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The Potential Application of Weather Derivatives to Hedge Harvest Value Risk in the Champagne Region of France

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THE POTENTIAL APPLICATION OF WEATHER DERIVATIVES TO HEDGE HARVEST VALUE RISK IN THE CHAMPAGNE REGION OF FRANCE

SUBMITTED TO

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FOR

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“My only regret in life is that I did not drink more Champagne”
-John Maynard Keynes

I. Introduction

The Champagne appellation of France is uniquely valuable. Although it covers less than four percent of France’s planted vineyards, it produces over one-third of French wine exports in value. One hectare of land in Champagne is over six times as valuable as one in Alsace or Burgundy, France’s second and third most expensive wine regions. (Deluze, 2010) The demand for Champagne has increased tenfold over the last sixty years, with sales growing from 31 million bottles in 1952 to an estimated 330 million in 2011. (CIVC, 2009) Although the CIVC will not release official figures until later this year, it estimates that 2011 sales approached four and one half billion Euros. **Figure 1** details Champagne sales over time.

As one might expect, grapes are the most expensive component of Champagne. Champagne producers, or maisons, don’t grow many grapes themselves: while they sell two-thirds of the wine that comes out of Champagne, maisons only grow 10% of the grapes they use to make it and have to buy the rest from grape growers, or vignerons. (Cyr et al., 2010) They crush the grapes to produce still wine; this wine is then put into bottles to ferment for a minimum of three years before coming to market. The continuous increase in Champagne production cannot continue much longer: of the 35,280 hectares in the region, 34,000 of them have been planted with vines and 33,000 currently produce grapes. Although an expansion of the region has been approved and

new land is being planted, this increase in production will not affect the market until they begin to produce grapes, beginning sometime after 2017. (Deluze, 2010) If production cannot keep up with demand, Champagne prices will increase and grape prices with them.

The production of Champagne is highly regulated. Part of what makes both the land and grapes of Champagne so expensive is that Champagne wine is only made from grapes grown in the Champagne appellation d'origine controlee, or AOC.[1] It is illegal for anyone to label sparkling wine made outside the AOC as Champagne. Californians make bubbly, Italians make prosecco, Germans make sekt, and Spaniards make cava; although the word "Champagne" has been colloquially appropriated to mean sparkling wine, it only refers to wine made with grapes from the Champagne AOC. The Comité Interprofessionnel du Vin de Champagne[2] enforces the proper use of the Champagne name and works to maintain and enhance Champagne's brand image. In addition to protecting Champagne's name, they manage the quantity of wine it produces. It is vital to the Champagne brand to keep production limited to meet market demand: if the region overproduces, maisons have to reduce prices to move stock. The market interprets any decrease in the price of Champagne as a decrease in quality, which leads them to purchase other sparkling wine. (Declerck, 2005) Although they have had other tools in the past, since 1990 the CIVC has managed production exclusively with harvest yield

[1] In France, an AOC is the legally defined and protected geographical indication used to identify where grapes are grown and functions in the same way as an AVA or "American Viticultural Area" in the US. (CIVC, 2012)

[2] The CIVC is a government-mandated cooperative intermediary between maisons and vignerons, staffed by representatives of both groups. (CIVC, 2012)

limits, limits on the quantity of grapes per hectare that can be harvested and made into wine each year.

The harvest yield limit of any given year is imposed by the CIVC based on the quality of the vintage, available reserves of still wine, and the market demand for Champagne. Most Champagne is non-vintage, which means it is a blend of the current vintage and reserves from other seasons. This mixing of vintages allows maisons greater control over the quality of their product: instead of relying on the flavors that present themselves from a single grape harvest, vintners have a cellared catalogue of flavors to choose from, which they blend to create the flavor profile of the finished Champagne. It allows them to develop house styles and to improve the quality of lesser vintages with reserve wine from better ones. In poor vintages, fewer grapes are harvested and maisons will use more still wine from older vintages in that year's blend; in good years, more grapes are harvested and used in that year's bottled blend; excess still wine is stored to blend with future vintages. When there is a reduction in the global demand for Champagne, the maisons' reserves become full, they cannot purchase as many grapes, and the harvest yield limit is reduced. In the short term, this is not good for vignerons, who want to sell as many grapes as possible, but it maintains Champagne's price and brand image by limiting supply to match demand. Lower harvest yield limits mean lower grape harvest values and lower revenues for grape growers for those vintages.

Grape quality is highly dependent on weather. (Zara, 2010) Frost, extreme precipitation, and temperature can have serious negative effects on a vintage. Frost cut the harvest yield limit in 1957 down to 2260 kg/Ha; bad weather during the flowering

seasons of 1978 and 1981 led to very low harvest yield limits, of 3678 kg/Ha and 4353 kg/Ha, respectively. (Deluze, 2010) Harvest values can be seriously adversely affected by a poor vintage due to adverse weather conditions and the corresponding reduction in harvest yield limit by the CIVC. The connection between poor weather and reduced harvest value is an opportunity to use weather derivatives to hedge risk. Champagne is conveniently located ninety miles from the Paris weather index set up by the Chicago Mercantile Exchange (CME) and shares a similar climate.

Weather derivatives have been used to hedge against weather risk since Enron made its first contract with Florida in 1997. They are used extensively in the energy sector, but have been slow to catch on as a means to hedge risk in agriculture. (CME Group, 2009) According to a recent survey by the CME, 82% of the American firms that responded to their survey recognize weather risk, but only 10% of them hedge it effectively. The scenario is more extreme for agriculture: 94% of farmers who responded to the survey recognize weather risk; only 8% of them hedge it effectively. (Cyr et al, 2010)

This paper assesses the potential application of weather derivatives to hedge harvest risk in Champagne. I hypothesized vignerons could use weather derivatives to hedge against low harvest values. I performed an empirical analysis using historical grape harvest data and historical weather data to simulate historical values of the CME's Paris cumulative average temperature (CAT) index. The grape harvest data come from the CIVC's database of historical harvest yield limits. Paris weather data are from MDA

systems, from whom the CME also sources their data; the CME Paris CAT index is currently determined by the same data.

II. Literature Review

There has been extensive research on the application of weather derivatives to hedge grape harvest value risk by Don Cyr and Martin Kusy. They found that weather derivatives are in fact applicable and effectual hedges of weather risk for ice wine producers in Canada's Niagara appellation. They performed similar experiments in 2007 and 2010 that explored the design of over-the-counter derivative contracts "to address a particular weather-related risk faced in viticulture" using temperature and rain as primary variables, respectively. (Cyr et al., 2010) In the 2007 study, they used temperature derivatives to hedge against the warm weather that hurts ice wine production. They used Monte Carlo simulation to "derive a range of benchmark option values based upon varying assumptions regarding the stochastic process for an underlying temperature variable" and found that such options contracts could provide valuable hedging opportunities for producers. (Cyr et al., 2007) In the 2010 study, they chose an actuarial approach to price OTC cumulative rainfall futures and found that options on those futures could provide valuable hedging opportunities. According to their research, both rain and temperature are acceptable primary variables to use to hedge weather risk in viticulture. Other research suggests that temperature based indices suffer from significantly less basis risk than precipitation indices. (Myyrä, 2009)

The market for weather derivatives is growing quickly as people and businesses come to realize the potential value of their proper allocation. From 2010 to 2011, the size

of the market had grown 20% from the year before to 11.8 billion dollars. (WRMA, 2011) The majority of growth in the industry has been generated by an increase in the use of over-the-counter (OTC) contracts.

OTC weather derivative products are effective in that they can be tailored to fit the needs of the parties involved. This includes using non-standard variables like rainfall as primary variables for the hedge as well as smaller, better-located weather stations. The danger of OTC contracts lies in credit risk: these are contracts between two private individuals arranged by a third party financial firm. Not only is there a risk of default, it may be difficult to find buyers for these OTC contracts on a regular basis.

Golden et al. found using standardized weather indices like those on the CME superior to OTC contracts. These indices are not customizable like OTC contracts and may suffer from basis risk as a result of the observing weather station being geographically distant from the parties involved. However, they do not expose parties to any credit risk and basis risk can be effectively hedged with smaller OTC contracts. (Considine, 2000)

Index traded derivatives also provide price transparency that capacitates and should lead to the future growth of options trading. Researchers have suggested using an actuarial approach, extended risk neutral evaluation, utility maximization including consumption based asset-pricing models, and indifference pricing techniques to value OTC contracts, but they each have flaws and there is no consensus as to whether any of them is superior to the others. (Cyr et al, 2010)

The Champagne AOC is less than 90 miles northeast of Paris, where the CME has a cumulative average temperature weather index. Golden et al.'s and Myyrä's findings indicate that using this kind of temperature-based index will provide a better hedge than OTC contracts and precipitation-based indices. Given that I will perform my analysis with backtesting, an actuarial approach seems appropriate for pricing historical index values.

