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Financial risk management in the design of products under uncertainty

Craig Whitnack, Ashley Heller, Michael T. Frow, Susan Kerr, Miguel J. Bagajewicz*

School of Chemical, Biological and Materials Engineering, University of Oklahoma, 100 E. Boyd St., Norman, OK 73019, USA

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ABSTRACT

In this paper we extend a recently presented methodology for product design (Bagajewicz, M. (2007). On the role of macroeconomics multi-scale planning and finances in product design. *AIChE Journal, 53*(12), 3155–3170) to consider uncertainty in the model parameters. We also extend the methodology to the discussion of alternative profitable scenarios and their associated risk. To illustrate the method, we picked wine making. To illustrate the method, we present a simplified consumer preference model, and show how vineyards can guide the selection of wine properties (wine quality), in association with a production rate and a selling price based on their attitude towards financial risk.

1. Introduction

In a recent paper, Bagajewicz (2007) presented a methodology that incorporates microeconomics into product design. The argument is that consumer preferences as well as their reaction to price, both combined, establish demand, which in turn determines profit. As a result, the most profitable product is not always the best product from the consumer preference point of view, a well-known fact that the paper helps quantify. The procedure, however, provides a quantitative means of constructing a meaningful price–demand–quality relationship which can be used to determine the optimal product structure. This was illustrated by Bagajewicz (2007) and by Street, Woody, Ardila, and Bagajewicz (2008). In this paper we illustrate how uncertainty can make one choose a different optimum and how financial risk can be managed. We use wine-making to illustrate the concepts.

The paper is structured as follows: we first overview the product used for the example: wine. Then, we review briefly some of the consumer preference functions. We then compute a net present value as a function of price for different qualities as suggested by Bagajewicz (2007). Finally, we discuss the uncertainty associated to the model and suggest means to deal with uncertainty. Portions of this paper were advanced in a condensed conference article by Whitnack, Ashley, and Bagajewicz (2008).

2. Wine making

Wine has long been considered an art form, where quality was controlled by the producer. However, in the current competitive world wine producers must now consider several other factors, besides quality. In order to identify with the market, the producer must understand the motivations behind the consumer's choice. Currently, after the wine has been bottled, it is outsourced to labs where tests are performed to measure the qualities that the wine possesses. Wine varietals are also sent to tasting competitions, where they are tasted by experts and awarded for overall quality. Experts form their opinions after tasting each individual wine and rank them based on a standard set of criteria, pre-determined by the host of each competition. While these methods are both beneficial and educational to the producer, neither truly addresses the perceptions of the consumers, nor they connect these with the cost to the producer. The producer also has no way of controlling the product at this point. It has been bottled and is simply awaiting distribution. If this knowledge was attainable before the product was complete, the process could, in theory, be modified to attain the overall quality sought by the consumer.

The quality of wine, however, can be known before it is bottled, and that each batch of wine can be engineered to manipulate consumer's preferences in any market, whether it is the highest quality possible or less. After quantification of the consumer's predicted overall satisfaction with the product, the wine can be compared to the quality of any competitor. By comparing its quality to that of the competition, the selling price of the wine can

* Corresponding author. Tel.: +1 405 325 5458; fax: +1 405 325 5813.
E-mail address: bagajewicz@ou.edu (M.J. Bagajewicz).

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be set, optimizing the producer's return on investment. This is the core of the ideas proposed by Bagajewicz (2007).

Consumer preferences are identified, allowing the data generated by market analysis to be related to wine properties. These wine properties are easily measured throughout the winemaking process and can be manipulated by the manufacturer at little cost. Modifiable processes include fermentation, clarification and stabilization, barrel toasting and aging (Cooke & Lapsley, 1988; Eismann, 1999). Finally after the consumer overall preferences are identified, the wine can be compared to the competitor and the selling price of the wine can be set by optimizing the producer's return on investment. Appendix A provides additional background of the manufacturing process.

The wine industry is comprised of several different economic segments. Wines range from economy to premium and ultra-premium to artisan. Economy wines are those costing the consumer less than \$7 per 750 mL bottle. These wines dominate 70% of the wine industry (Tinney, 2005) and 27–28% of the industry is made up of premium table wines, which range from approximately \$8 to \$40 per 750 mL bottle, while only 2–3% of the wine market is owned by the ultra-premium and artisan wines, which are the most expensive of wines available (Bisson, Waterhouse, Ebeler, Walker, & Lapsley, 2002). The premium table wine market segment in the US is the only market segment with stable demand growth (Folwell & Volanti, 2003).

In our particular case we are concentrating on Pinot noir to demonstrate our methodology. Pinot noir is the softest of the reds and is considered to be the red wine choice of the white wine drinker. It is described as being "soft" and "supple" on the palate and is generally not high in tannins.

Adapting a certain existing manufacturing facility (winery in this case) to produce a new (or even a slightly different) product is a subset of the bigger problem posed by Bagajewicz (2007) for product design. Indeed, although manufacturing and supply chain architecture and operation modality are not subject to change, the major and most important ingredients of the approach, namely the connections between consumer preferences, price and choices of wine properties, remain and are used to determine the properties of a product. We would still call this "product design", although others might prefer a different name.

3. Pricing and consumer preference models

We use the same constant elasticity of substitution model as Bagajewicz (2007). This model is a small modification of the constant elasticity of substitution models found in literature (Hirshleifer & Hirshleifer, 1998; Varian, 1992) where hedonic theory is incorporated. This was extended to multiple competitors by Street et al. (2008). The final expression relating demand of new product to price is

$$d_1 = \left(\frac{\alpha}{\beta}\right)^{\rho} \frac{p_2}{p_1} \left(\frac{Y - p_1 d_1}{p_2}\right)^{1-\rho} d_1^{\rho} \quad (1)$$

where d_1 is the demand of the new product, p_1 its proposed price, p_2 the average price of competitor wines, ρ a predetermined constant, α a zero to one measure of the amount of knowledge the consumer has for the product of interest and, Y is the consumer budget, which satisfies

$$Y \geq p_1 d_1 + p_2 d_2 \quad (2)$$

Finally, β is a positive coefficient that relates how much more appealing the consumer will find the product of interest in comparison to the competing product. It is defined as the ratio of the consumer preference functions $\beta = H_2/H_1$. In turn, the consumer preference functions are related to product attribute scores (y_i; in our case, taste, bitterness, sweetness, etc.) as follows:

$$H_i = \sum_i w_i y_i \quad (3)$$

Each attribute is weighted based on the rank of importance (w_i) to the consumer. Thus, the scores, or values of y_i, can be manipulated by altering the production process as well as the raw materials used, including their quality.

Each of these characteristics is evaluated individually by the consumer's level of preference attained. This level of preference will be normalized on a scale ranging from 0 (minimum of 0% preference) to 1 (maximum of 100% preference). A curve is formed that describes the individual's preferences as a function of the characteristic identified and the consumer descriptions ("as tasty as", "as sweet as", "as acid as", etc.) used to evaluate each characteristic. These descriptions can then be related to physical, measurable qualities. For example, if one says, "as acid as pure kitchen vinegar", then one can relate this description to a particular pH, that of kitchen table vinegar. By identifying the correlation of the consumer's words to these qualities, the qualities can then be related to the consumer's preferences.

