Recommendations on Cultivating Wine Varieties in the Finger Lakes

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EXECUTIVE SUMMARY

We were asked to advise a firm in the Finger Lakes region about the proportions of its vineyard that should be allocated to six different types of varietals given that it wants to maximize profits and minimize risk.

We established early on that minimizing risk and maximizing profits are interdependent, and we incorporated this into a constrained profit maximizing model by taking into account how the temperature and yield interact with the costs and temperature ranges associated with each varietal. We use our model to figure out when the vineyard owner would be recommended to transition the crop to one more suited to expected temperatures, and we typically found that the vineyard owner should not change the crop too rapidly.

Based off our expectations for increasing temperatures and the need to accommodate for extreme changes in the temperature, our model has predicted that Cabernet Franc and Merlot become the grapevines of choice that will be profit maximizing; however, throughout the years leading up to their dominance, there are shifting proportions of many varietals.

PART 1. THE QUESTION

We have been asked to provide a Finger Lakes winery assistance on what the allocations (proportions) of **R**iesling, **G**erwurtztraminer, **C**hardonnay, **M**erlot, **P**inot Noir, and Cabernet **F**ranc grapes for their vineyard should be, given that the firm wants to maximize its annual profit. As profit is largely dependent on temperature, the best advice we can provide is a hedging strategy of the proportions of each type of wine grape should be given the temperature ranges of each. Since temperatures and prices are expected to change in the long term, we were asked to recommend when the winery should consider growing different proportions of each grape. From this point, we will refer to each wine with its capital letter, in **boldface**.

PART 2. QUALITATIVE CLARIFICATIONS

In this section, we consider some economic circumstances of the firm to motivate our model and provide necessary intuition; this will help justify our methodology of deducing the prices and our hedging strategy. We will proceed in further detail once we introduce the actual math in the paper.

THE MARKET

We consider this firm to be part of a **monopolistically competitive** market, viz. the Finger Lakes market for wines. From a monopolistic point of view, the firm is selling a differentiated product compared to its competitors, its own label of wines (we assume that the firm does not sell its grapes to other firms). Furthermore, this firm can reasonably expect to make a profit; since there are barriers to entry, like costs of land or facilities that a potential market-entering firm would have to swallow for its first few years of operation, not all the potential profits in this industry would be eroded as is the case in pure competition.

In monopolistic competition, a firm sets its own supply equal to its marginal cost, and produces at the price demanded that corresponds to the quantity where marginal cost equals the marginal revenue (which is derived from the demand). The pricing in this model for grapes will be considered to be a function of the yield of the firm in question, and throughout the analysis we assume that the firm's wines are relatively substitutable with the other firms' products.

From a competitive point of view, the number of wineries in the Finger Lakes is large – roughly 130 (A), so we do not expect that the firm has a *major* impact on the price of the wine. Actually, since all the firms in the market will face the same climate conditions and consumer demands in long run equilibrium, all the firms in the market will be pricing their wines the same as what they consider to be equivalent wines from their competitors. This will simplify analysis of what we expect the firm to charge in the future, given the large amount of historical data on the prices of wine. The wine connoisseur Robert Joseph said in May 2013 that "When wine was bought as a luxury… people were more interested in the pleasure or status the liquid confirmed." Consequently, he feels that wine is in reality treated as a commodity (B). In either case, whether the firm is monopolistically competitive or, as Joseph indirectly implies, mainly competitive, by treating all the prices as those considered after the market has digested data about climate conditions and other vineyards' losses, the pricing should converge.

The market for grapes is a bit trickier to consider, since a grape is a grape. However, these grapes are not intended for direct commercial consumption, and each vineyard will have its own standard for growing the grapes for the wineries. Therefore, grape-growers in the Finger Lakes may also be considered to be monopolistically competitive (which explains variations in the prices of each grape that we shall see later in this report). As in the case with the wines however, all the grapes will be priced similarly in the long run and the problem almost decomposes to that of a competitive market. This makes sense, since “ordinary” grapes are commodities and are priced accordingly (in a competitive market).

PROFITS

As the firm has mentioned, whenever a grape vine is planted, it takes three years for it to start producing fruit. This means that the firm must plan ahead for future temperature changes three years in advance if it wants to have a crop that is best suited to that future years’ average temperatures. For the firm’s success three years on, it must swallow some profit in two ways: some acreage of the vineyard is not producing any profit since it is not fully grown nor producing any fruit, and the resulting available plots of land (which are smaller than size) means that overall the firm is producing fewer grapes than before. **Unless we state otherwise, we are profit maximizing grapes for a time *at least* three years in advance** (we can delay planting the new crop until the time closest to when the plant will flower when its favourable conditions happen, or we can do it earlier)**.** Each year, we will update our estimates of profit given the present year’s profit. To save money, if a plant exists, and there is another plant that will be more profitable in three years’ time, we will still keep the existing plant if we expect that it will continue to generate revenues.

The firm cannot constantly update its expectations for future, because if it is always choosing to switch its crop, there will be a waste as the firm tries to chase the temperatures of each year. This makes sense; given the partial element of randomness in the temperature, there should be no distinction of successfully matching a current crop with future conditions between a firm which chooses to constantly update its plans for allocating for certain grapes or if it slows down and a firm which only chooses to evaluate its position after some arbitrary unit of time, since whatever weather occurs is not bounded by the firms’ expectations. However, the firm will have to re-evaluate its crop after a reasonable amount of time, otherwise it is entirely possible that either the crop will be unsuited to current demands (and hence is not profit maximizing) or may be altogether dead.

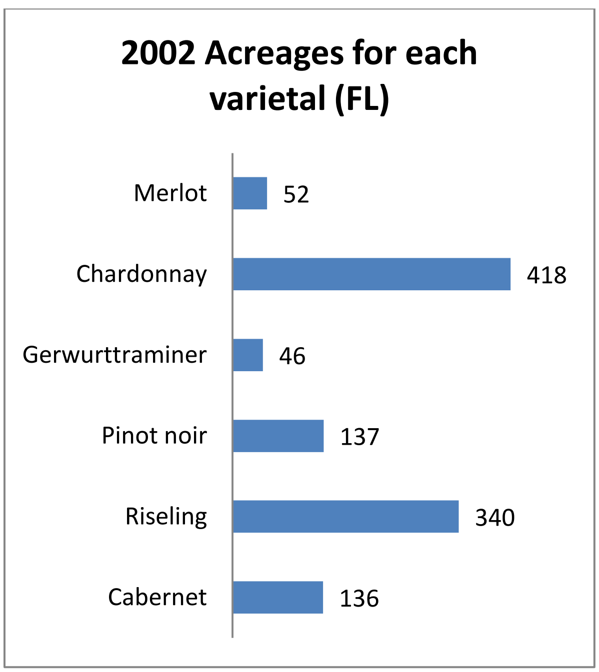
Although we must maximize profit, the firm is only asking for the ideal proportions of the varieties in the crop each year, which means that the exact number in dollars of the profit is not meaningful.