III. Theory

I tested the effectiveness of weather derivatives as tools to hedge harvest risk in the Champagne appellation of France by running a historical simulation of harvest values with and without a hedge. The objective of the hedge is to minimize year-to-year harvest value variance by receiving a payout when weather is cold, or the value of the Paris CAT index is low, and harvest yield limits should be lower. To achieve this objective, I hedged the variance of unhedged profits with the variance of hedged profits by applying a protective collar hedging strategy. A protective collar hedging strategy is one in which the vigneron would buy put options and write covered call options. The vignerons would buy put options and write covered call options at the same exercise value so that they could write the covered calls without subjecting themselves to any additional risk. Individuals writing calls on the CME can post any "readily marketable securities" as collateral to cover their calls, but this can be a capital-intensive process and not an option (no pun intended) for small grape growing operations. (CME, 2012) Letters of credit are also acceptable collateral; I would recommend vignerons to develop a line of credit that could be secured by harvest revenues.

In application, this strategy pays out when the weather in Paris is cold and harvest values in Champagne are down, thus reducing harvest value variance year to year. Writing covered call options helps pay for the premiums on put options and limits the upside in good years, further minimizing variance. Unhedged harvest values per hectare can be defined as:

$$\Pi = HarvestYieldLimit * GrapePx$$

Before transaction costs, hedged harvest values per hectare can be defined as:

$$\Pi = HarvestYieldLimit * GrapePx + (\Pi_{Put} + \Pi_{call}) * qty_{options}$$

The value of the put options before transaction costs can be defined as follows:

$$\Pi_{Put} = \left[0,(IndexValue - K_{Put}) \times €20\right]$$

As K_{Put} and K_{Call} are equal, the value of the call options will always be zero in my study. The definitive prices of options on the CME Paris CAT index are impossible to determine. There is no historical data to work from, and the market for weather derivatives is incomplete: it is not possible to duplicate the expected payoff of weather-based contracts with a portfolio of basic, tradable securities. The underlying assets, being climactic variables like temperature and rainfall, are non-tradable so the no-arbitrage assumption for the Black-Scholes model does not hold for weather derivatives pricing. Although there is extensive literature on pricing incomplete markets and several economics papers have made attempts, there is no definitive method for pricing weather derivatives. (Cyr et al., 2010)

Given that the protective collar strategy I used involves both buying put options and writing covered calls, the transaction cost of buying one put and one call would be the bid-ask spread between the hypothetical option prices, which would include the cost of risk. The goal of my study is not to determine the exact value of my hedging strategy, but to determine whether or not it could be applied to effectively hedge harvest value risk. As such, a large reduction in variance will not be significantly diminished by the transaction costs of the hedge, where a small one might.

I determined option payouts using CME's index model in conjunction with historical temperature data and an actuarial valuation approach. Using this information, I used a collar hedging strategy that minimizes the variance of yearly harvest values across the sample by finding the optimal strike value and quantity of options to buy and write per hectare. I calculated the harvest value per hectare without a hedge and comparing it to the harvest value per hectare with a hedge at a range of exercise values between 420 and 660 for each year between 1952 and 2011, as shown in **figure 2**. I then compared the variance of harvest values across all years at each exercise value and chose the exercise value with the smallest variance as the optimal exercise value. Once I found the optimal exercise value for the sample, I found the optimal number of options to write and purchase as a linear function of the grape price per kilogram the vigneron would receive. I hypothesize vignerons will be able to use a collar hedging strategy with options on the Paris CAT index traded on the CME to effectively hedge harvest value risk.

IV. Data

The purpose of my study is to determine if Champagne harvest value risk can be effectively hedged using weather options traded on the CME. To perform my analysis, I used a sample of historical temperatures, historical harvest yield limits, and historical option payouts from 1952 to 2011. The historical temperatures are from MDA systems, the same source the CME uses for its weather data. Harvest yield limits were provided by the CIVC. Historical option payouts were determined by applying historical weather data to the Paris CAT index model.

The Chicago Mercantile Exchange has sold weather futures and options since 1999. It began in 10 U.S. cities and only spread to Europe in 2003. (CME, 2011) As such, I had to simulate historical index values using historical weather data. The Paris cumulative average temperature index is traded for the calendar months from April through October. Its monetary value is equal to the accumulation of daily temperatures over a calendar month rounded to the nearest integer multiplied by 20 Euros.

$$W_t = \frac{(\min temp_{(0600UTC_t, 0559UTC_{t+1})} + \max temp_{(1800UTC_{t-1}, 1759UTC_t)})}{2}$$

Each daily temperature W_t is determined by the arithmetic average of the maximum temperature measured at the Paris-Orly weather station between 0600 UTC the current day and 0559 UTC the following day and the minimum temperature between 1800 UTC the previous day and 1759 UTC the current day. Using these historical index values, I determined the value of put options at a range of exercise values.

The CIVC provided historical harvest yield limit data. Given that harvest value per hectare can be expressed as harvest yield limit per hectare multiplied by grape price, the same data also provide historical harvest values, keeping grape price constant. Over the sample, the average harvest value was 9536 kg/Ha with a standard deviation of 3071 kg/Ha. The median of the sample was only just higher, at 9613 kg/Ha. The average harvest yield limit has changed significantly over the years, however, from 6220 kg/Ha from 1952 to 1961 to 12361 kg/Ha from 2002-2011, as shown in **figure 3**.

In a regression of harvest yield limit on Paris CAT index value over all calendar months and years in the sample, I found that only June Paris CAT values, and therefore also June temperature, are significantly correlated with harvest yield limits. This makes sense, given Champagne's grape vines tend to flower in June, when they are particularly susceptible to cold weather. If the weather in June is not warm enough, some grape flowers remain unfertilized and do not become fruit. In a linear regression of harvest yield limits on June CAT across the sample from 1952 to 2011, the correlation between June CAT and harvest yield limits is significantly different from zero at a p-value of .01 with a coefficient of 31.8 per degree and a correlation coefficient of .45, as shown in the summary statistics in **table 1**. The median and mean values of the June Paris CAT index for the sample are both 514 degrees Celsius, with a standard deviation of 43 degrees. In recent years, the average weather in Paris has become warmer, as shown in **figure 4** and **figure 7**, which could imply a change in correlation between June temperatures and harvest yield limit, and therefore harvest value, over time.

In a regression of harvest yield limit on Champagne sales, the increase in average harvest yield across the sample is correlated with the increase in Champagne sales over the same period and was significantly different from zero at a p-value of .01 with a coefficient of .0002 per million bottles sold and a correlation coefficient of .69, as shown in **table 1**. This increase could also reflect improvements in agricultural practices. Technical progress in viticulture and chemistry combined with the climate change shown in **figure 4** has reduced the risk of extremely low harvest like those in 1957, 1978, and 1981. (Deluze, 2010)

V. Empirical Findings

The purpose of my study is to determine if Champagne harvest value risk can be effectively hedged using weather options traded on the CME. Although I found that the minimum variance hedging strategy reduced average harvest value variance across all years of the sample by 31.32% and increased mean harvest value by 7.86% before transaction costs, the results vary significantly by time period when the sample is split, as shown in **table 1**. For the years from 1952 to 1991, the strategy reduced average harvest value variance by 11.52% and increased mean harvest value by 6.10% before transaction costs; from 1992 onwards, the average reduction in harvest value variance was just 1.49% and the increase in mean harvest value just 1.16%, a negligible improvement after transaction costs. The evolution of the harvest values with and without the hedge for the 1952-2011 sample is shown in **figure 5**. Detailed harvest value data for each of the three periods can be found in **table 3**, **table 4**, and **table 5**.

For the period between 1952 and 2011, I found that the minimum variance exercise value was 556, which resulted in a mean harvest value per hectare of €50,464.35 and a standard deviation of €11,026.77, increasing average harvest value per hectare by 20.83% and reducing variance by 48.78%. However, this minimum variance exercise value is not a feasible one: the average Paris June CAT for the sample is 514 degrees. Put options expected to be in the money are not sold; 514 was the closest feasibly marketable value of a put option, which I used to value the payout, as shown in **figure 2**. I had similar findings for the period from 1952-1991: the minimum variance exercise value was 568 while average Paris June CAT for the sample is 499. In both cases, the increase in harvest value per hectare and reduction in variance were both less when using the average Paris June CAT, but still large enough that they might have yielded net increases in revenue after transaction costs. The minimum variance exercise value for the period between 1992 and 2011 was 538, 7 degrees below the period average Paris June CAT of 545.