We now describe each wine characteristic separately.

4. Preference functions

Consumer preferences for each attribute (y_i) and the weights (w_i) can be identified through market research. The most important and commonly judged characteristics of wine that we will use to build our example are as follows:

- Acidity
- Sweetness
- Bitterness
- Clarity
- Color
- Brightness
- Bouquet
- Body/texture
- Finish/aftertaste

These are only a small fraction of the large list of characteristics (The Wine Pages, 2006). One should also consider other factors like brand strength, or others, etc. in the preference function. Although this is in principle (but arguably) a constant term in (3) that can be easily added, we ignore it in this paper. Although many of these characteristics interfere with each other sometimes, one masking the effects of others, we treat them here independently. Our objective is to address the nonlinear versions of Eq. (3), multivariable relations between y_i and physical properties in future work and effect of advertisement in brand strength and product loyalty. Because our purpose is to highlight the methodology we rely on informal surveys on small population samples (around 45 persons).

4.1. Weights

Informal surveys were made and the weights given in Table 1 were obtained.

4.2. Acidity

This characteristic is the result of the balance or lack of balance between the acidity level, alcohol content, and body. Acidity can be broken down into different levels based on consumer descriptions (Pandell, 1999). If the acidity is too high, it begins to taste tart,

Table 1
Wine characteristic weights.

Characteristic	w_i
Acidity	0.0714
Sweetness	0.0714
Bitterness	0.0714
Clarity	0.1429
Color	0.0714
Brightness	0.0714
Bouquet	0.2858
Body/texture	0.1429
Finish/aftertaste	0.0714

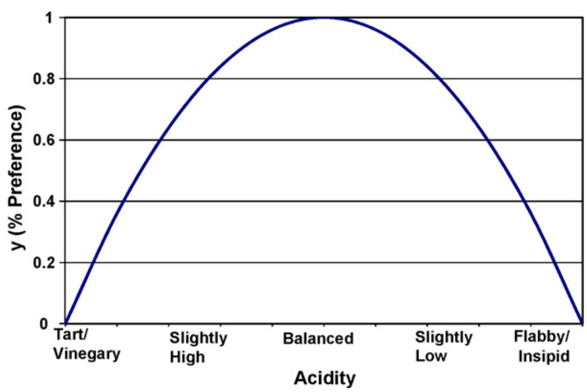

Fig. 1. Consumer preference curve for acidity.

vinegary, sharp or harsh and unbalanced, whereas if it is too low, the wine can taste flat, flabby and insipid. This presents a need for a balance in acidity, where consumer preference is at an optimum (100% preference). For example, consumers assign 0% preference to wine with tart/vinegary and flabby/insipid attributes, as these acidity levels are undesired. Thus a parabolic-shaped curve, with the apex associated with a “balanced” wine describes consumer preference relating to acidity levels (Fig. 1).

The correlation of tart/vinegary, balanced and flabby/insipid with pH is direct, so the connection is easily found. Typical table wines can range between a pH of 3.0 and 4.0. We consider that there is a linear relationship between consumer-described acidity and pH level (Fig. 2).

Once this relationship is established, the consumer utility can be plotted against the pH by combining both plots (Fig. 3). The pH, in turn, can be easily manipulated at the production stage without major cost changes. Acidity in particular can be controlled by malolactic fermentation. Malolactic fermentation is a naturally occurring process that lowers the acidity by converting malic acid

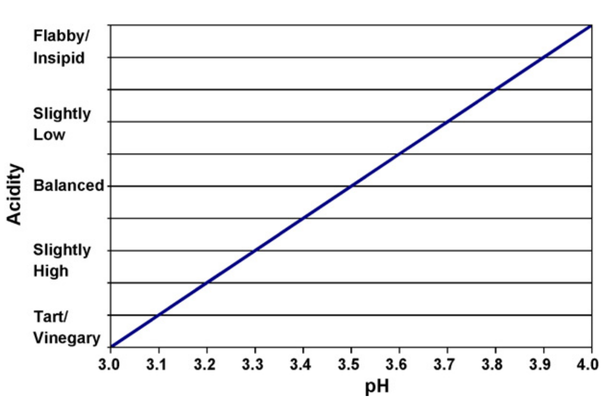

Fig. 2. Acidity descriptions vs. pH.

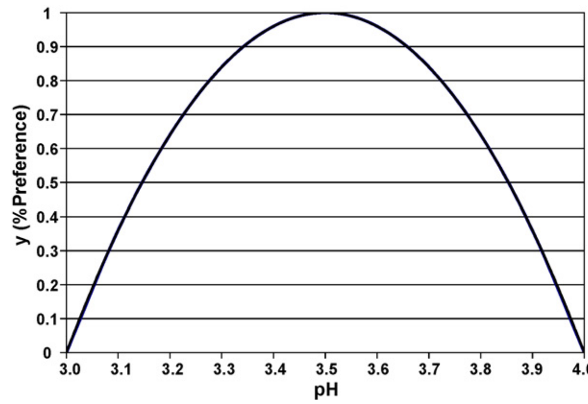

Fig. 3. Consumer preference curve as a function of pH.

to lactic acid and carbon dioxide. If a higher acidity is needed, acid can simply be added to the batch of wine. More malic acid can be added after the completion of the second fermentation, as well as adding tartaric acid.

4.3. Sweetness

Although the sweetness of the wine is usually countered by the acidity taste, as assumed above, we treat them here independently. Fig. 4 depicts consumer preferences related to sweetness. The sweetness of a wine can be measured by calculating the percent of residual sugar in the wine after fermentation (Fig. 5). Fig. 6

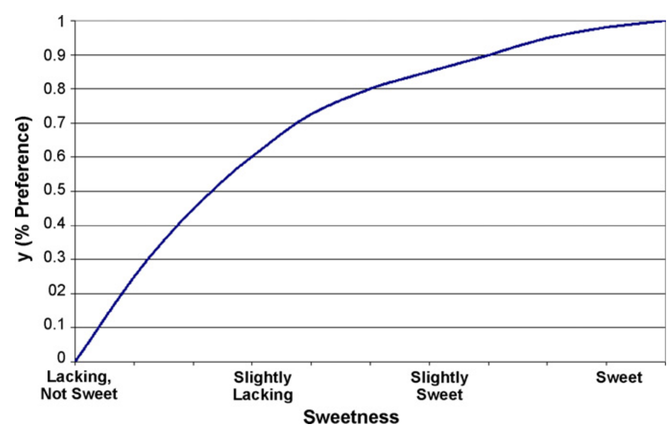

Fig. 4. Consumer preference for sweetness.