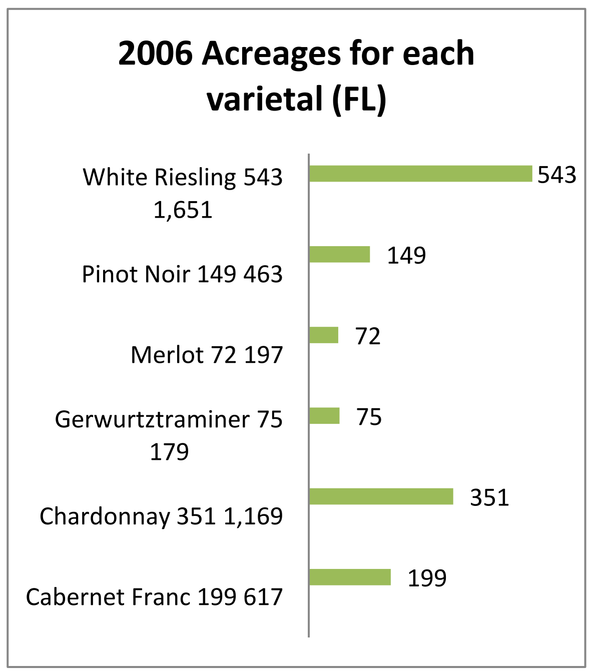
CONCERNING GRAPES

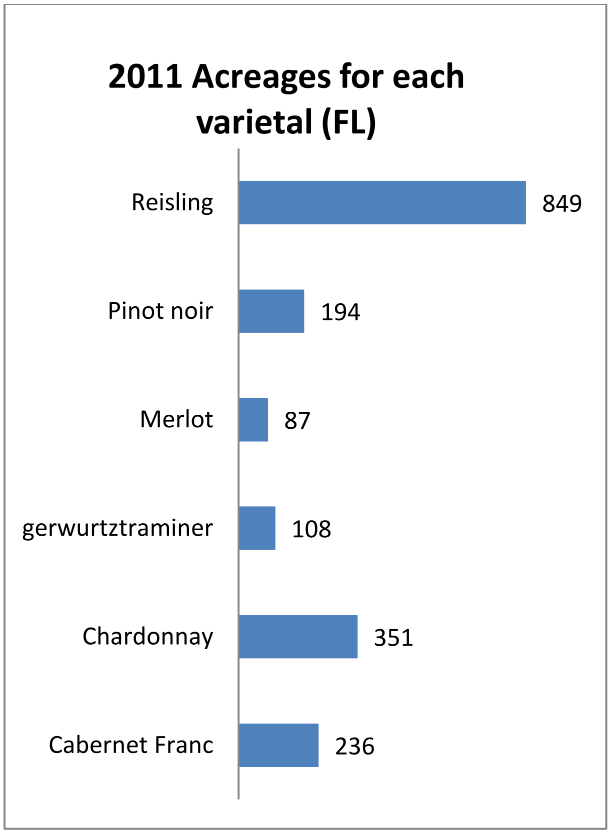
The firm we are advising is an established winery that has both its own vineyard as well as its wine processing facilities. Since the exact value of the profit is not necessary to calculate, it is reasonable to think that maximizing either the profit of the wines sold (which incorporates a five year delay, since wine plants may take three years to grow and then one year to harvest, followed by two years in processing (H)) or the market value of the grapes produced, should yield similar, if not the same, profit-maximizing allocations of the vineyard. Moreover, it is a simple economical fact that the price of the output is related to the price of the input, therefore the cost of the wine should share a very high degree of correlation with the cost of the grapes. High quality grapes produce high quality wine (although "special" treatment may increase the wine cost slightly), and low quality grapes give low grade wine. *Ceteris paribu*s, **a firm that profit maximizes grapes for the third year will be profit maximizing the wine sold in the fifth year.**

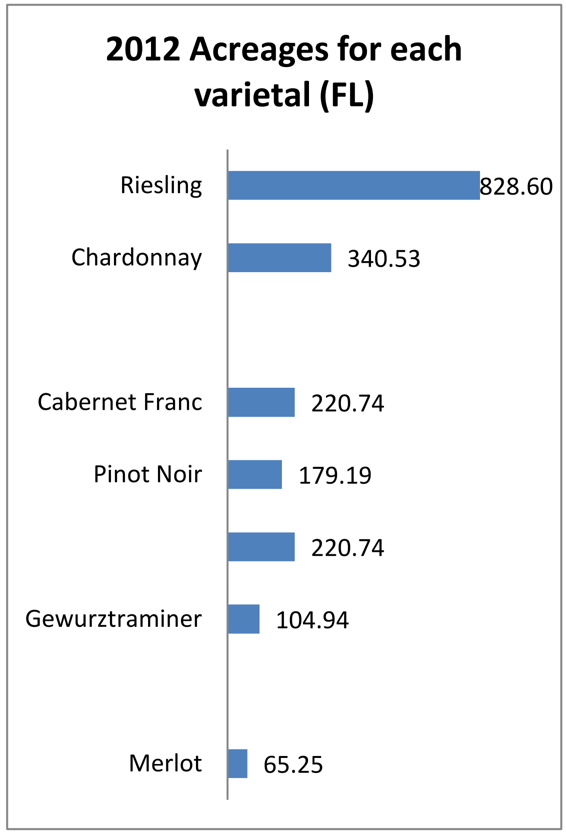
We think of profit maximization in terms of grapes, and not because of the greater availability of data. Actually, profit maximization in terms of the wines sold may be easier, given the fixed costs of the facilities and the only input in the model being the costs associated with and the number of the grapes, but examining the problem from the perspective of the grapes allows a better analysis of how temperature can affect the yield and price of the grapes. Furthermore, the firm's question is what the proportion should be of the grapes they are growing, so we wanted to stay close to the investment at hand—the grapes.

We initially thought that we could consider the industry as a whole and let the firm choose its proportions as the entire Finger Lakes industry does—because the market would have known best. However, we found that the proportions of the varietals, while general trends might be preserved (for example, the continued popularity of Riesling), the proportions still change. We were unable to research futures markets for the grapes to come up with an estimate for the price of the wine. We provide the total acreage throughout the years in the Finger Lakes region allocated to each varietal below (L,M,N,O). If one calculates the proportions for each year, they change.









COSTS

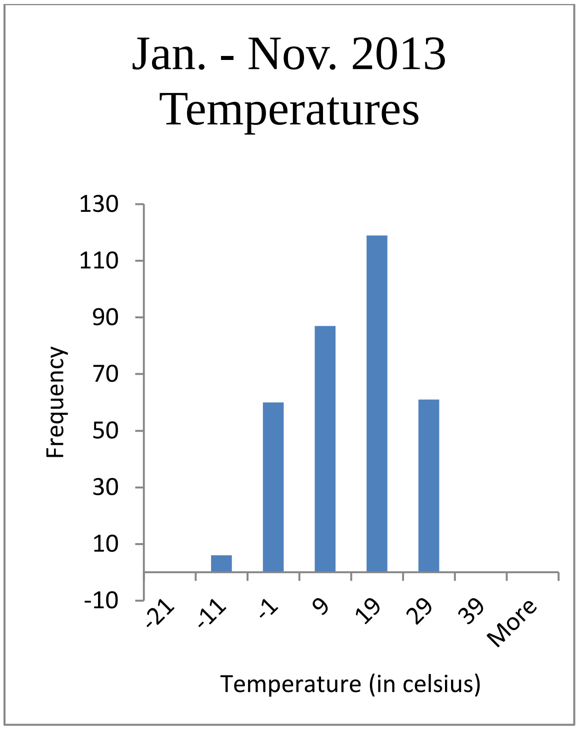
We consider costs to be the costs associated with cultivating each kind of grapevine. We assume that the firm will operate for at least three years if the cost of harvesting the crop is less than the revenue created. In a sense, if part of the crop falls ill or is damaged, for instance if the trunks of the grapevine are damaged, then it will need to be replaced and it will take three years for that unit to produce grapes and profit again.