The break in the effectiveness of the hedge in the sample coincides with a tumultuous time in Champagne. In 1989, Champagne sales were booming, up over 29% from 1985. (CIVC, 2009) The next year, Champagne grapes markets were liberalized and the CIVC lost its power to control grape prices, which considerably reduced its power as a regulator, (Deluze, 2010) but allowed vignerons to cash in on booming demand with higher grape prices. Grape prices were already high before deregulation at €5.53 kg/Ha in 1989, but rose to an average price of €7 kg/Ha in 1990 (in 2011 Euros). (CIVC, 2009) Champagne was flying off the shelves, and maisons reacted to stock shortages by raising prices to reduce demand. (Declerck, 2005)

They could not have picked a worse time to raise prices. In 1991-1992, a recession hit Western Europe and North America, reducing the global demand for Champagne from 237 million in 1990 to 213 million bottles in 1991. (CIVC, 2009) The market was flooded with excess wine, and in order to excess inventory, maisons had to reduce prices and sell their wine in supermarkets, which damaged Champagne's brand image as a premium product. (Declerck, 2005) The CIVC's only remaining tool to manage production was the harvest yield limit, which they used to reduce production to take financial pressure off the maisons, who were trapped between low market prices, high inventory levels, and low margins due to the high prices they paid for grapes from 1988 until the recession in 1991.

This transition towards using harvest yield limits to manage production for reasons unrelated to weather corresponds directly with a break in the correlation of cumulative average temperatures in Paris in June as shown in **table 1**. After 1991, the correlation becomes insignificant with a p-value of .34 a correlation coefficient of .24. For the period from 1952 through 1991, the correlation is significantly different from zero at a p-value of .01 with a correlation coefficient of .43. This absence of correlation between temperature and harvest yield limit after 1991 is accompanied by a sharply decreasing trend in the value of the hedge holding grape price constant as shown in **figure 6**.

The loss of correlation between weather and harvest yield limit does not necessarily mean harvest yield limits are not still determined by the quality of the vintage. As shown in **figure 4**, the cumulative average temperature in Paris has steadily

increased since 1990, which suggests improved climactic conditions during the flowering season and correspondingly better vintages. There has not been a single June since 1991 with a cumulative average temperature below 500 degrees Celsius.

Improved growing conditions make for earlier and more consistent harvests. (Deluze, 2010) **Figure 7** shows the increase in harvest yield limit with temperature. From 1952 through 1991, 40% of harvests occurred in October; there has only been one since. Harvest yield limit variance in the sample is an average of 68% lower for the period after 1991 than for the period from 1952 through 1991 as shown in figure 4. There are data to support the idea that the CIVC still determines harvest yield limits based on vintage quality: in 2003, the harvest yield limit was 31% below the average of the period since 1992 after one of the hottest summers on record and a correspondingly less-than-average-quality vintage.

To gauge the effect of demand for Champagne on harvest yield limits, I ran a regression of harvest yield limits on bottles Champagne sold three years after that harvest (when that vintage has become salable Champagne), and, separately, of harvest yield limits on hectares of productive vines. Although harvest yield limits are significantly correlated with Champagne sales and hectares of productive vines over the entire sample and for the period from 1952 through 1991, they are not from 1992 to the present. I also looked at the correlation between harvest yield limits and the S&P 500 index in another attempt to gauge the effect of market demand for Champagne as a function of economic prosperity in the developed western world on the CIVC's harvest yield limit. While there was a significant correlation of .5 in both periods, the test changes from being

significantly different from zero at a p-value of .01 in the first period to a p-value of .05 in the second.

Although my findings for the period from 1952 through 1991 support my hypothesis that weather derivatives could provide an effective hedge against harvest value risk after transaction costs, my findings in the most recent period do not. After 1991, the correlation between weather and harvest yield limit (and therefore harvest value) becomes insignificant, and the variance of harvest values year-to-year drops by 68%. The quantity of champagne bottles sold does not appear to be an overwhelmingly deciding variable in the CIVC's determination of yearly harvest yield limits. Climactic conditions have improved and advances in viticulture and chemistry protect vines from pests that used to invade Champagne and damage harvests during periods of poor weather. (Deluze, 2010) More detailed data about market demand for champagne and still wine reserves could provide a more accurate picture of how the CIVC has determined harvest yield limits since they lost their power to regulate grape prices in 1990.

VI. Conclusion

I found that weather derivatives based on the Paris CAT index traded on the CME would not provide vignerons the opportunity to hedge harvest risk in Champagne, France. Although theoretically they could have provided a significant reduction in harvest value variance over most of the sample, they would not for the last twenty years. Weather is not significantly correlated with harvest yield limits from 1992 to the present; keeping grape price constant, this means weather is not significantly correlated with harvest values either. This is most likely due to improved climactic conditions and technological

progress that correspond with a 68% reduction in variance from the 1952-1991 period to the period after 1991.

The hope was that as the use of weather derivatives become more prevalent, hedging with weather derivatives traded on a CME index would be an easy way for vignerons to hedge harvest value risk. However, modern viticulture, improved climate, and the steadily increasing global demand for Champagne have already mitigated much of that risk. Although the correlation between the S&P 500 and harvest value is tenuous, trading options on another commodity that is more highly correlated with harvest values might yet provide an opportunity to hedge.

As the market for weather derivatives expands and options become more readily tradable on the CME, they have the potential to provide valuable hedging opportunities for agricultural industries correlated with temperature located near weather indices all over the world.

VII. Figures and Tables

Figure 1. Champagne Sales Over Time

Sample: 60 years of total bottle sales in millions from the Champagne region for the period between 1952 and 2011. Data come from the CIVC.