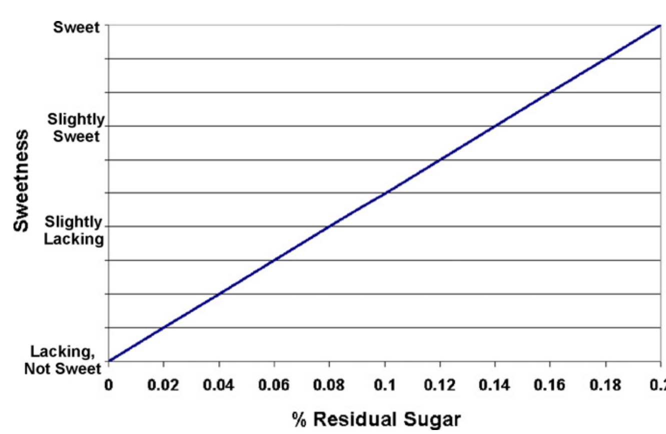

Fig. 5. Sweetness descriptions vs. % residual sugar.

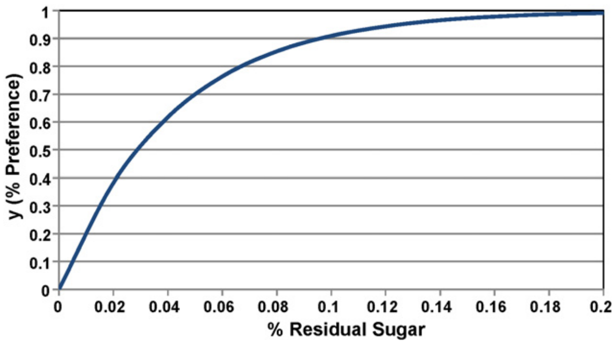

Fig. 6. Consumer preference for sweetness vs. % residual sugar.

combines these two figures to provide the desired preference function in terms of a measurable quantity.

During alcoholic fermentation, yeast converts the sugar found within the grape juice into ethyl alcohol and carbon dioxide. The amount of sugar that is fermented determines the wine's alcohol level and, ultimately, the amount of residual sugar left in the wine. These leftover sugars are what contribute to wine's sweet taste. This can be manipulated at no extra cost.

4.4. Bitterness

Bitterness is an undesirable characteristic that makes the wine harsh. It, along with the acidity and sweetness, needs to be in balance within the wine. Any kind of bitter taste to a wine is unpleasant to the consumer, but the preference levels actually achieved vary. The consumer preferences for bitterness are shown in Fig. 7. Bitterness, in turn, can be measured by the mass fraction of tannins within the wine. Because of this direct relationship between the amount of tannins and level of bitterness, a linear relationship is assumed. This correlation is shown in Fig. 8. Fig. 9 depicts the combined relationship sought.

The extraction of tannins is monitored by the manipulation of the skins, which rise to the top of the batch of wine, forming a cap. These skins are removed at the surface. Wine also gathers tannins by maceration or prolonged skin contact. The longer the juices are in contact with the skins, the more tannins are allowed into the wine. Fining agents can also be employed to decrease tannin concentration before wine bottling. These substances attach themselves to several tannins creating long, heavy compounds that settle to the bottom of the wine and can be removed through filtration at no significant extra cost.

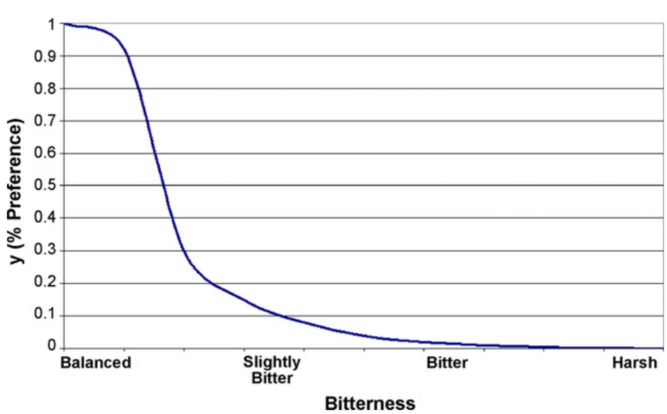

Fig. 7. Consumer preference for bitterness.

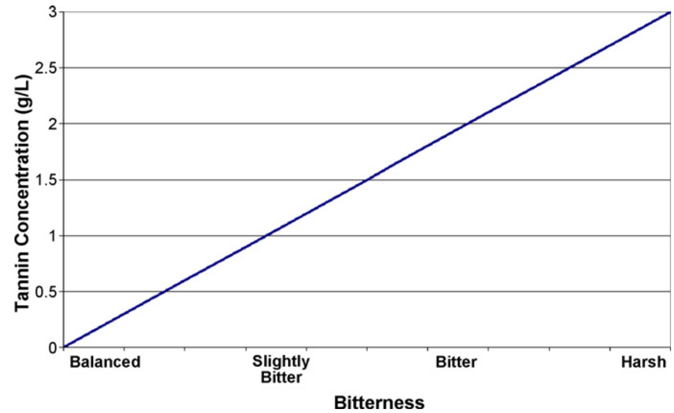

Fig. 8. Tannin concentration vs. bitterness.

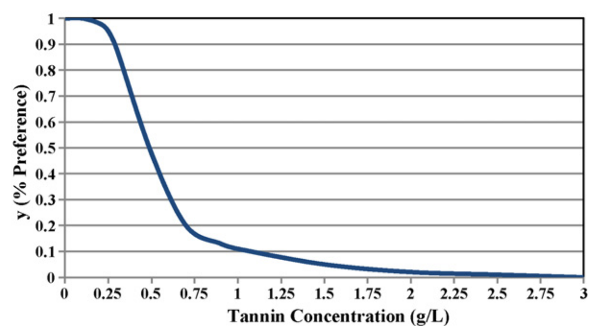

Fig. 9. Consumer preferences for bitterness vs. tannin concentration.

4.5. Clarity

When judging wine, the consumer has two areas of visual evaluation: clarity and color. The clarity of the pinot noir wine is expected to be crystal clear. Any type of cloudiness or sediment that can be seen in the wine disappoints the individual and hints to possible contamination as well as poor processing. It is an indication of possible bacteria, excess yeast, and unwanted compounds. Fig. 10 shows consumer preferences as a function of the different descriptors for clarity. This particular curve shows that the slightest change in clarity of the wine results in the consumer's preference level to drop significantly. The maximum occurs when the wine is described as being "crystal clear" whereas the minimum is shown to be at the presence of sediment. Clarity is, in turn, measured quantitatively using turbidity. Turbidity is defined as an "expression of

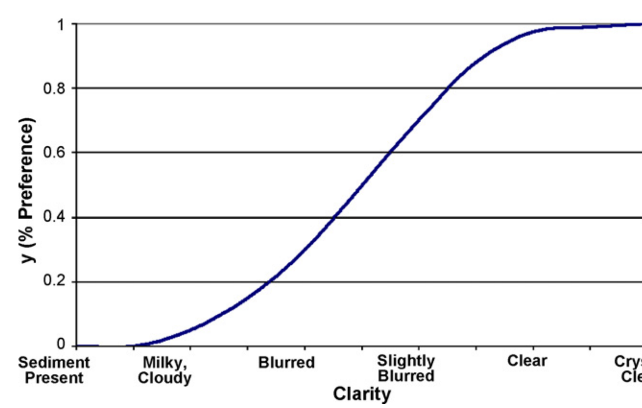

Fig. 10. Consumer preferences for clarity.