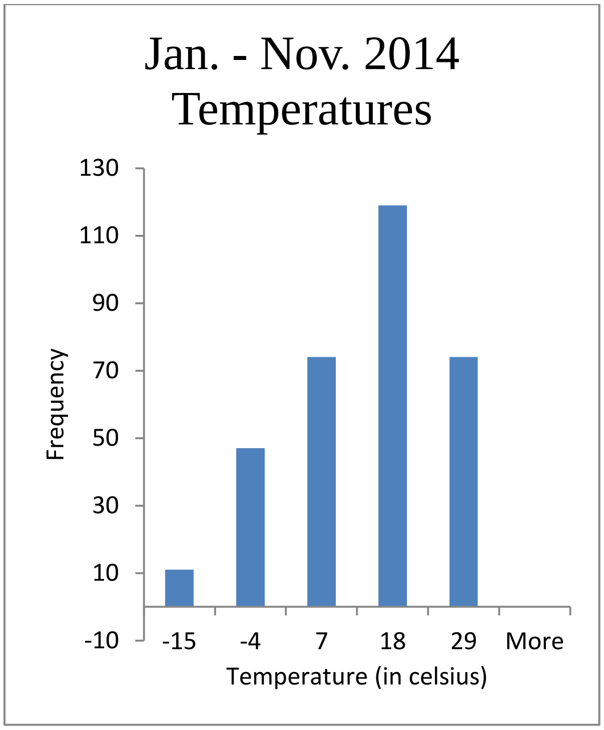
We do not consider fixed and unavoidable costs in this model, for instance the costs of the winery facilities or the costs deracinating an old crop to make way for a new plant species. The reason being is that this does not directly affect the proportions of each type of grape. However, we consider costs such as watering the grapes as fixed costs not related to the yield, since it is entirely possible for the firm to spend a lot of money on a crop, only for there to be no harvest if a crop fails.

In our model, we choose to pick the varieties that will best perform under the predicted temperature conditions. In case part (or the entire crop) is expected to fail, we choose to substitute with another type of grape. If we suggest that the firm plants a crop since we predict favorable conditions, and then the crop suffers from frost or a cold snap during the growing season, then this will be factored in as a cost.

TEMPERATURE AND ITS RELATIONSHIP WITH THE MODEL

Most of our model is based off temperature, which is predicted from existing data. We found that the average daily temperatures in any given year are normally distributed, which simplifies calculations for the predictions of future years. We illustrate the histograms for the months January to November for years 2013 and 2014 below of the Finger Lake's temperatures*. As expected, the mean temperatures of the average daily temperatures were similar, as were the standard deviation.





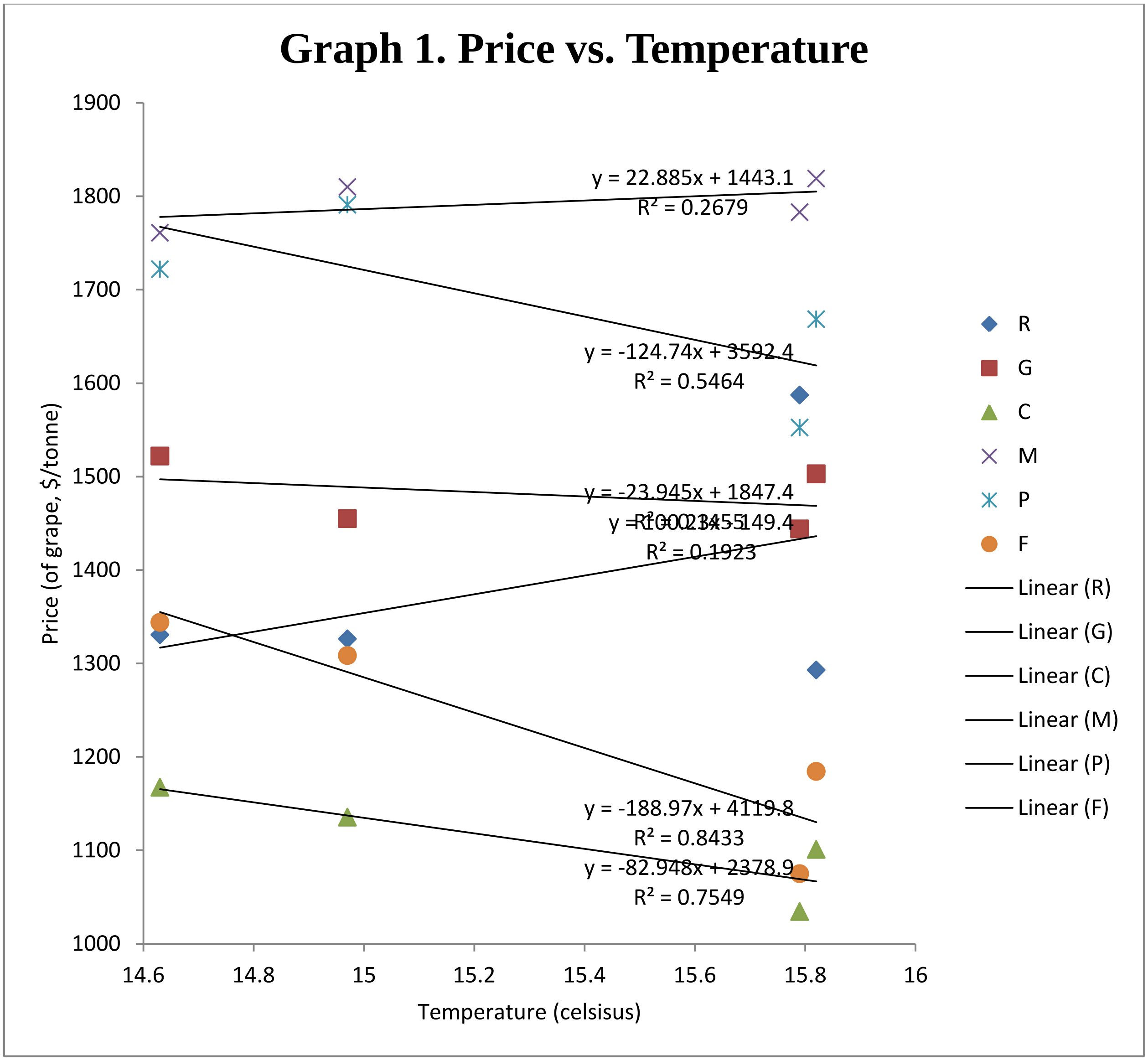
	Mean	Standard Deviation
2013	9.0577	10.14296
2014	**7.9533**	**11.38175**

*These values were calculated from data from the Northeast Regional Climate Center by Cornell University (E).

We assume that temperature will increase by 4 degrees centigrade by the end of this century. This has two implications for our analysis: a) the long run proportions of the crop should stabilize in the long run since the need to hedge against cold snaps may decrease, so we should have a rough idea that the crops chosen will be more chosen to be both highly profitable *and* thriving at high temperatures.