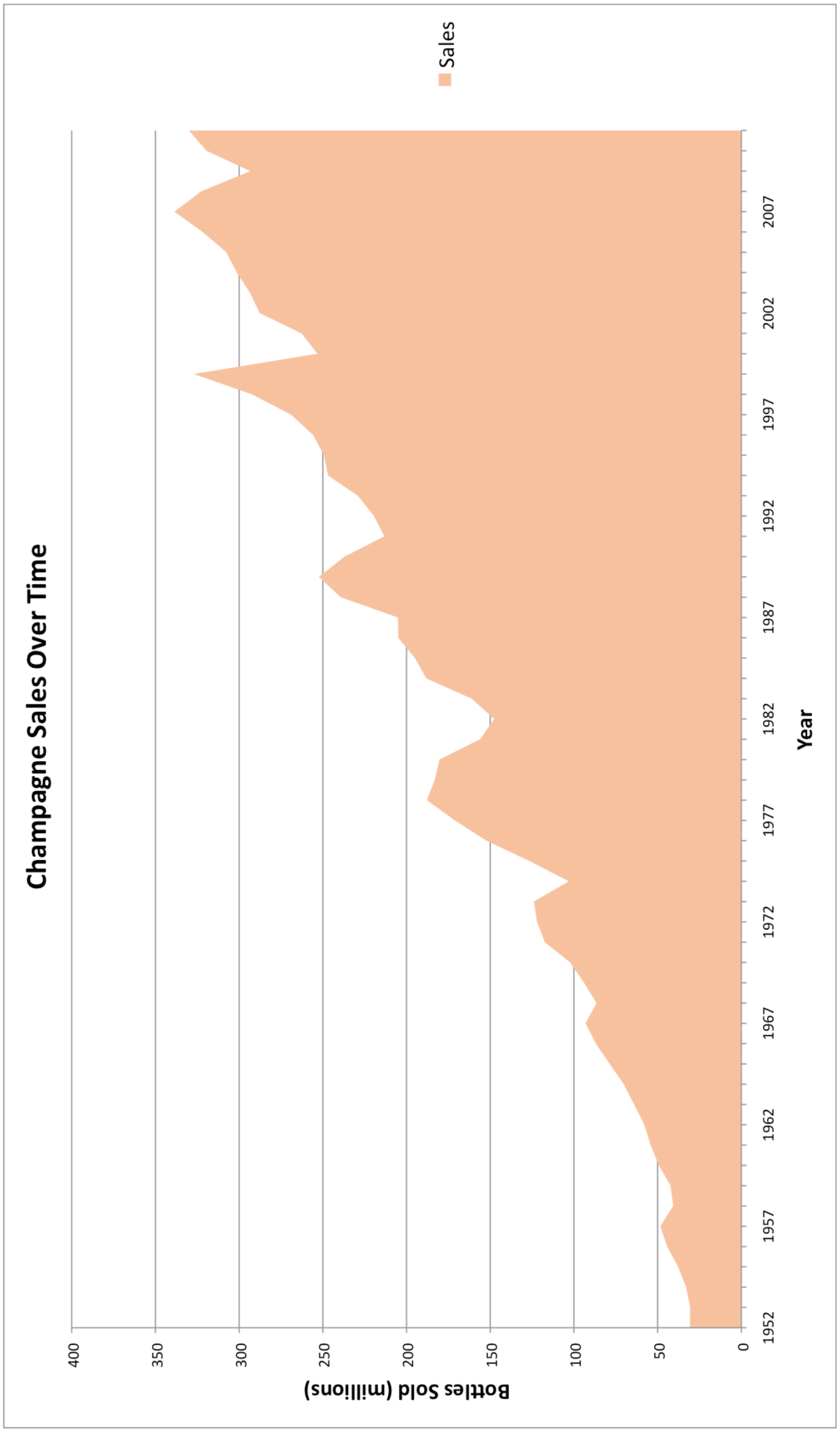

Figure 2. Minimum Variance Hedge

Optimal exercise values are determined by the variance of harvest values across all years. However, exercise values cannot go above the mean index value, as put options expected to be in the money will not be on the market. Sample: 240 data points at across the range of exercise values from 420 to 660. Data come from the CIVC and MDA information systems.

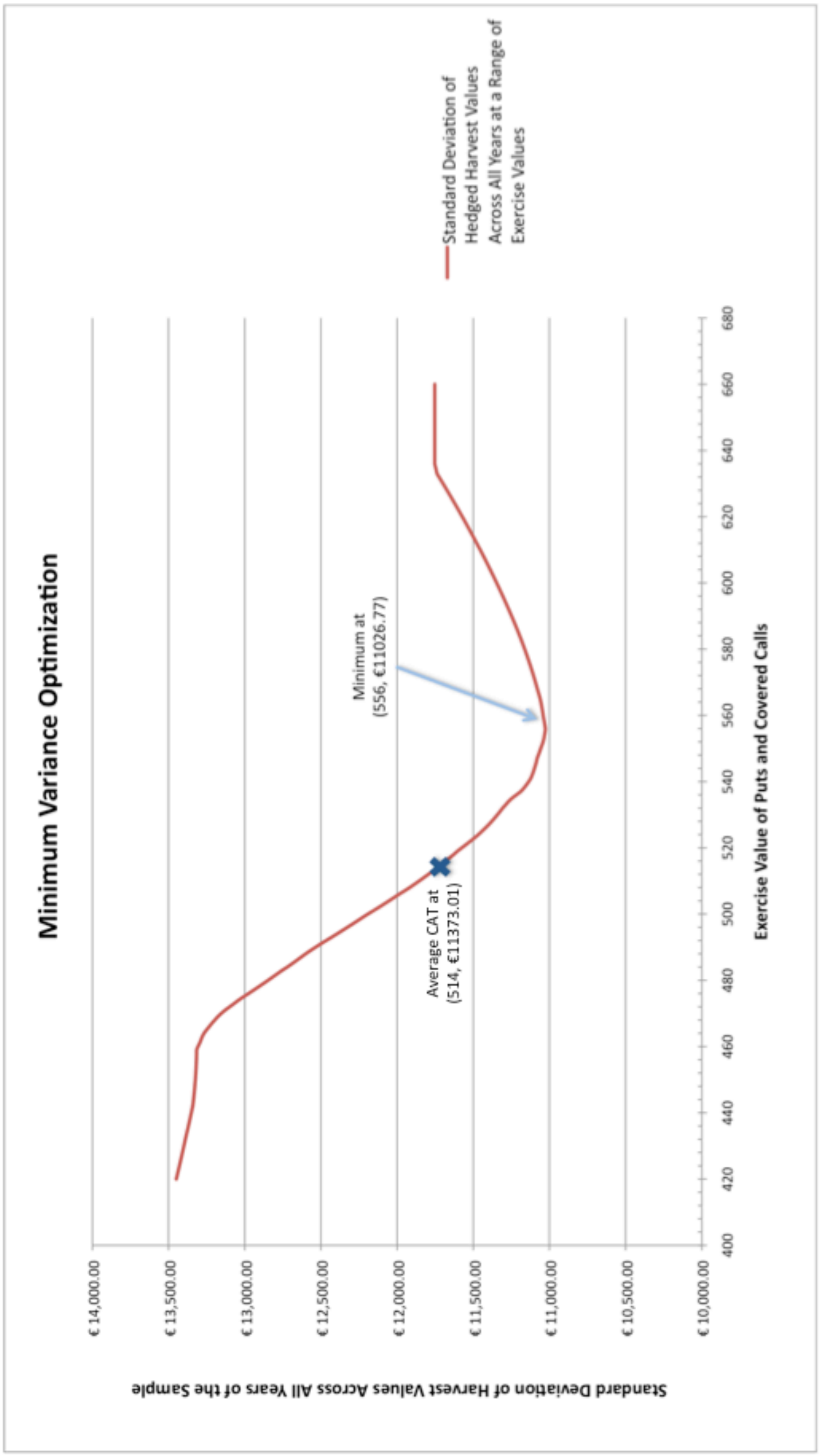

Figure 3. Average Harvest Yield Limit Over Time

The harvest yield limit is the quantity of grapes vignerons may sell to maisons in a given year. Sample: The arithmetic mean of each decade of 60 years of harvest yield limits from 1952 to 2011. Data come from the CIVC.