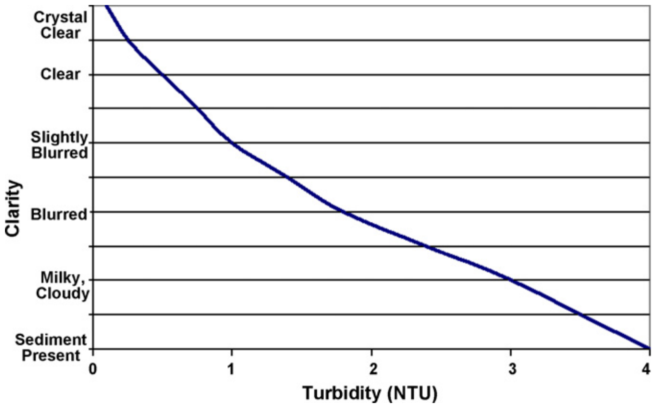

Fig. 11. Clarity descriptors vs. turbidity.

the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample". A correlation between consumer descriptors and turbidity needs to be established. This correlation has been established by noting that there are three places turbidity readings are made with the following expectations:

1. Alcoholic fermentation <600 NTU (NTU stands for Nephelometric Turbidity Units and are the units used for a turbidimeter.)
2. Malolactic fermentation <100 NTU.
3. Filtration <1.0 NTU.

Thus, the limpidity value for a bottled wine should not be greater than 4 NTU, so it is this region below 4 NTU that is the region to be evaluated by the consumer. Fig. 11 shows the correlation between consumer description and the turbidity measurement and Fig. 12 shows the resulting preference curve.

Turbidity can be reduced throughout the winemaking process by adding fining agents during the clarification stage. These fining agents attract the turbidity-causing particles in wine, such as salts, enzymes, and colloids, forming heavier compounds that can be separated from the wine by gravity.

4.6. Color

The color or hue of the wine is another visual property that is used to evaluate wine. White wines can range from light straw to a dark amber color. Blush wines range from light pink to light red. Red wines range from light red to dark, almost an opaque red. Color is evaluated using hue, which is the actual shade of color that is reflected. The expected hue of each different type of wine is different, i.e. white, blush, and red. The hue of red wine (our case) reflects

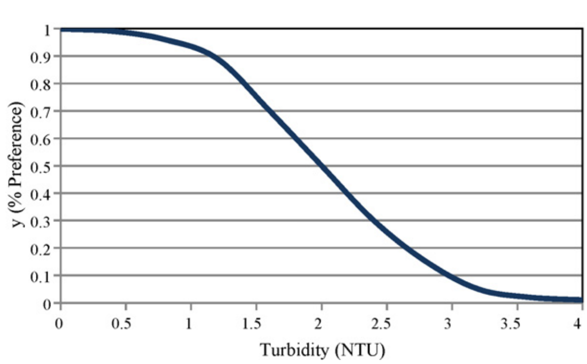

Fig. 12. Clarity preference vs. turbidity.

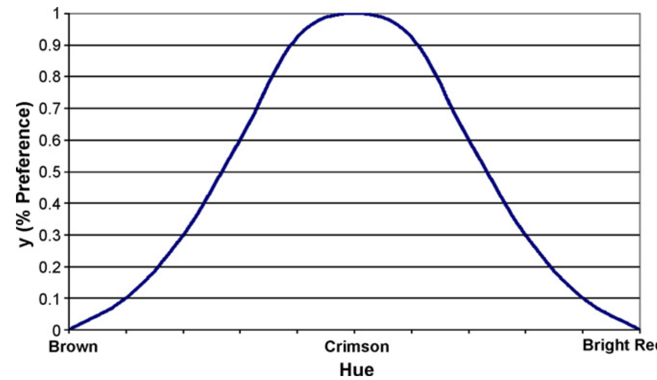

Fig. 13. Preference for color.

a clear judgment of not only the age of the wine but the particular level of quality it has reached within the aging process. Red wine has three different, easily identifiable hues that the consumer uses to describe the wine: red, crimson, and brown. The red hue is associated with a young wine that has not had ample time to age. It has not reached its peak of quality. When the hue is described as being crimson, more of a deeper red, it is here that the consumer views the wine to have aged enough and indicates a high quality. This color shows a maximum preference for the consumer. Once the wine proceeds through this stage, it begins to turn brown, and is interpreted as being of less quality. The wine has either aged too long or oxygen has been allowed to enter the bottle. Fig. 13 shows the relationship between the preference of the consumer and the hue of a red wine.

Hue, in turn is quantified using absorbance, which is obtained by measuring transmittance at two different wavelengths: 420 nm (yellow) and 520 nm (red). The absorbance (D) at these wavelengths can be calculated as a function of the logarithm of the percent transmittance ($\%T$) at each individual wavelength (λ) ($D_A = -\log T$). The actual hue of a red wine is given by the ratio of the absorbencies at the 420 nm and 520 nm wavelengths (D_{420}/D_{520}) (Heredia & Guzman-Chozas, 1993; Sudraud, 1958). This ratio has the following ranges that correspond to it for red wines:

- Red: <0.44.
- Crimson: 0.44–1.0.
- Brown: >1.0.

These values of the ratio associated with the descriptions of the hues, allow the measurement and the formation of the correlation as a function of the absorbance ratio. This relationship can be seen in Fig. 14. The brown hue has a low absorbance ratio due to the wine absorbing more light at the 520 nm wavelength,

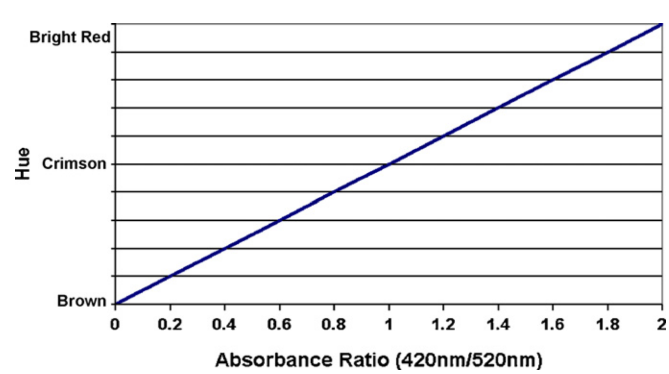

Fig. 14. Hue vs. absorbance ratio.

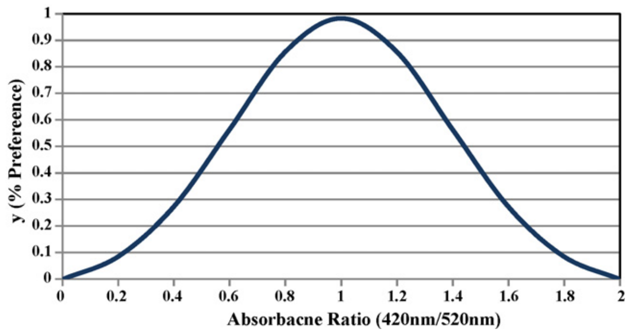

Fig. 15. Color preference vs. absorbance ratio.