To predict temperature, we take treat the 2014 mean value and standard deviations of the seed and construct a random distribution with its mean equal to the 2014 mean and its variance equal to the 2014 variance. We then proceed to find normally distributed temperatures for every year whose mean temperature is slightly increased from the previous year. All subsequent calculations will not involve changing the variance, since each normal model is homoskedastic (the standard deviations calculated for previous years such as in 2005 were similar to those in 2014 and 2013), but we add a term equal to (0.04 Celsius/ Year) * the year to the previous year's mean to get the present year's mean. This is our `Temperature` function, whose argument is time in element of years. Therefore, $temp\widehat{era}ture$ is a linear function of the mean of a year's average daily temperatures. The unpredictability is represented by spread of the normal models.

Preliminary investigations on data from the Cornell Finger Lakes Grape Program (D) revealed that some of the varieties' average temperature and price of grapes had a weak or very weak degree of correlation. Depending on the variety, a certain type of grape will not be grown if the temperature is unfavorable, and so they would never be available to consumers at a price in the first place (**Graph 1)**.



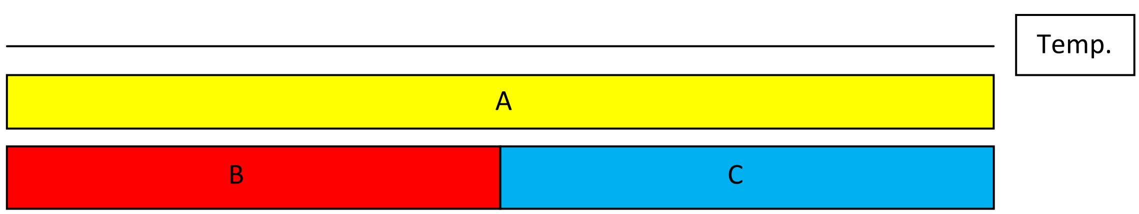
We define our productivity function's output as yield. Productivity is influenced by temperature. To better consider the long run, we aim to construct a model that will also take into account inflation. We think that the long run proportion will be largely independent of proportions in the short run, since the temperature ranges in the growing season will be changing each year. Since yield and quality are inversely related, and since yield and temperature are related, quality and temperature are related.

HEDGING

The strategy is simple. Given whatever species can survive in a given temperature range, we pick the one that we predict to be the most profitable. This will help ensure that the expected profit of the crop is as positive as possible. The hedging strategy that we will suggest in this report is grounded in the fact that the firm, whenever it chooses to upgrade its vineyard's crop, must imagine what the temperatures will be like for three years in advance, and then plan to grow the variety best suited to the average temperature ranges predicted.

Assuming there is no dead vegetation (which the firm could not avoid to suffer), the firm is subtracting profit by substituting a revenue producing variety with plants that take three years to return the profit. In the situation that there are three grapes, A, B, and C as shown in **figure one** , even if C might be predicted more profitable than A for any particular year, we will suggest that the firm choose to remain with A rather than diversify with B and C, since there is a chance that C will die out if the temperature is below its ideal temperature range. In the long run, A will perform better than B and C combined.

Figure One: In this scenario, given each plant's temperature ranges and profitability, where Pc > Pa, we stick with plant A. This is because C may fail.



Therefore, no matter how risk averse the firm is concerning the third year from their present time of evaluation, unless a crop is expected to completely fail, the firm cannot completely substitute an entire crop since the chances of not producing returns are too great.

In this model, we do not consider the costs of transitioning (i.e. any lost revenues in the profit maximization) because although there will be changes in the proportions of areas that are generating profit (with the other areas being sown with the new type of grape), profit maximization implies cost minimization; in a sense, the introduction of another species that may have **better chances of survival** and thus increase profits, will be minimizing risk because the crop will have increased diversity. **The proportion of each type of grape crop in the present viewing frame is related to the probability that the crop succeeds.**

When we begin our analysis of the firm, we assume that the firm will accept that the first three years could theoretically produce zero profits since we may end up suggesting that the firm should be substituting the existing crop entirely, if the existing crop is not predicted to be dead in the second year (or if it is not dead already).

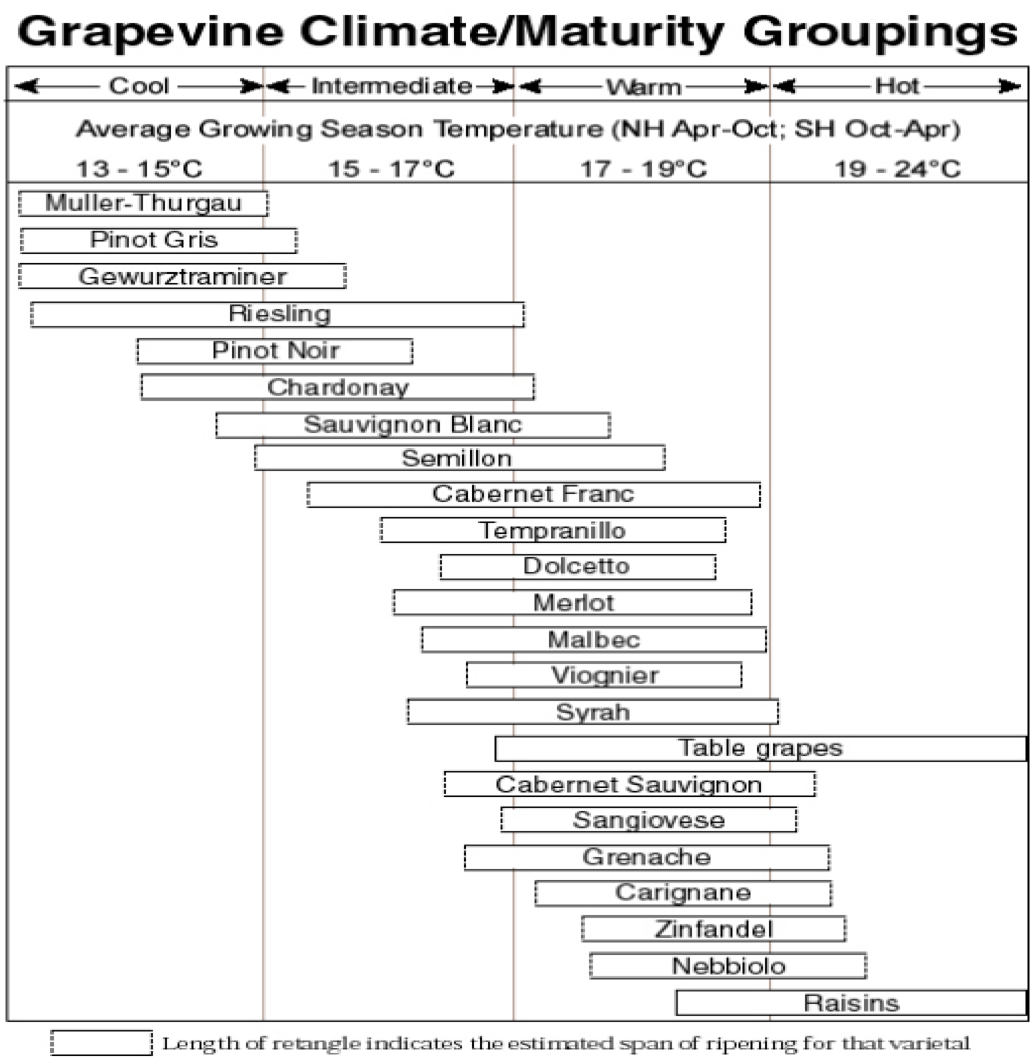
AREA OF THE VINEYARD

The firm will always be growing at least two different varieties of species to hedge against low temperatures, and to profit maximize given the high temperatures that are also expected. The number of the type of grapes is also related to the size of the area of the vineyard however, since certain types of grapes will not produce good wine if their aromas are contaminated. Of course, it is also the case that the smaller the area, the greater the feasibility of handpicking the grapes (which will both increase price and increase costs). We will keep the area variable and expect our model to work for both high acreage and low acreage vineyards.