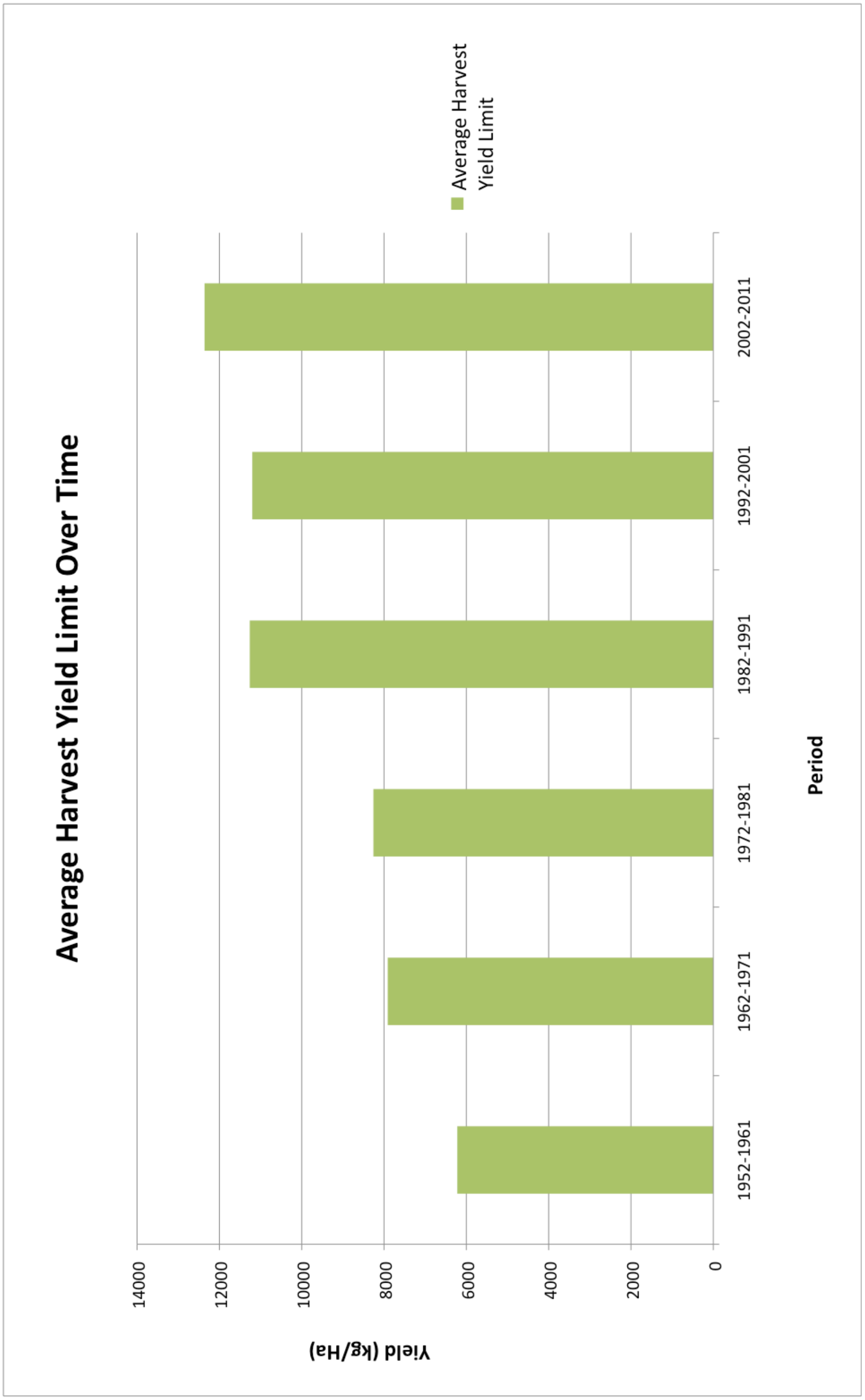

Figure 4. June Temperature Over Time

Grape vines flower in the month of June; warmer temperatures make for better harvests in the fall. Sample: 60 years of June temperature data from the Paris-Orly weather station for the period between 1952 and 2011. Temperature data come from MDA information systems.

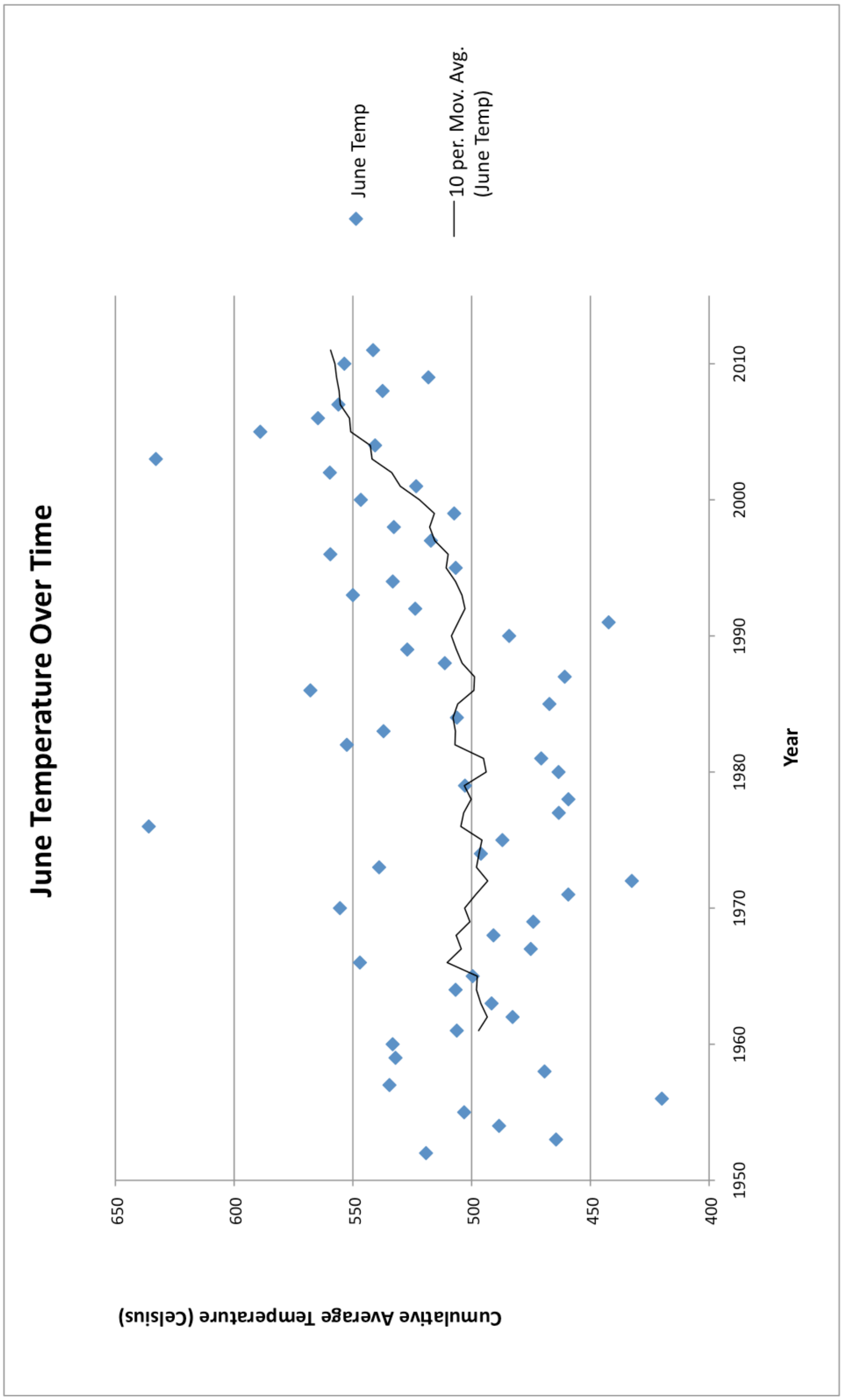

Figure 5. Harvest Value Over Time

Sample: 60 years of harvest yield limits and June cumulative average temperatures from 1952 to 2011. Harvest values are given as harvest yield limit/Ha*grape price/kg with a constant grape price in 2011 Euros. The harvest values with a hedge are given as harvest yield limit/Ha*grape price/kg+(June temperature-optimal exercise value)*optimal quantity of options. Harvest yield limit data comes from the CIVC; temperature data come from MDA Information Systems.