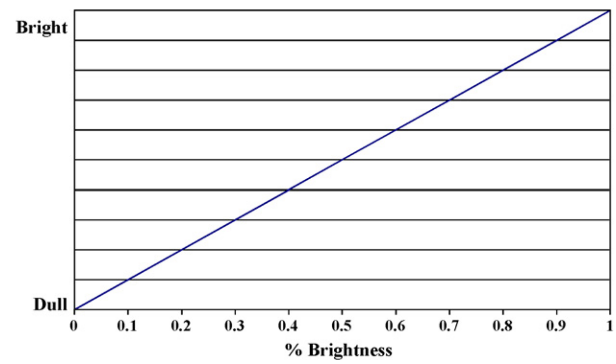

Fig. 17. Brightness descriptors vs. sum of absorbencies.

leading to the light being reflected having shades of yellow. This results in the brown shade that consumers describe. The same trend occurs at the red hue range, which results in high values for the absorbance ratio. More light is absorbed at 420 nm (yellow) and reflects the 520 nm (red) resulting in the characteristic red hue. Crimson, the consumer's maximum level of preference with a red wine, indicates a balance required by the absorbance of both 420 nm and 520 nm wavelengths. Fig. 15 depicts the final relationship. The color of the wine can be manipulated by the adjustment to the melanoidins, or coloring particles of wine. In order to adjust the process to accommodate necessary absorbance ratios for the needed consumer preference score, cold soaking can be used. This method does not allow the juices to extract as many phenolic compounds as in regular soaking, because it does not facilitate further fermentation to take place.

4.7. Brightness

Brightness is the second property used to evaluate color. Brightness ranges from dull to bright. The duller the wine, the less appealing it is to the consumer, because it indicates too much aging of the wine. A bright color adds intrigue and indicates freshness, making the wine more appetizing. The response of the consumer can be seen in Fig. 16. Brightness is in turn quantified by the sum of absorbencies at 420 nm and 520 nm, the wavelengths at which red wines absorb (% brightness = $D_{420} + D_{520}$) (Sudraud, 1958). Fig. 17 depicts the consumer descriptors vs. this sum and Fig. 18 the combined plot. Brightness is manipulated with the same soaking and fining methods for the control of color.

4.8. Aroma and bouquet

The strongest sense used in evaluating is the nose. The nose houses over 200 identifiable scents. Therefore, when evaluating food, drinks, or any type of decision, the scent is most often the sense that most controls the consumer's decision and evaluation. There are two different types of odors that are used in evaluating wine: aroma and bouquet. Aroma is the scent associated with grape variety and type. These scents can be found in the fresh juice before fermentation. Bouquet is the odor used to describe the characteristics of wine due to processing. The bouquet of a wine is generated by the byproducts of fermentation and the oak barrels the wine is aged and stored within for example. Thus, while aroma is inherent to the grapes used, bouquet can be manipulated.

Bouquets can also be evaluated further by the formation of aroma profiles. Aroma profiles are made by evaluating the intensity of distinct aromatic compounds. Some of these compounds are the result of the grapes, the tannins present, but also the oak with which the wine is processed. Fig. 19 shows an example of two pinot noirs: one is normally aged in oak, while the other has been aged with "heavy toasted" oak barrels. The traditionally oak aged wine (red) is compared to the same wine soaked in a "heavy toast" of oak (blue). The profile shows a high level of intensity for the 4-methylguaiacol and guaiacol, which are both associated with heavy smells of smoke (ETS Laboratories, 2001). These flavor profiles can be constructed for each different wine that is to be measured in order to evaluate the wine more specifically.

Bouquet was examined in detail to identify specific compounds which contributed to the consumer-identified aromas of the bouquet of wine stored in a toasted oak barrel. Important bouquets include butterscotch/caramel, clove, vanilla, and oak/coconut. Butterscotch/caramel bouquet is due to levels of furfural and 5-methylfurfural, with typical values ranging from 100 to 270 mg/kg of wine. A clove characteristic is due to the presence of small amounts of eugenol ranging between 5 and 25 μg/L. Vanilla levels in wine can be attributed to the amount of vanillin present. Typical values of vanillin in toasted wine range from 25 to 55 mg/kg of wine. Oak lactones are responsible for the oak/coconut presence

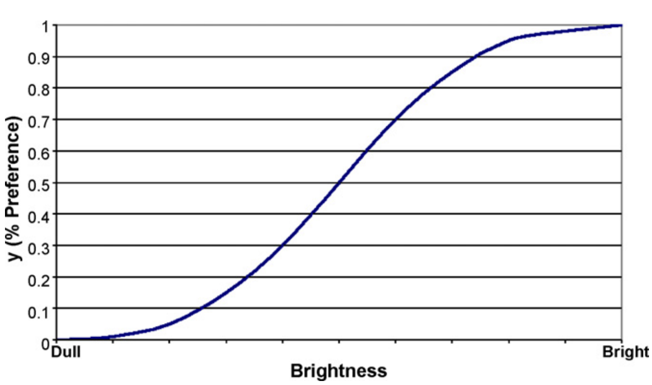

Fig. 16. Brightness preference vs. brightness descriptors.

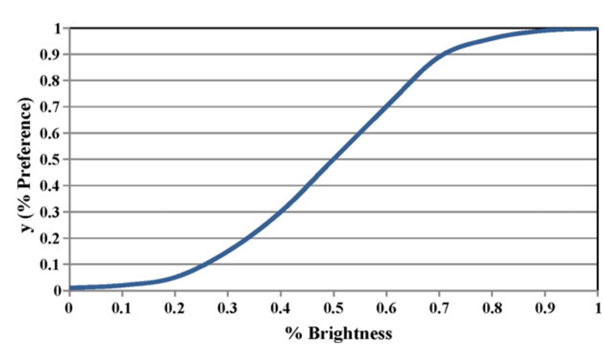

Fig. 18. Brightness preferences.

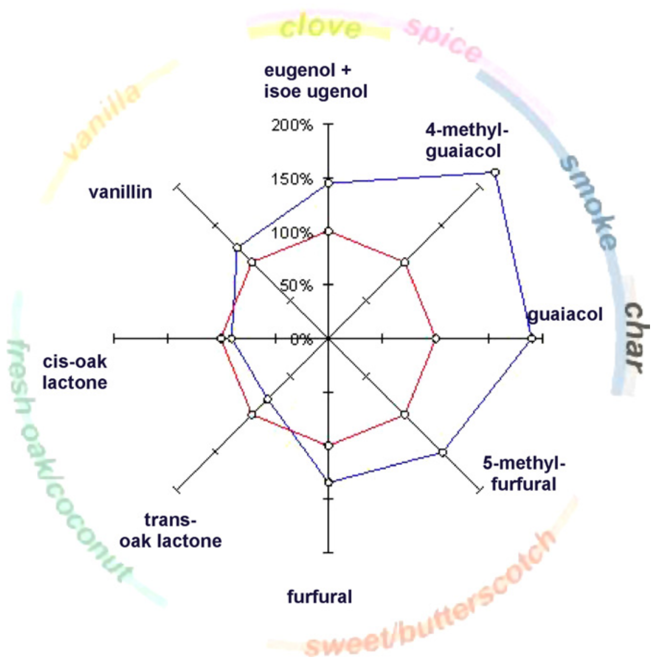

Fig. 19. Aromatics profiles for two differently aged pinot noir (ETS Laboratories, 2001).