PART 3. PROPERTIES OF THE GRAPES

Each wine grape has its own costs to grow, potential prices to be sold at, and average temperatures at which it can safely be assumed to grow. They also have certain tolerances for extreme temperature changes during the growing season and during the winter.

Certain grapes are required to be planted in high density, particularly the Gerwurztraminer. Therefore, in order for its yield to be comparable to the other varieties, this will have to be taken into consideration, most likely with a constant (C).



The above diagram shows the growing temperature range best suited for each type of grape (F).

The following are the optimal average temperatures during growing season (April to October in north hemisphere).

R: 13.2 ~17.1	C: 14 ~17.2	P: 14 ~16
G: 13.1 ~15.1	M: 15.7 ~18.8	F: 15.3 ~18.9

Currently, Riesling is the dominant grape varietal in the Finger Lakes (I).

PART 4. FUNCTIONS

Yield

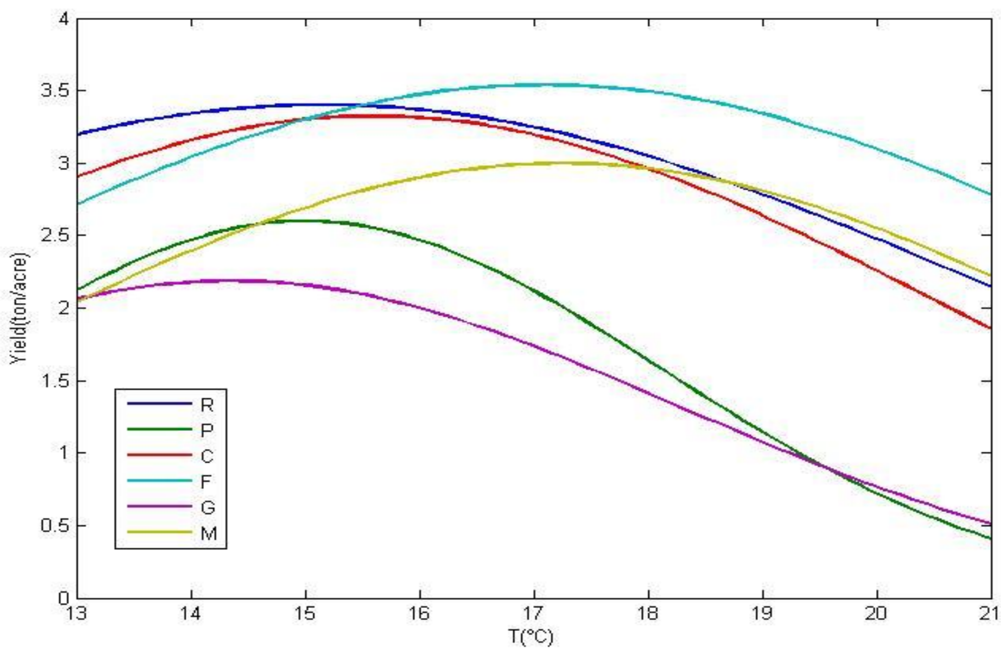


Figure #2 Yield as a function of AGST for each variety.

The yield of a variety depends on whether the average temperature during growing seasons lies within its optimal temperature range. We get the optimal Average Growing Season

Temperature (AGST). And we assumed that the dependency of the yield on AGST follows a Gaussian function, whose mean value is the middle point of the optimal AGST range. Because the yield will not change dramatically within the optimal AGST range, we take the standard deviation of the Gaussian function so that the ratio between the yield values at the middle of the peak and at the edge of the optimal AGST range is 0.95.

Now, we have to determine the peak height of the Gaussian function. On Table 1, we have the actual data for the yield and the corresponding year's AGST. Using the data set, we estimated the peak yield value. The result is in **Figure 3.** The justification for the normal model's downward sloping tales is that the vineyard manager is risk averse.

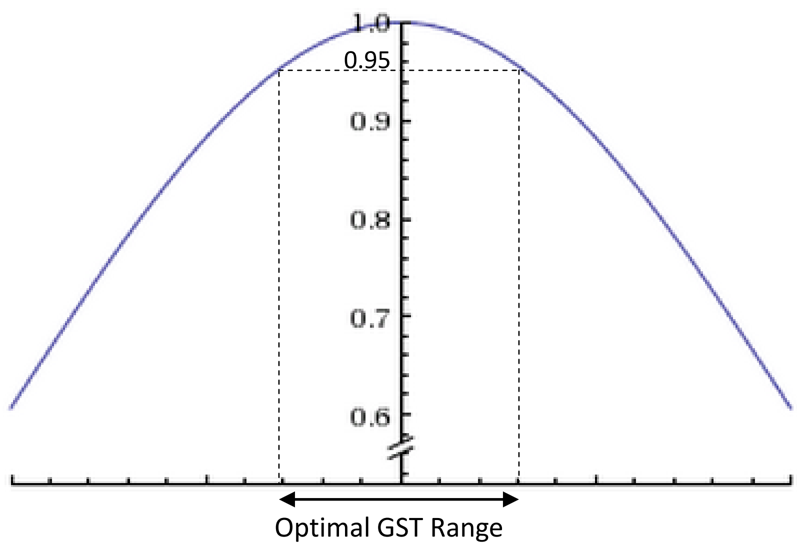


Figure #3. Yield estimation. The y-axis is the relative yield value, and the origin of the x-axis is at the middle of the optimal average growing season temperature range.

Table 1 Optimal AGST Range data
Real Yields Data is from Yeh, etc., 2014 (R, P, C, F) and from 2012 Oregon Vineyard and Winery Census Report (G, M)
AGST of corresponding year was obtained in http://www.nrcc.cornell.edu/climate/ithaca/ (R, P, C, F, near Finger Lakes Region) and http://www.usclimatedata.com/climate/portland/oregon/united-states/usor0275 (G, M near Portland, Oregon).

Varieties	Optimal AGST Range (°C)	Real Yields Data (ton/acre)	AGST of corresponding year (°C)
R	13.2~17.1	3.4	15
P	14.0~16.0	2.6	15
C	14.0~17.2	3.3	15
F	15.3~18.9	3.3	15

G	13.1~15.6	2.0	16
M	15.7~18.8	2.9	16

Cost

We get the data of the cost per acre for the varieties R, P, C, F from Yeh, etc., 2014. (Figure 3) The graph, based on the obtained data, tells us an obviously linear relation between the cost per acre and the yield. For other two varieties, M and G, we couldn't find relevant data. Based on the fact that the cost/acre—yield lines do not differ much between varieties, we assumed that M and G follows the average line of other four lines.