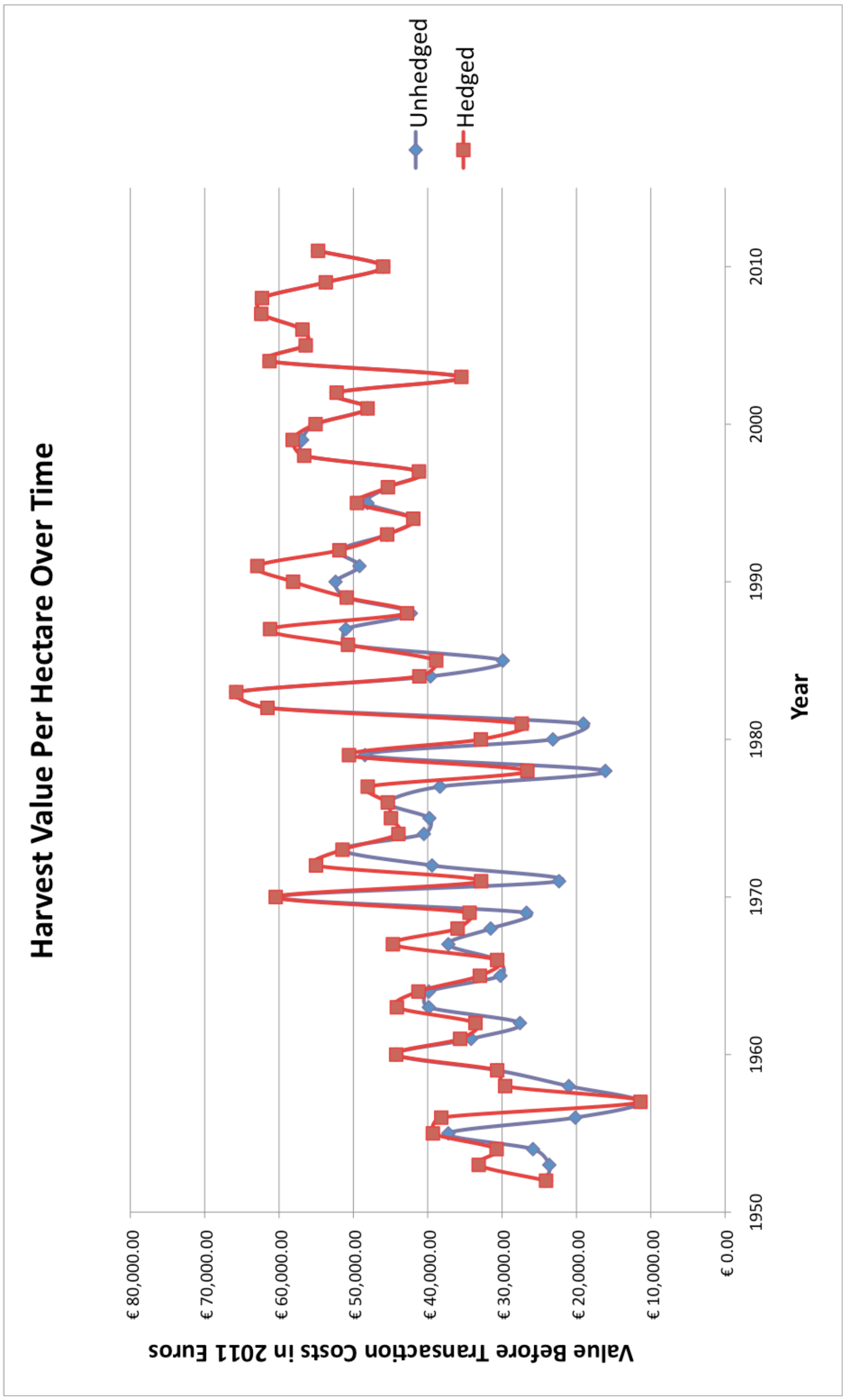

Figure 6. Hedge Value Over Time

Sample: 60 years of hedge values determined by 60 years of June cumulative average temperatures from 1952 to 2011 with a constant grape price. The value of the hedge is given as (June temperature-optimal exercise value)*optimal quantity of options*grape price. Optimal exercise values and quantities of options change significantly between 1991 and 1992. June temperature data come from MDA information systems.

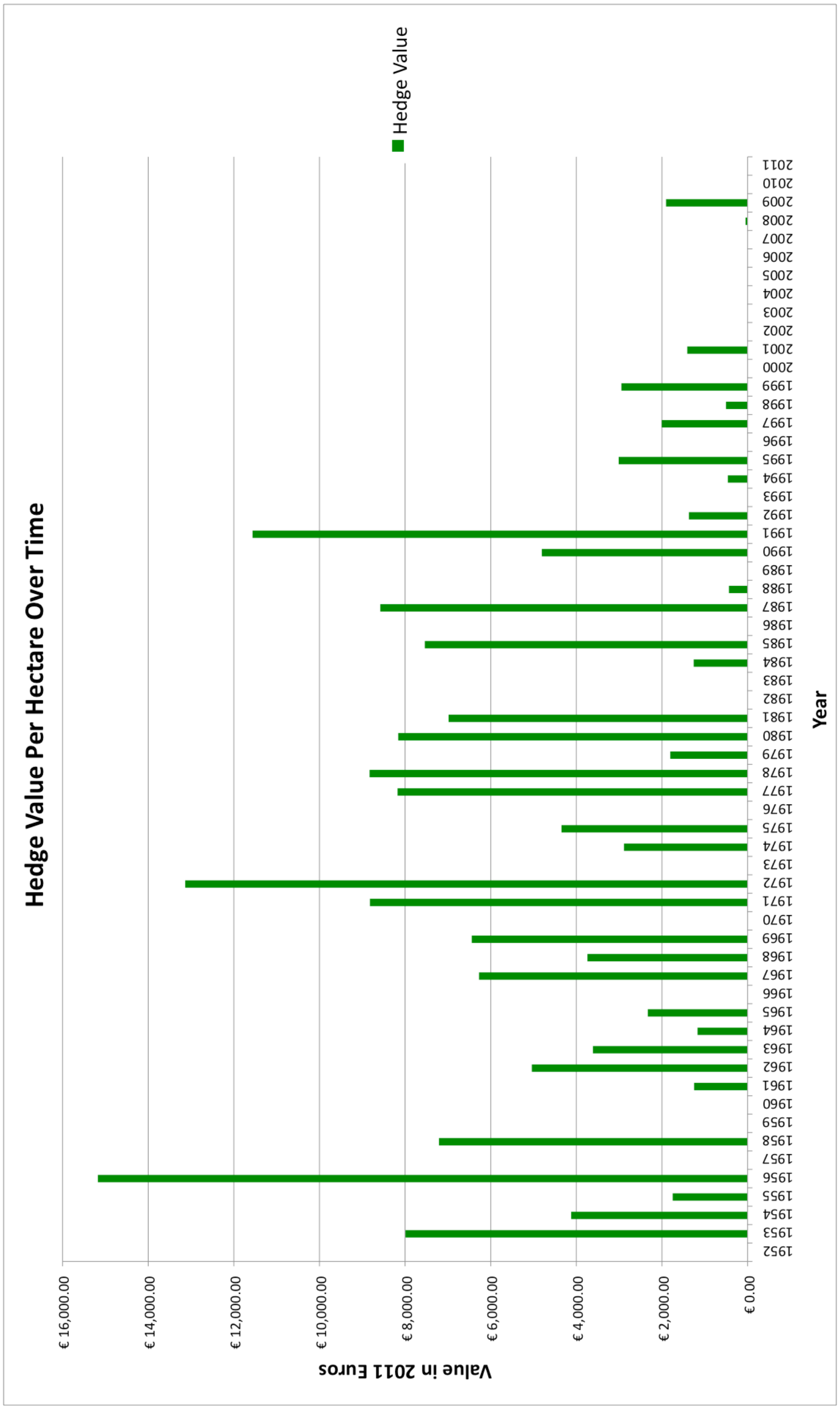

Figure 7. Average Harvest Yield Limit and June CAT Over Time

Sample: The arithmetic mean of each decade of 60 years of harvest yield limits and June cumulative average temperatures from 1952 to 2011. Harvest yield limit data comes from the CIVC. June temperature data come from MDA information systems.