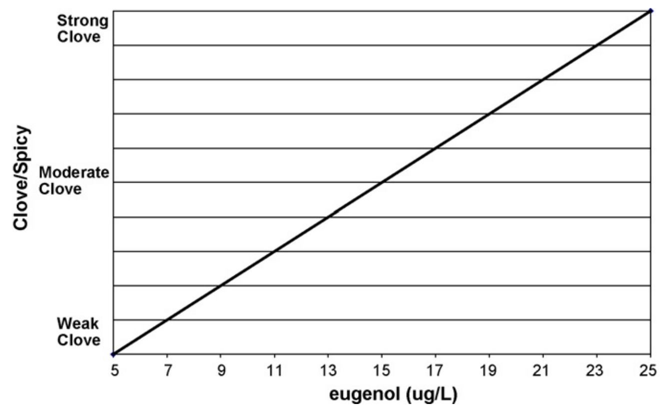

Fig. 21. Consumer descriptors of clove bouquet vs. eugenol concentration.

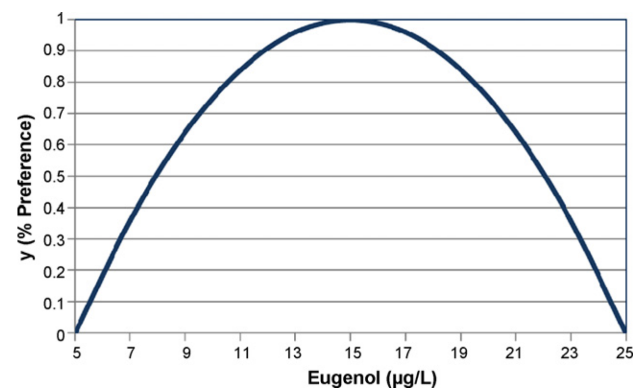

Fig. 22. Consumer preference curve for clove bouquet as a function of eugenol.

in the bouquet, with typical values between 105 and 200 µg/L (Gutierrez, 2003).

Consumer preference for clove is described in Fig. 20. After the relationship between clove bouquet descriptors is identified (Fig. 21), we arrive at the preference function for clove bouquet as a function of eugenol concentration (Gawel, 2007) (Fig. 22). This procedure, which can be repeated for all other bouquets, is omitted here.

Bouquet can now be obtained by exploring all the different options available for toasting the oak barrels. Toasting can be further categorized by different intensities from light to heavy toasts. Medium toasts offer the most potential for flavor, as heavy toasts tend to breakdown important compounds contributing towards the bouquet (Hale, McCafferty, Larmie, Newton, & Swan, 1999).

4.9. Body/texture

Body or texture is what is used to describe the feeling of wine in the mouth. A full-bodied wine feels heavy and viscous within the mouth. The body is ranked as being appropriate for the type and age of the wine. For example, a cabernet sauvignon has a much fuller body than that of a white zinfandel. The preferences are shown in Fig. 23. The body/texture can be calculated the percent alcohol of the wine (Cooke & Lapsley, 1988). After normalizing the consumer's descriptions (Fig. 24) with the % alcohol, Fig. 25 shows the correlation that describes the consumer's body/texture preferences with the % alcohol. Alcohol amount is easily manipulated during the wine manufacturing process. The amount of fermentation that takes place affects the overall alcohol mass fraction.

4.10. Finish/aftertaste

The finish or aftertaste of the wine is one of the final characteristics evaluated when deciding the quality of the wine. Finish is attributed to tannins as well as the alcohol content of the wine.

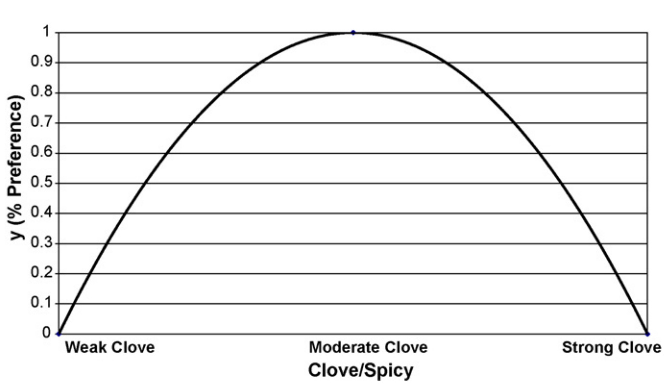

Fig. 20. Consumer preference curve for clove bouquet.

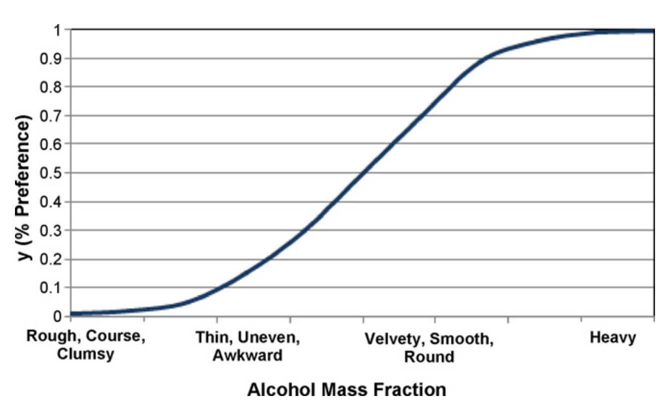

Fig. 23. Consumer preference curve for texture.

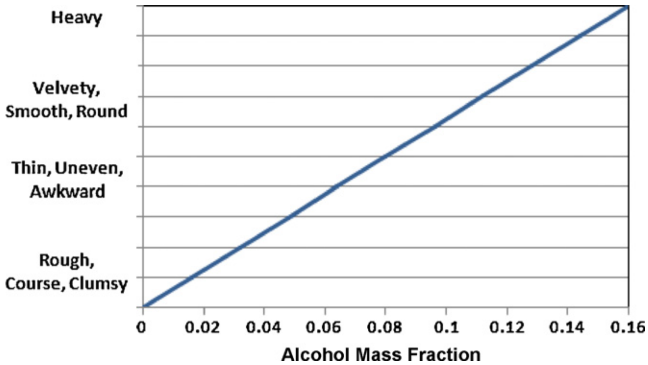

Fig. 24. Consumer descriptors as a function of % ethanol.

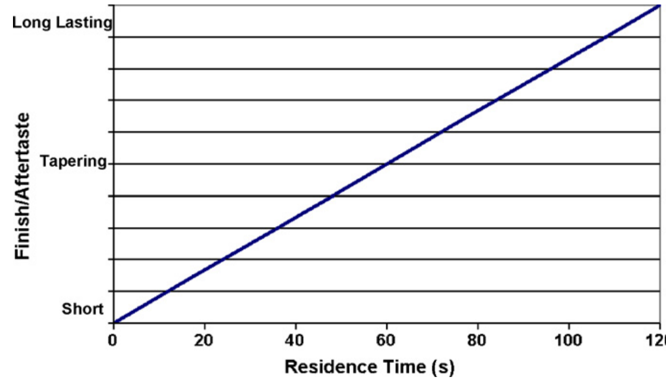

Fig. 27. Consumer descriptors for aftertaste vs. residence time.