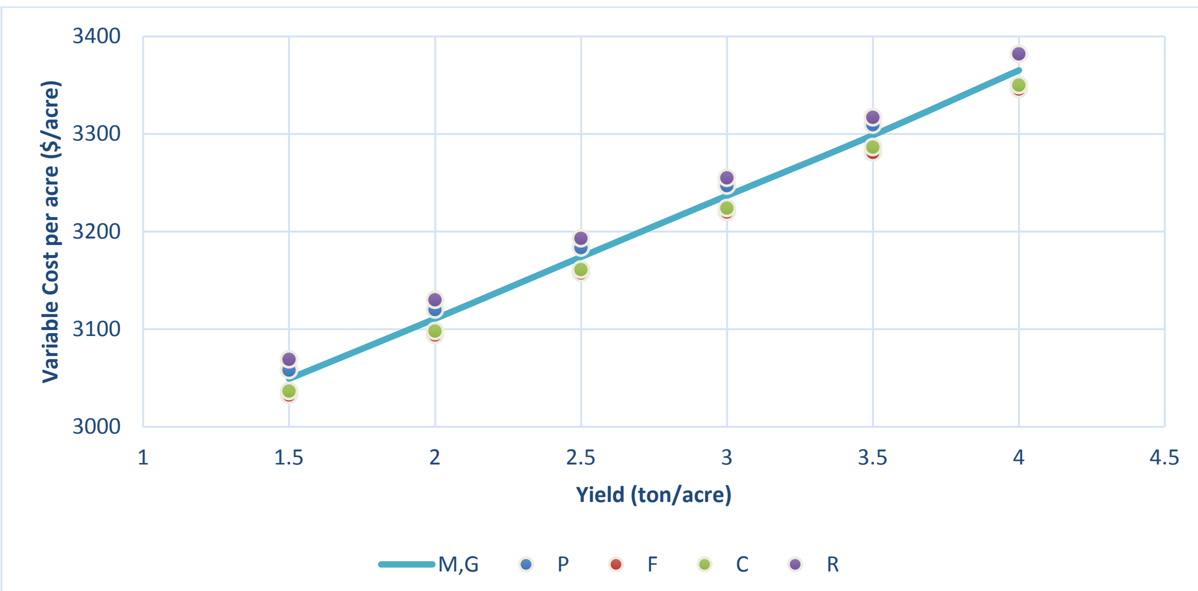


Figure #4 R, P, C, F follow the actual data from Yeh, etc., 2014. Because there are no significant differences between the lines, we took the average and assumed that M and G follow that average line.

Susceptibility to Winter Injury Module

In this module, we take into account the mortality during the harsh winter. There is an

Low Winter Temperature (USDA Hardiness Zone)	*Suitable Varieties*	
0°F (Zone 7a)	Almost any	M, G
-5°F (Zone 6b)	Most northern vinifera	P, C, F
-10°F (Zone 6a)	Hardy vinifera and moderately hardy hybrids	R
-15°F (Zone 5b)	Hardy hybrids and most American varieties	
<-15°F (Zone 5a and colder)	Hardy American varieties	

Figure # Lowest threshold temperatures below which the buds start to die. Table from Eames-Sheavly, 2003 (http://www.gardening.cornell.edu/fruit/homefruit/4grapes.pdf).

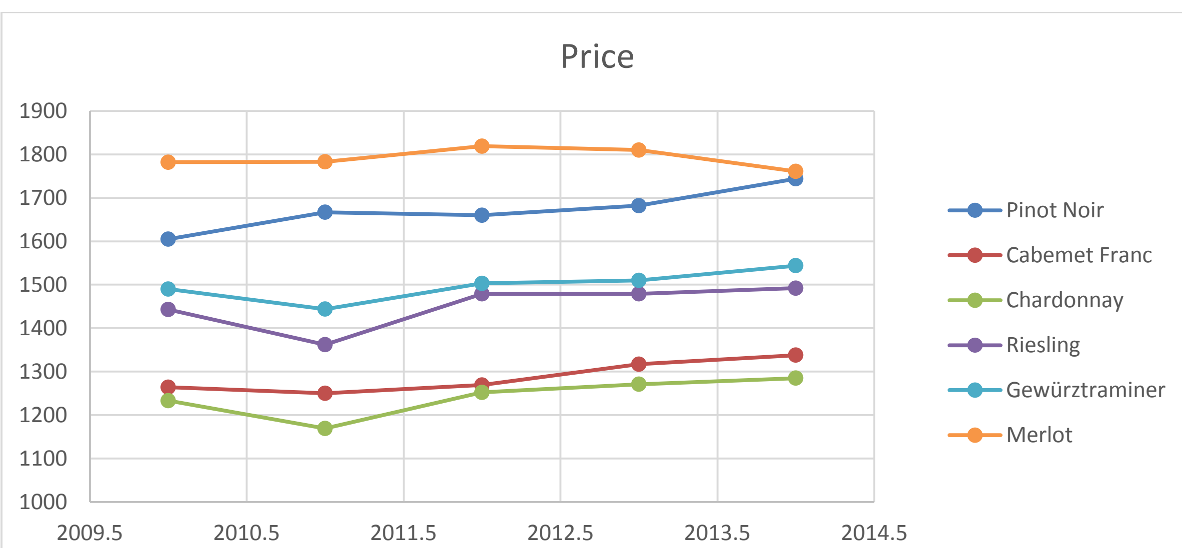
index called USDS Winter Hardiness for plants (Table 3 (right)).

We assumed that, starting from the threshold low winter temperature, the mortality of buds during winter increases by 10% for 1°C temperature drop. This seems quite arbitrary; however, it is sufficiently reasonable approach in our model's accuracy level. Actually, the Bud Hardiness data from Cornell (https://grapesandwine.cals.cornell.edu/extension/bud-hardiness-data) shows that LT90 (the temperature where the mortality is 90%) is approximately 8~10°C lower than LT10 (the temperature where the mortality is 10%).

Price

In this model, we assumed that the firm is monopolistically competitive as a winery. As a grower of grapes however, the demand curve which it expects to face from consumers will be relatively flat since grapes are, as discussed, almost like a commodity. Therefore, demand and marginal revenue are relatively flat, and we therefore proceeded to model the price as an average.

We tried to link our model with other parameters, such as time, but the available data did not evidence any specific trends.



Profit maximization FUNCTION TO SOLVE FOR PROPORTIONS

We represent profit maximization, in dollars, as a constrained optimization problem, where proportions of each grape are unknown. Every type of wine, R, G, F, C, P, and M has its own prices, costs, and quantities. Functions are in bold.

$$\max_{q_i} \pi = A * \sum_{R,G,F,C,P,M} q_i * \Big(\mathbf{yield}_i\big(\overline{\boldsymbol{Growing\ Season\ Temperature}\ (\mathrm{time})}\big) * \mathbf{price}_i\Big(\mathbf{yield_i}\big(\overline{\boldsymbol{Growing\ Season\ Temperature}\ (\mathrm{time})}\big)\Big) * \mathrm{S_i}(\mathbf{Survivability\ temperature}(\mathrm{time})) - \mathbf{cost_i}\Big(\mathbf{yield_i}\big(\overline{\boldsymbol{Growing\ Season\ Temperature}\ (\mathrm{time})}\big)\Big)\Big), \text{ where } \sum_i q_i = 1.$$

We realize that there is a chance that this function will result in only one single plant being grown, which intuitively is not ideal since risk is not minimized. Therefore, we relax the constraint and maximize only the individual plants' profits.

The survivability temperature is defined as the lowest temperature in March, which is in the growing season. The Growing Season Temperature is a function of time, which we already discussed in Temperature. *A* is area in acres, S_i is the probability of survival, and q_i is the proportion of the crop which is a given type of grape.