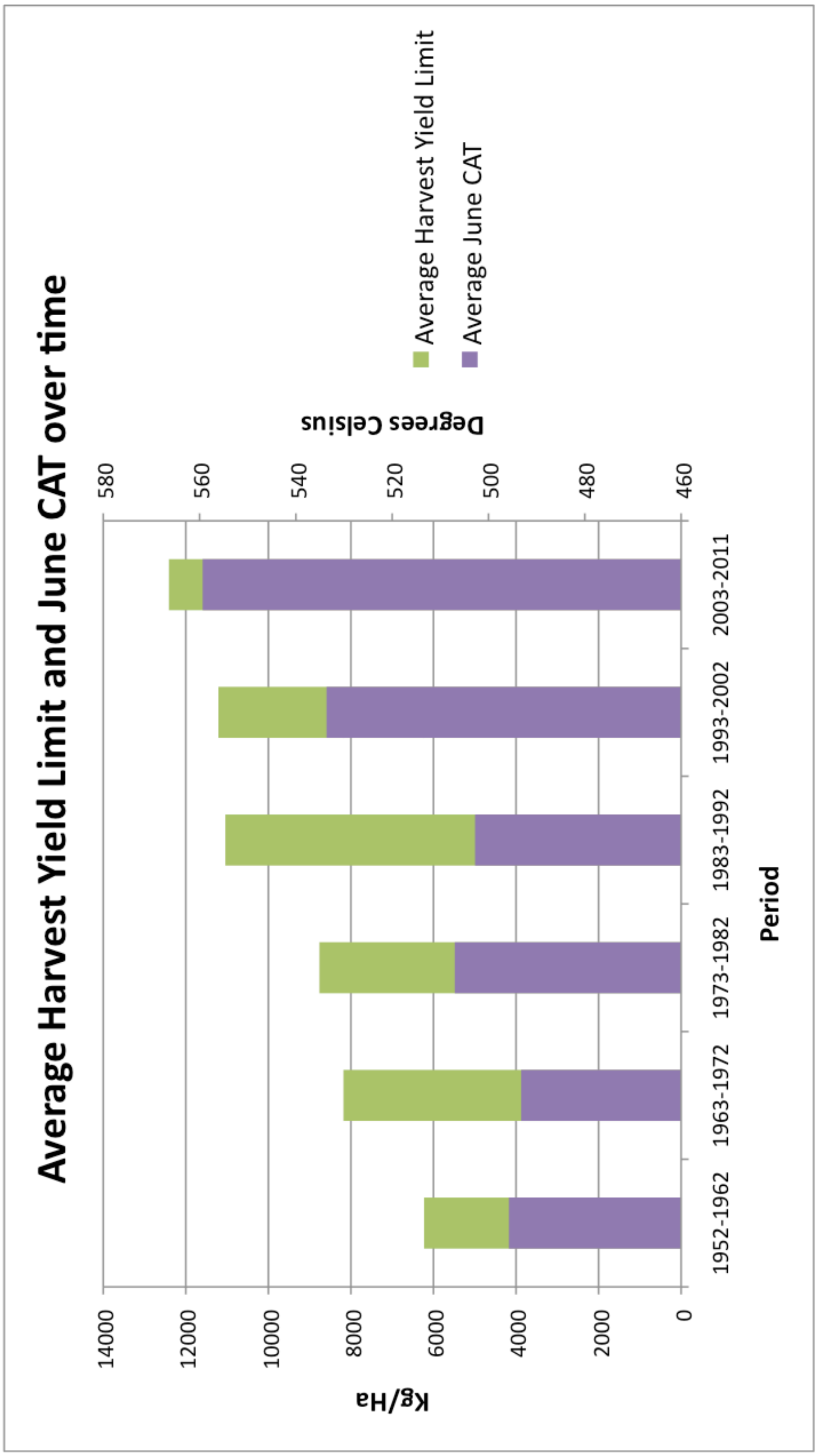

Table 1. Summary Statistics

Sample: 60 years of harvest yield limits, June cumulative average temperatures, and Champagne sales in millions of bottles from 1952 to 2011. Harvest values are given as harvest yield limit/Ha*grape price/kg with a constant grape price in 2011 Euros. The harvest values with a hedge are given as harvest yield limit/Ha*grape price/kg+(June temperature-optimal exercise value)*optimal quantity of options. Harvest yield limit data and Champagne sales data come from the CIVC; temperature data comes from MDA Information Systems.

	Summary Statistics		
Sample Period	1952-2011	1952-1991	1992-2011
Mean Harvest Yield (kg/Ha)	9536	8413	11781
Std Dev of Harvest Yield (kg/Ha)	3071	2997	1697
Median Harvest Yield (kg/Ha)	9613	8628	12096
Average Cumulative June Temperature (Degrees Celsius)	514	499	545
Std Dev of Cumulative June Temperature (Degrees Celsius)	43	41	29
Average Harvest Variance Reduction from Hedging Strategy (%)	31.32%	11.52%	1.49%
Average Harvest Value Increase from Hedging Strategy (%)	7.86%	6.10%	1.16%
Optimal Exercise Value	556	568	538
Equation for Optimal Quantity of Contracts	GrapePx*2.1821 +0.0232	GrapePx*1.6088 +.0196	GrapePx*0.9531 +0.0435
Significance of Harvest Value Correlation with June Temperatures (p-value)	0.00019	0.00504	0.32592
Regression Coefficient for Harvest Yield Limit on June CAT	31.768	31.454	-13.997
Correlation Coefficient of Harvest Values and June Temperatures	0.46318	0.43488	0.23828
Significance of Harvest Value Correlation with Champagne Sales (p-value)	0.	0.00005	0.18162
Regression Coefficient for Harvest Yield Limit on Champagne Sales	0.00002	0.00003	0.0002
Correlation Coefficient of Harvest Values and Champagne Sales	0.69098	0.59552	0.34012

Table 2. Sample Mean Variance Optimal Hedge 1952-2011

Sample: 60 years of harvest yield limits and June cumulative average temperatures from 1952 to 2011. Grape Px/Kg is the average of recorded grape prices for the period. Harvest values are given as harvest yield limit/Ha*grape price/kg with a constant grape price in 2011 Euros. The harvest values with a hedge are given as harvest yield limit/Ha*grape price/kg+(June temperature-optimal exercise value)*optimal quantity of options. Harvest yield limit data comes from the CIVC; temperature data come from MDA Information Systems.

	Year	June Temp	Yield Kg/Ha	Without Hedge	514	556
Grape Px/Kg	1952	519.2	5500	€ 24,090.00	€ 24,090.00	€ 31,141.47
4.38	1953	464.45	5400	€ 23,652.00	€ 33,146.57	€ 41,194.44
Ha in Production	1954	488.45	5900	€ 25,842.00	€ 30,737.79	€ 38,785.66
10000	1955	503.15	8500	€ 37,230.00	€ 39,309.03	€ 47,356.90
Qty Options/Ha	1956	419.9	4600	€ 20,148.00	€ 38,179.06	€ 46,226.93
9.5808	1957	534.6	2600	€ 11,388.00	€ 11,388.00	€ 15,488.58
Minimum Std Dev	1958	469.3	4800	€ 21,024.00	€ 29,589.23	€ 37,637.10
€ 11,737.01	1959	532.05	7000	€ 30,660.00	€ 30,660.00	€ 35,249.20
Strike Value	1960	533.25	10100	€ 44,238.00	€ 44,238.00	€ 48,597.26
514	1961	506.25	7800	€ 34,164.00	€ 35,649.02	€ 43,696.89
€ reduction of variance	1962	482.75	6300	€ 27,594.00	€ 33,582.00	€ 41,629.87
€ 43,141,421.54	1963	491.6	9100	€ 39,858.00	€ 44,150.20	€ 52,198.07
% reduction of variance	1964	506.75	9100	€ 39,858.00	€ 41,247.22	€ 49,295.09
31.32%	1965	499.55	6900	€ 30,222.00	€ 32,990.85	€ 41,038.72
% increase in revenue	1966	547.05	7000	€ 30,660.00	€ 30,660.00	€ 32,374.96
7.86%	1967	475.1	8500	€ 37,230.00	€ 44,683.86	€ 52,731.73
	1968	490.8	7200	€ 31,536.00	€ 35,981.49	€ 44,029.36
	1969	474.05	6100	€ 26,718.00	€ 34,373.06	€ 42,420.93
	1970	555.45	13800	€ 60,444.00	€ 60,444.00	€ 60,549.39
	1971	459.3	5100	€ 22,338.00	€ 32,819.39	€ 40,867.26
	1972	432.55	9000	€ 39,420.00	€ 55,027.12	€ 63,074.99
	1973	538.95	11750	€ 51,465.00	€ 51,465.00	€ 54,732.05
	1974	496.1	9250	€ 40,515.00	€ 43,944.93	€ 51,992.80
	1975	487.05	9082	€ 39,779.16	€ 44,943.21	€ 52,991.08
	1976	635.95	10359	€ 45,372.42	€ 45,372.42	€ 45,372.42
	1977	463.3	8757	€ 38,355.66	€ 48,070.59	€ 56,118.46
	1978	459.25	3678	€ 16,109.64	€ 26,600.61	€ 34,648.48
	1979	502.8	11061	€ 48,447.18	€ 50,593.28	€ 58,641.15
	1980	463.4	5289	€ 23,165.82	€ 32,861.59	€ 40,909.46
	1981	470.7	4353	€ 19,066.14	€ 27,363.11	€ 35,410.98
	1982	552.55	14054	€ 61,556.52	€ 61,556.52	€ 62,217.60
	1983	537.1	15012	€ 65,752.56	€ 65,752.56	€ 69,374.10
	1984	506.2	9048	€ 39,630.24	€ 41,124.84	€ 49,172.71
	1985	467.25	6827	€ 29,902.26	€ 38,860.31	€ 46,908.18
	1986	567.9	11582	€ 50,729.16	€ 50,729.16	€ 50,729.16
	1987	460.8	11647	€ 51,013.86	€ 61,207.83	€ 69,255.70
	1988	511.3	9650	€ 42,267.00	€ 42,784.36	€ 50,832.23
	1989	527.1	11619	€ 50,891.22	€ 50,891.22	€ 56,428.92
	1990	484.2	11963	€ 52,397.94	€ 58,108.10	€ 66,155.97
	1991	442.3	11228	€ 49,178.64	€ 62,917.50	€ 70,965.37
	1992	523.75	11844	€ 51,876.72	€ 51,876.72	€ 58,056.33
	1993	550	10379	€ 45,460.02	€ 45,460.02	€ 46,609.72
	1994	533.2	9577	€ 41,947.26	€ 41,947.26	€ 46,316.10
	1995	506.7	10986	€ 48,118.68	€ 49,517.48	€ 57,565.35
	1996	559.5	10356	€ 45,359.28	€ 45,359.28	€ 45,359.28
	1997	517.15	9402	€ 41,180.76	€ 41,180.76	€ 48,625.04
	1998	532.75	12926	€ 56,615.88	€ 56,615.88	€ 61,070.95
	1999	507.35	12989	€ 56,891.82	€ 58,166.07	€ 66,213.94
	2000	546.65	12577	€ 55,087.26	€ 55,087.26	€ 56,878.87
	2001	523.35	10980	€ 48,092.40	€ 48,092.40	€ 54,348.66
	2002	559.7	11930	€ 52,253.40	€ 52,253.40	€ 52,253.40
	2003	632.95	8100	€ 35,478.00	€ 35,478.00	€ 35,478.00
	2004	540.65	13990	€ 61,276.20	€ 61,276.20	€ 64,217.50
	2005	589	12880	€ 56,414.40	€ 56,414.40	€ 56,414.40
	2006	564.7	12980	€ 56,852.40	€ 56,852.40	€ 56,852.40
	2007	556.1	14244	€ 62,388.72	€ 62,388.72	€ 62,388.72
	2008	537.5	14222	€ 62,292.36	€ 62,292.36	€ 65,837.26
	2009	518.2	12263	€ 53,711.94	€ 53,711.94	€ 60,955.02
	2010	553.6	10500	€ 45,990.00	€ 45,990.00	€ 46,449.88
	2011	541.5	12500	€ 54,750.00	€ 54,750.00	€ 57,528.43
	Average	514.234167	9535.56667	€ 41,765.78	€ 45,046.73	€ 50,464.35
	Standard Dev.	43.4211671	3070.74519	€ 13,449.86	€ 11,737.01	€ 11,026.77