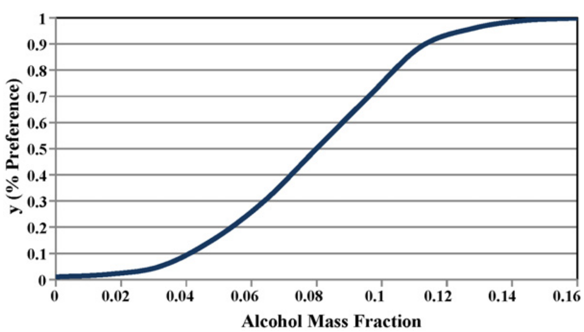

Fig. 25. Consumer preference vs. alcohol content.

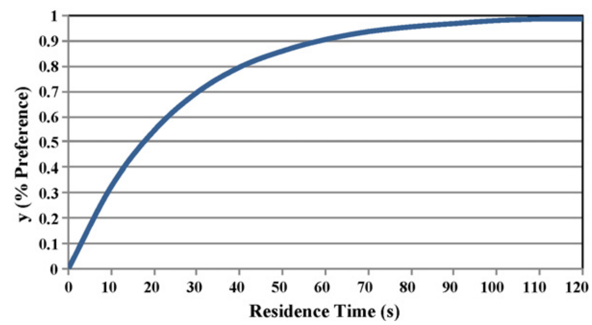

Fig. 28. Consumer preference for aftertaste vs. residence time.

Excess tannin in wine produces dry, puckering, and tart flavors and tends to give a coating on the teeth of the taster. The younger the wine, the more tannins are present. With age, the tannins dissolve, and the wines begin to ripen and smooth, leaving the astringency or harshness behind. Red wines typically have many more tannins than those of white wines due to their processing being with the vines and stems. Residence time on the palate can be used to correlate the consumer's description of finish/aftertaste. Fig. 26 describes the consumer preferences, Fig. 27 provides a relationship between the descriptors and the residence time and Fig. 28 displays the final function.

Many factors play a role in the aftertaste of a red wine. Tannins, aromatics, and other compounds, leave a small residue on the tongue, thus affecting the aftertaste. Therefore, just as the case with several other characteristics, reducing or increasing the amount of these compounds will affect aftertaste.

Fig. 26. Consumer preference for aftertaste.

5. Best product

If one desires to maximize the consumer preferences (maximum H_1), then the product corresponds to the following scores and the following properties (Table 2).

These values were obtained by analyzing each consumer preference curve and deciding on an optimal yet achievable score. When the resulting y_i values were found and multiplied by their respective weights (Eq. (3)), the H_1 value is 0.98. An H_2 value (competitors consumer preference score) of 0.7 (typical completion wines) is used in this paper. This gives a β value of 0.71. These values of H_1 and H_2 is uncertain and they have an impact on β only.

6. Optimal decisions under deterministic conditions

For any business, the ultimate goal is to maximize the profit. We use net present worth. Our methodology follows Bagajewicz

Table 2
Scores for an optimal bottle of wine.

Characteristic	x_i
Acidity (pH)	3.5
Sweetness (wt% residual sugar)	0.16
Bitterness (g tannin/L wine)	0.25
Clarity (NTU)	0.02
Color (absorbance ratio)	1
Brightness (% brightness)	0.95
Bouquet	
Butterscotch (mg furfural/kg wood)	270
Clove (μg eugenol/L)	15
Vanilla (mg vanillin/kg wood)	55
Oak/coconut (μg lactones/L)	105
Body (wt% alcohol)	10.14
Finish/aftertaste (s)	120

(2007), who establishes that one way of solving the optimization problem is the following decomposition:

- Fix the quality (β).
- Determine the product structure that fits the chosen value of β at minimum cost.
- Chose some other business parameters and determine the demand for different prices. Compute the capital needed for each projected demand.
- Calculate the NPW for each price.
- Modify the quality and repeat the process.

With α and β functions defined and integrated into the demand model, the selling price was varied at several different production rates to determine the optimum selling price based on the largest net present value calculated. Several variables were held constant, including the competition selling price p_2, interest and inflation rate, rate of return, and working capital. The superiority function β was chosen such that the "optimum" bottle of wine was being produced which maximized consumer utility for all wine attributes. Finally, as it was sometimes suggested above, the manipulation of the aforementioned variables was assumed to always have the same cost. Although small variations exist, these are negligible compared to the overall manufacturing cost in this case.

The following manufacturing costs were considered: raw materials (grapes, yeast, and chemicals), packaging, labor, supervision, utilities, maintenance and other expenses, capital depreciation (something that one might want to exclude if the winery is well established).

Fig. 29 displays the resulting range of net present values at each scenario. The graph shows a maximum net present value of approximately $180 million at a production rate of 2.5 million bottles per year and a selling price of $36.

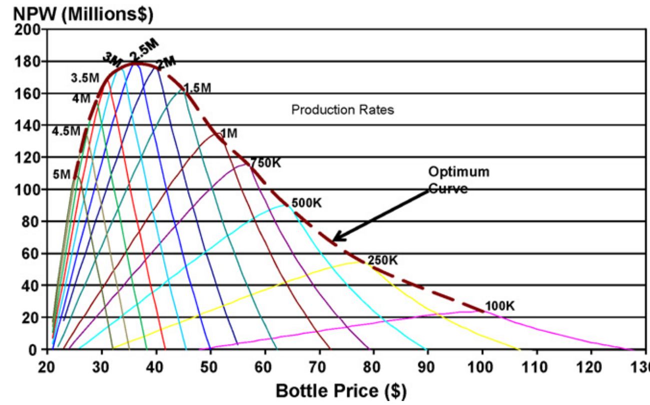

Fig. 29. Net present value as a function of selling price at different production rates.

7. Optimal decisions under uncertainty

Uncertainty was incorporated into the model, essentially allowing variations around a mean for the following main parameters: consumer preference (H_2 and H_1), competitor price, consumer budget, and the interest rate. The resulting risk curve obtained for this optimum scenario (2.5 M, $36) is shown in Figs. 30 and 31 using dark large red rhombuses. These risk curves were obtained making a Monte Carlo simulation as explained in Bagajewicz (2007). The curve indicates that the probability of losing money with this product is around 16%. To explore other alternatives that could be less risky, 81 random scenarios were chosen that lie between $24 and $40 in Fig. 3 and that are not necessarily on the curve of maximums. In other words, because of uncertainty, less risky propositions can come from a combination of price and production that is not on the envelope. Production rates between 1 million and 5 million bottles per year were subjected to each price range. Expected net

Table 3
Scenario summary sorted by decreasing ENPV.

