	25		189	0	200	83	28
	3	200	119	73	83	25		189	0	200	83	28
	4	200	145	47	83	25		189	0	200	83	28
4. Spot												
	0	192	0	200	83	25		192	0	200	83	25
	0,5	192	0	200	83	25		192	0	200	83	25
	1	200	28	164	83	25		192	0	200	83	25
	2	200	168	24	83	25		192	0	200	83	25
	3	200	192	0	83	25		120	108	200	47	25
	4	192	200	0	83	25		99	200	155	21	25

Appendix 3: Optimization model

ΣΣπ	(ΣΣπ)/Atot		Portfolio σ^2	Portfolio σ		CE max		RRAC		ARAC		Idle investment (FC)		Wealth
1078015	2156,0		3,03E+11	550002		597852		4		1,5873E-06		7843	Idle capacity i	1260000
	Amb	Amb (feed)	Aoats	Aoats (feed)	Amw	Amw (feed)	Ar	Xmb	Xmw	Xr	Xf	Atot		
Hectares	70,000	30,000	101,390	43,453	18,730	4,682	41,667	100,000	23,412	41,667	25,000	500		
wi	0,140	0,060	0,203	0,087	0,037	0,009	0,083	0,200	0,047	0,083	0,050	1,000		
yield	5681	5681	4939	4939	6414	6414	2409	5455	6414	2409	0	0		
π	2924,329	1676,25513	1503,00212	387,08724	2913,53581	2662,659582	3645,462333	2469,23467	2706,31975	3625,28122	-744,44444	0		
σ	2105,1076	2016,80842	1067,82475	1136,89877	3065,23782	3002,07095	1208,07613	2160,15519	2789,03375	1166,31146	158,777447	0		
Σπ	204703,03	50287,654	152389,218	16820,0281	54569,323	12467,62872	151894,2639	246923,467	63360,315	151053,384	-18611,111	0		
Total land	1	1	1	1	1	1	1	1	1	1	1	-1	=	0
Max land												1	=	500
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		-0,1666667	<=	0
Barley quality	0,3	-0,7											=	0
Oats quality risk			0,3	-0,7									=	0
Wheat quality risk					0,2	-0,8							=	0
h* malting ba	-0,5	-0,5						0,5					=	0
h* milling wheat					-0,5	-0,5			0,5				=	0
h* rapeseed							-0,5			0,5			=	0
Storage Max	8,48	8,48	9,88	9,88	8,33	8,33	3,59	8,48	8,33	3,59			<=	4130
					Ctrl + R	Results								
Restrictions						RRAC	ΣΣπ	Portfolio σ	barley	oats	wheat	rapeseed	fallow	Utility
Total land	-2,82E-08	=	0			0	2619,51202	1527,75263	200	3,2404E-14	191,666667	83,3333333	25	2619,51202
Max land	500	=	500			0,25	2619,51202	1527,75263	200	3,2404E-14	191,666667	83,3333333	25	2503,73682
Min fallow	0	<=	0			0,5	2619,51202	1527,75263	200	3,2404E-14	191,666667	83,3333333	25	2387,96161
Max barley	0	<=	0			0,75	2619,51202	1527,75263	200	3,2404E-14	191,666667	83,3333333	25	2272,18641
Max oats	-55,157302	<=	0			1	2619,51202	1527,75263	200	3,2404E-14	191,666667	83,3333333	25	2156,41121
Max wheat	-153,17603	<=	0			1,5	2619,51202	1527,75263	200	3,2404E-14	191,666667	83,3333333	25	1924,8608
Max rapeseed	0	<=	0			2	2406,63461	1297,55717	200	66,5261708	125,140496	83,3333333	25	1738,5177
Barley quality	-3,553E-15	=	0			2,5	2306,392434	1206,77477	200	97,8527809	93,8138848	83,3333333	25	1584,01875
Oats quality ri	2,613E-11	=	0			2,75	2269,940738	1177,35255	200	109,244277	82,4223899	83,3333333	25	1513,60396
Wheat quality	4,441E-16	=	0			3	2239,564321	1154,47261	200	118,737189	72,929477	83,3333333	25	1446,22682
h* malting ba	-7,105E-15	=	0			3,5	2191,829956	1121,75817	200	133,654623	58,0120435	83,3333333	25	1317,98177
h* milling wh	4,32E-08	=	0			4	2156,02918	1100,0047	200	144,842698	46,8239681	83,3333333	25	1195,70351
h* rapeseed	0	=	0											
Storage Max	3816,2208	<=	4130		Acreage	Period	Level	Yield risk	Price risk	Quality risk	PoB	h*	MB Futures	Strategy
					500ha	09-17	case farm	Yes	Yes	Yes	Ss	50%	Yes	Static