Table 3. Sample Mean Variance Optimal Hedge 1952-1991

Sample: 40 years of harvest yield limits and June cumulative average temperatures from 1952 to 1991. Grape Px/Kg is the average of recorded grape prices for the period. Harvest values are given as harvest yield limit/Ha*grape price/kg with a constant grape price in 2011 Euros. The harvest values with a hedge are given as harvest yield limit/Ha*grape price/kg+(June temperature-optimal exercise value)*optimal quantity of options. Harvest yield limit data comes from the CIVC; temperature data come from MDA Information Systems.

	Year	June Temp	Yield Kg/Ha	Without Hedge	499	568
Grape Px/Kg	1952	519.2	5500	€ 23,650.00	€ 23,650.00	€ 30,420.94
4.3	1953	464.45	5400	€ 23,220.00	€ 28,013.77	€ 37,587.44
Ha in Production	1954	488.45	5900	€ 25,370.00	€ 26,833.80	€ 36,407.47
10000	1955	503.15	8500	€ 36,550.00	€ 36,550.00	€ 45,547.86
Qty Options/Ha	1956	419.9	4600	€ 19,780.00	€ 30,755.03	€ 40,328.70
6.93744	1957	534.6	2600	€ 11,180.00	€ 11,180.00	€ 15,814.21
Minimum Std Dev	1958	469.3	4800	€ 20,640.00	€ 24,760.84	€ 34,334.51
€ 11,479.81	1959	532.05	7000	€ 30,100.00	€ 30,100.00	€ 35,088.02
Exercise Value	1960	533.25	10100	€ 43,430.00	€ 43,430.00	€ 48,251.52
499	1961	506.25	7800	€ 33,540.00	€ 33,540.00	€ 42,107.74
€ reduction of variance	1962	482.75	6300	€ 27,090.00	€ 29,344.67	€ 38,918.34
€ 148,935,728.67	1963	491.6	9100	€ 39,130.00	€ 40,156.74	€ 49,730.41
% reduction of variance	1964	506.75	9100	€ 39,130.00	€ 39,130.00	€ 47,628.36
11.52%	1965	499.55	6900	€ 29,670.00	€ 29,670.00	€ 39,167.36
% increase in revenue	1966	547.05	7000	€ 30,100.00	€ 30,100.00	€ 33,006.79
6.10%	1967	475.1	8500	€ 36,550.00	€ 39,866.10	€ 49,439.76
	1968	490.8	7200	€ 30,960.00	€ 32,097.74	€ 41,671.41
	1969	474.05	6100	€ 26,230.00	€ 29,691.78	€ 39,265.45
	1970	555.45	13800	€ 59,340.00	€ 59,340.00	€ 61,081.30
	1971	459.3	5100	€ 21,930.00	€ 27,438.33	€ 37,011.99
	1972	432.55	9000	€ 38,700.00	€ 47,919.86	€ 57,493.52
	1973	538.95	11750	€ 50,525.00	€ 50,525.00	€ 54,555.65
	1974	496.1	9250	€ 39,775.00	€ 40,177.37	€ 49,751.04
	1975	487.05	9082	€ 39,052.60	€ 40,710.65	€ 50,284.32
	1976	635.95	10359	€ 44,543.70	€ 44,543.70	€ 44,543.70
	1977	463.3	8757	€ 37,655.10	€ 42,608.43	€ 52,182.10
	1978	459.25	3678	€ 15,815.40	€ 21,330.66	€ 30,904.33
	1979	502.8	11061	€ 47,562.30	€ 47,562.30	€ 56,608.72
	1980	463.4	5289	€ 22,742.70	€ 27,682.16	€ 37,255.82
	1981	470.7	4353	€ 18,717.90	€ 22,644.49	€ 32,218.16
	1982	552.55	14054	€ 60,432.20	€ 60,432.20	€ 62,575.87
	1983	537.1	15012	€ 64,551.60	€ 64,551.60	€ 68,838.94
	1984	506.2	9048	€ 38,906.40	€ 38,906.40	€ 47,481.08
	1985	467.25	6827	€ 29,356.10	€ 33,761.37	€ 43,335.04
	1986	567.9	11582	€ 49,802.60	€ 49,802.60	€ 49,816.47
	1987	460.8	11647	€ 50,082.10	€ 55,382.30	€ 64,955.97
	1988	511.3	9650	€ 41,495.00	€ 41,495.00	€ 49,362.06
	1989	527.1	11619	€ 49,961.70	€ 49,961.70	€ 55,636.53
	1990	484.2	11963	€ 51,440.90	€ 53,494.38	€ 63,068.05
	442.3	11228	€ 48,280.40	€ 65,721.12	€ 56,147.46	
	Average	498.99375	8412.725	€ 36,174.72	€ 38,382.21	€ 45,984.95
	Standard Dev.	41.4425292	2997.17453	€ 12,887.85	€ 12,203.92	€ 11,479.81

Table 4. Sample Minimum Variance Hedge 1992-2011

Sample: 20 years of harvest yield limits and June cumulative average temperatures from 1992 to 2011. Grape Px/Kg is the average of recorded grape prices for the period. Harvest values are given as harvest yield limit/Ha*grape price/kg with a constant grape price in 2011 Euros. The harvest values with a hedge are given as harvest yield limit/Ha*grape price/kg+(June temperature-optimal exercise value)*optimal quantity of options. Harvest yield limit data comes from the CIVC; temperature data come from MDA Information Systems.

	Year	June Temp	Yield Kg/Ha	Without Hedge	538
Grape Px/Kg	1992	523.75	11844	€ 59,220.00	€ 60,590.57
5	1993	550	10379	€ 51,895.00	€ 51,895.00
Ha in Production	1994	533.2	9577	€ 47,885.00	€ 48,346.66
10000	1995	506.7	10986	€ 54,930.00	€ 57,940.43
Qty Options/Ha	1996	559.5	10356	€ 51,780.00	€ 51,780.00
5	1997	517.15	9402	€ 47,010.00	€ 49,015.35
Minimum Std Dev	1998	532.75	12926	€ 64,630.00	€ 65,134.95
€ 8,421.63	1999	507.35	12989	€ 64,945.00	€ 67,892.92
Exercise Value	2000	546.65	12577	€ 62,885.00	€ 62,885.00
538	2001	523.35	10980	€ 54,900.00	€ 56,309.04
€ reduction of variance	2002	559.7	11930	€ 59,650.00	€ 59,650.00
€ 1,059,204.56	2003	632	8100	€ 40,500.00	€ 40,500.00
% reduction of variance	2004	540.65	13990	€ 69,950.00	€ 69,950.00
1.49%	2005	589	12880	€ 64,400.00	€ 64,400.00
% increase in revenue	2006	564.7	12980	€ 64,900.00	€ 64,900.00
1.16%	2007	556.1	14244	€ 71,220.00	€ 71,220.00
	2008	537.5	14222	€ 71,110.00	€ 71,158.09
	2009	518.2	12263	€ 61,315.00	€ 63,219.36
	2010	553.6	10500	€ 52,500.00	€ 52,500.00
	2011	541.5	12500	€ 62,500.00	€ 62,500.00
	Average	544.6675	11781.25	€ 58,906.25	€ 59,589.37
	Standard Dev.	29.2155297	1696.85663	€ 8,484.28	€ 8,421.63

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