We consider acreage as a variable unit of area. Quality is affected by the area since proximity to other species may alter aroma, etc, so a large area is more adept to hosting multiple varieties than a smaller one. We will aim to produce a model where *A* is canceled out, since we want a proportion. However, profit is still affected by quality of each wine; the function's output would be penalized by a factor of *proportion of each wine * A.* For this paper, we consider the vineyard with *A* is sufficiently large so that quality, which is really a subjective amount, can then be described as inherent to temperature.

Notice that many of these components are a function of temperature and indirectly of time. With consideration to this profit maximization equation, we consider the problem of solving for the optimal proportions in two steps.

PART 5. IMPLEMENTING THE STRATEGY

STEP ONE: FIGURING OUT THE TIME

The reason we split up the summation is because we will otherwise consistently only get one plant all the time. At least every plant has a chance now, and the proportion of a field dedicated to the particular crop will be one.

For each year, each plant will have its own profit, which itself is maximized. We will run *many* trials simulating a century and for each trial we will find the most profitable plant each year for a century.

By observation and comparing each data set of each century, we will deduce the general pattern of the changing proportions and the associated time at which the firm should thus decide to grow a new type of grape. We find this out by literally counting the number of consecutive years where a plant is successfully dominant. In case there is complete oscillation in *all* the data sets, then we do not segment until the oscillation ends; however, due to the fact that we treat each year individually and that each year does share a similar average simulated temperature, this scenario should not pose too much of a menace.

Although this method of "eyeballing" whatever the segments should be is less rigorous, in the context of the problem, the segments should be relatively distinct and one can assume that the winery and vineyard owner will require plenty of time to make a decision.

STEP TWO: FIGURING OUT WHAT TO GROW

Having identified the segments based off multiple sample centuries and the profit-maximizing grape crop of each year, we are tasked to determine which plant to pick. Although we already have the data of what the expected profit of each plant is, since we will be performing many simulations anyway, we choose to break away from step one and repeat the profit maximization for the whole interval. We will be guaranteed to get a single plant during the whole interval for one trial, but we will repeat the trial a sufficient number of times. Most likely, there will be different plants appearing in the interval, and we figure out what the frequency of each plants occur and make this the optimal proportions. The output is therefore multiple segments of the century, each with its own ideal ratio, for example 1 R : 2M : 3G.

STEP THREE: IMPLEMENTING THE TRANSITION

The final task is determining exactly *when* to implement the transitions between segments within the century. Let us suppose for the sake of argument that the following optimal proportions exist in these three segments from the simulations run in the previous step: A = {4P : 1 M : 1R}, B = {4R : 2G : 3C}, and C = {2R: 3M : 3F}. Of course the lengths of A, B, and C in years are thus 6, 9, and 8 respectively. This makes sense; intuitively, the more diversified a planting, the longer some of it should last.

To achieve the desired proportions, our goal is to determine whether to start planting either within segment A and segment B, segment A and segment C, or segment B and segment C. We offer the vineyard manager the following criteria:

- Given two consecutive segments, find the total profit of each segment characterized by their allocations of each variety
- If the profit of the succeeding segment, S2, is greater than that of the preceding segment, S1, then there is no point in eating away the profits of S2. Therefore, given the time (in

years) at which the segments are split, start planting t-3 years beforehand so that the crop will be ready by the time interval of S2.

- If the profit of S2 is less than that of S1, likewise it makes no sense to eat away the profits of S1 by taking away some time where fruit could be grown and sold to replace the crop for the less profitable S2 segment. Therefore, wait until the very end of the interval of S1, and then right at the beginning of S2 plant the new crop for S2, at time *t* , where *t* is the present year of interest in years.

This analysis assumes that both the segments S1 and S2 are larger than three years. If either S1 or S2 are intervals with length less than three years, then the firm will not have time to fully realize the gains of its current or future crop of grapes. The human eye will be able to detect quite easily if the segments are too many or too short.

As for how the strategy can be implemented, we track each individual Δq_i, specifically whether the change in proportions from one segment to another is positive or negative. For any increasing proportion, the space in the vineyard will arise where the first decreasing q is substituted away with a new crop to increase the existing proportion of whatever grape.

More formally, we wish $\sum_i \Delta q_i = 0$. In the scenario where the time interval is less than three years, this will not equal zero since not all of the required change for a certain proportion of grapevines will be fully grown. Therefore, the **absolute lower limit** to the length of any segment should be three years.

PART 6. CAVEATS AND CRITICISMS

There were some aspects of the model which required assumptions that may not always be true. Furthermore, the model tended to be excessively dependent on certain criteria, which could lead to extreme values.

We noticed at the last minute that our model makes extensive use of temperatures in Ithaca, N.Y. However, even though Ithaca is located near Cayuga Lake and its temperatures are sufficiently moderated, we found enough evidence that Ithaca N.Y.'s temperatures are significantly lower than that of other cities in the region. This will lead to artificially low estimates of temperature for the firm, **assuming that the firm is not located near Cayuga Lake**.

Furthermore, the calculation of temperature will be off for most of the time, because there appears to be a sinusoidal element in its variations. The following links show that there are patterns in weather that occur over periods of years, such as la nina, and that a linear estimator will tend to have errors which are not randomly distributed.

Finally, the calculation of the price of the grapes requires a lot of assumptions about the nature of the firm. The idea that the price should be above the marginal revenue for it to make profit is true, but the method of representing fluctuations in price is dubious. We would have preferred to have found more data on prices of the grapevines.

PART 7. SIMULATIONS OF THE STRATEGY

Optimal Proportion	**R**	**P**	**C**	**F**	**G**	**M**
For the first 20 years	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0(0)
21^{st} ~40^{th} years	0.984 (0.013)	0 (0)	0 (0)	0.016 (0.013)	0 (0)	0 (0)
41^{st} ~ 60^{th} years	0.748 (0.180)	0 (0)	0 (0)	0.092 (0.083)	0 (0)	0.160 (0.178)
61^{st} ~80^{th} years	0.425 (0.185)	0 (0)	0 (0)	0.572 (0.183)	0 (0)	0.003 (0.004)
81^{st} ~100^{th} years	0.255 (0.191)	0 (0)	0 (0)	0.378 (0.171)	0 (0)	0.367 (0.203)

Table 2. Optimal Proportion for each segment. We ran the simulation 5 times for each cell and averaged them together. The values in the parenthesis are the errors.

Using our model, we now provide the optimal proportions to maximize a profit within a given length of segment. Here, we chose the segment to be 20-year-long. Because of the fact that our model is stochastic, each running gave us slightly or enormously different results. Though, for the best proportion of this present year, we always ended having only Riesling for every simulation. It does make sense because, for now, Riesling is the most profitable variety in terms of its moderate price and a good yield as the actual acre proportion in page 7-8 shows the dominance of Riesling in these days.

We also provide the optimal proportions for every starting year of each segment in the future. As time goes by, the proportion of other varieties comes in. If you look into the optimal proportions for the fourth and fifth segments, you will notice that the proportion of Cabernet Franc and Merlot is increasing. This is consistent with the optimal temperature range diagram above. In the diagram, it shows that the optimal growing season temperature ranges of Cabernet Franc and Merlot span the higher temperature than Riesling. Thus, even if Riesling is now the most profitable variety, within a few decade, the global warming will make Merlot and Cabernet Franc more suitable for growing. That's why we get an occurrence of non-zero proportion of Merlot and Cabernet Franc in the future years despite they are not currently the most profitable; they WILL become the most profitable in the future. The yield graph in page 15 also shows that the yield of Riesling is going down as the temperature rises and the yield of Cabernet Franc and Merlot is going up. So our stochastic model does reflect some basic reasonable predictions.

But the limit of our model is that it is too trial-sensitive, which means that the average optimal proportions differ a lot in each simulation. In other words, this probability model fluctuates a lot so that we need too large number of trials to get a converging result. As you can see the order of error values are comparable the actual proportion values. Also, this model somewhat ignores Pinot Noir, Chardonnay, and Gewürztraminer. In fact, it is not particularly unreasonable to ignore them because they are the varieties which are not lucrative both in the present and in the future.

PART 8. CONCERNING TRADE/OFFS BETWEEN RISK AND AVERAGE

Our model actually has risk minimization built into the average case, given the second step of our hedging strategy. The worst realistic scenarios are mitigated within our strategy of determining proportions.

PART 9. FUTURE WORK

We would like to see how this model can take into account diseases. Our model implicitly tackles the question with the survivability function since the plants are most vulnerable in the cold. However, we are aware of diseases effecting specific varieties of grapes and wine and would like to multiply an additional term in the profit maximization model that accounts for whether a plant will have a probability of getting sick or not.

Some of the plants have specific properties that can be further used to fine tune the model. For instance, Pinot Noir can suffer from sunburns (G).

Furthermore, we would like to see how this model can apply to other types of regions and types of wines.

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O. http://www.fingerlakeswinealliance.com/varietals.html

PART 9. MATLAB CODE

```
function YEILD = Yield(T,TYPE)
   switch TYPE
      case 'R'
         lowedgeT = 13.2;
         highedgeT = 17.1;
         yieldStandard = 3.4;
         TStandard = 15;
      case 'G'
         lowedgeT = 13.1;
         highedgeT = 15.6;
         yieldStandard = 2;
         TStandard = 16;
      case 'C'
         lowedgeT = 14;
         highedgeT = 17.2;
         yieldStandard = 3.3;
         TStandard = 15;
      case 'M'
         lowedgeT = 15.7;
         highedgeT = 18.8;
         yieldStandard = 2.9;
         TStandard = 16;
      case 'P'
         lowedgeT = 14;
         highedgeT = 16;
         yieldStandard = 2.6;
         TStandard = 15;
      case 'F'
         lowedgeT = 15.3;
         highedgeT = 18.9;
         yieldStandard = 3.3;
         TStandard = 15;
   end
   averT = 0.5*(lowedgeT+highedgeT);
   varT = -1/log(0.95)/2*(highedgeT-averT)^2;
   heightOfDistribution = yieldStandard*exp(((TStandard-averT).^2)/2/varT);
   YEILD = heightOfDistribution*exp(-((T-averT).^2)/2/varT);
```

```
function survivability = WinterInjury(lowestT, TYPE)
  switch TYPE
    case 'R'
      thresholdT = -23;
    case {'G','M'}
      thresholdT = -17;
    case {'C','P','F'}
      thresholdT = -20;
  end
  if lowestT > thresholdT
    survivability = 1;
  else
    survivability = max(1 - 0.1 * (lowestT + thresholdT),0);
  end
***
function lowestT = LowestTempGenerator(year)
  minTempArrayFrom2000To2014 = [-13 -6 -5 -15 -6 -13 -1 -9 -11 -22];
  averT = sum(minTempArrayFrom2000To2014)/length(minTempArrayFrom2000To2014);
  stdT = sqrt(length(minTempArrayFrom2000To2014))*std(minTempArrayFrom2000To2014);
  lowestT = normrnd(averT + 0.04 * year, stdT);
***
function COST = Cost(Y, TYPE)
  switch TYPE
    case 'R'
      [a, b] = polyfit([1.5 2 2.5 3 3.5 4], [5331 5392 5455 5517 5579 5644], 1);
      FixedCost = 2294;
    case 'G'
      [a, b] = polyfit([1.5 2 2.5 3 3.5 4], [5319 5380.5 5443.75 5506.5 5568.5 5635], 1);
      FixedCost = 2270;
    case 'C'
      [a, b] = polyfit([1.5 2 2.5 3 3.5 4], [5290.5 5352 5415 5478 5540.5 5604], 1);
      FixedCost = 2254;
    case 'M'
      [a, b] = polyfit([1.5 2 2.5 3 3.5 4], [5319 5380.5 5443.75 5506.5 5568.5 5635], 1);
      FixedCost = 2270;
    case 'P'
      [a, b] = polyfit([1.5 2 2.5 3 3.5 4], [5352 5414 5477.5 5541 5603.5 5676], 1);
      FixedCost = 2262;
    case 'F'
      [a, b] = polyfit([1.5 2 2.5 3 3.5 4], [5302.5 5364 5427.5 5490 5551 5616], 1);
      FixedCost = 2270;
  end
  COST = a*Y+b-FixedCost;
```

```
function proportion=proportion(ts, te)
%Temp is a 100*n array that simulates temperature each day
%in the growing season for 100 years
%ts is the start time
%te is the end time
Temp=temp(15,7);            %change this
A=zeros(1,6);
proportion=zeros(1,6);
for k=1:1000
   pgrape=zeros(1,6);
   for i=ts:te
      LowestT=LowestTempGenerator(i);
      profit=Profit(Temp(i,:),LowestT);
      for j=1:6
         pgrape(j)=pgrape(j)+profit(j);
      end
   end
   [i,maxProfit]=max(pgrape);
   A(i)=A(i)+1;
end
for i=1:6
   proportion(i)=A(i)/1000
end
end

***
function temp=temp(mu,var)
for n=1:100
   mu=mu+0.04;
   for k=1:213
      temp(n,k)=normrnd(mu,var);
   end
end
***

function proportion=proportion(ts, te)
%Temp is a 100*n array that simulates temperature each day
%in the growing season for 100 years
%ts is the start time
%te is the end time
Temp=temp(15.11,6.5);            %change this
A=zeros(1,6);
proportion=zeros(1,6);
for k=1:1000
```

```
  pgrape=zeros(1,6);
  for i=ts:te
    LowestT=LowestTempGenerator(i);
    profit=Profit(Temp(i,:),LowestT);
    for j=1:6
      pgrape(j)=pgrape(j)+profit(j);
    end
  end
  [maxProfit,index]=max(pgrape);
  A(index)=A(index)+1;
end
for i=1:6
  proportion(i)=A(i)/1000;
end
end
```

**

```
function PRICE = grapeprice(TYPE)
  switch TYPE
    case 'R'
      priceFromPreviousFiveYears = [1443 1362 1479 1479 1492];
    case 'G'
      priceFromPreviousFiveYears = [1490 1444 1503 1510 1544];
    case 'C'
      priceFromPreviousFiveYears = [1233 1169 1252 1271 1285];
    case 'M'
      priceFromPreviousFiveYears = [1782 1783 1819 1810 1761];
    case 'P'
      priceFromPreviousFiveYears = [1605 1667 1660 1682 1744];
    case 'F'
      priceFromPreviousFiveYears = [1264 1250 1269 1317 1338];
  end
  averP = sum(priceFromPreviousFiveYears)/length(priceFromPreviousFiveYears);
  stdP = std(priceFromPreviousFiveYears);
  PRICE = normrnd(averP, stdP);
```