K (mil)	p_1	NPW ($M)	ROI	ENPW ($M)	EROI	$\Omega = 0$	VAR ($M)	OV ($M)
2.0	$40	$164.4809	174.4%	$111.48	117.0%	13.2%	$199.8601	$68.0365
2.0	$38	$145.4147	154.2%	$105.52	114.8%	10.8%	$182.1242	$52.1656
2.5	$38	$180.0475	153.0%	$103.54	89.3%	18.5%	$238.8682	$95.3255
2.5	$36	$157.9517	134.2%	$101.71	86.8%	16.1%	$199.2029	$74.9491
2.0	$36	$125.2131	132.8%	$100.31	104.5%	8.2%	$137.1119	$38.1458
2.5	$34	$133.6295	113.5%	$98.83	79.6%	10.4%	$170.6370	$49.9637
2.5	$40	$196.9221	167.3%	$98.49	85.0%	23.1%	$230.9303	$123.5832
1.5	$40	$121.0204	169.8%	$98.24	140.7%	7.7%	$130.4865	$33.3729
3.0	$34	$160.6865	114.3%	$91.97	66.1%	18.8%	$207.9432	$91.0473
1.5	$38	$105.9404	148.7%	$90.39	126.7%	5.8%	$95.7308	$26.3069
3.0	$36	$184.1008	131.0%	$90.36	62.7%	24.4%	$244.9740	$118.8886
2.0	$34	$104.9871	111.3%	$87.77	93.0%	6.1%	$98.7443	$31.1438
3.0	$38	$185.4520	131.9%	$87.21	59.3%	26.0%	$254.0560	$152.0215
3.0	$32	$132.5604	94.3%	$86.06	60.5%	15.0%	$187.7438	$67.3659
2.5	$32	$108.3433	92.1%	$85.41	73.6%	8.0%	$123.3082	$39.9674
1.5	$36	$90.2628	126.7%	$80.20	115.0%	3.4%	$65.0989	$21.2959
3.5	$32	$152.7577	93.4%	$74.56	45.3%	23.0%	$228.0411	$101.4466
3.0	$40	$157.2034	111.8%	$74.48	51.6%	31.5%	$281.9888	$191.5980
2.0	$32	$84.0452	89.1%	$73.74	79.0%	4.6%	$66.5060	$25.1770
3.5	$34	$176.1513	107.7%	$71.83	44.8%	28.7%	$238.0507	$137.0774
3.0	$30	$102.2899	72.8%	$71.82	52.0%	11.2%	$156.0294	$52.6648
1.0	$40	$75.5822	156.9%	$70.23	143.1%	2.4%	$21.1210	$13.0995
2.5	$30	$82.4890	70.1%	$68.46	59.0%	7.2%	$85.6172	$30.8341
1.5	$34	$74.5563	104.6%	$68.32	96.3%	3.0%	$24.7534	$17.1203
3.5	$30	$120.8002	73.9%	$66.33	42.1%	20.2%	$206.1311	$75.8775
1.0	$38	$65.1112	135.2%	$62.14	127.6%	1.5%	$11.4904	$10.8190
3.5	$36	$155.4855	95.1%	$60.62	40.2%	33.8%	$277.0839	$182.8640
2.0	$30	$63.1033	66.9%	$58.11	61.3%	3.0%	$23.5901	$20.3750
1.5	$32	$58.8499	82.6%	$55.86	76.2%	1.6%	$13.0822	$13.4282
3.5	$28	$85.7525	52.4%	$55.56	34.5%	13.9%	$153.4309	$54.7424

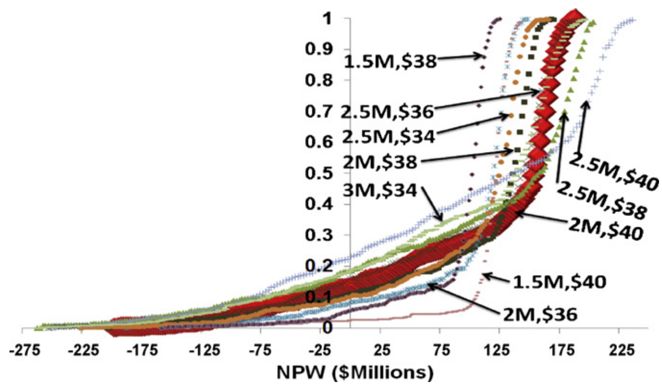

Fig. 30. First 10 risk curves for scenarios in Table 2. The large font curve (2 M, $40) indicates the scenario with the largest ENPW.

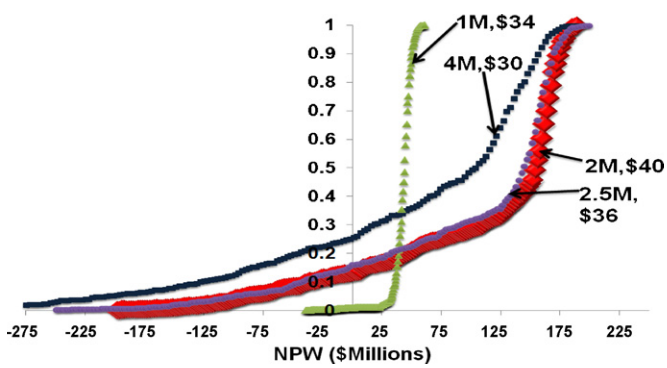

Fig. 31. Notable curves. The 1 M, $34 curve shows very small risk, while the 4 M, $30 curve has a large amount of risk.

present values and return on investments were documented and summarized along with opportunity values to display several different profitable decisions. Table 3 and Fig. 30 summarize the top 10 best scenarios sorted by decreasing expected net present value and Fig. 31 includes some of the most interesting ones risk-wise, including one of very small risk.

The quality (β) function was further manipulated to examine the effects it had on associated risk. It was found that manufacturing a wine of lower consumer utility (higher beta) can, in some cases, reduce the risk at similar aspiration levels. A decrease in risk is always accompanied by a lower opportunity value. This delicate balance between associated risk and opportunity value is an important factor for decision making in economics. "Risk lovers" will greatly consider the opportunity value when deciding operating conditions and selling price. In other words, they will take more risk for the chance to make more money. "Risk averse" is a term used to describe those who make decisions by valuing lower profits more than larger profits in favor of lower risk. They look at the value at risk and decide whether or not they are willing to take the chance of making less than the ENPW.

8. Conclusions

Each bottle of wine can be engineered to maximize the profit of the producer by use of the demand model. Incorporating uncertainty into the demand model can change the optimal product and allows manipulating financial risk. Altering the quality of the wine, or β, can in some cases, lower the associated risk with that decision.

Appendix A

A.1. Wine manufacturing

The process can be broken down into four stages: harvesting, fermentation, aging, and distribution. This process is shown in Fig. 32.

Harvesting grapes: This process begins in late July or early August when the grower or sommelier informs the president of the impending harvest. Picking of the grapes begins early in the morning to keep the fruit cool and helps prevent spoiling of fruit while reducing refrigeration costs of the grapes. If the grapes are warm, they should proceed immediately to the refrigeration unit until their temperature reaches ~68 °F. The crushing/destemming unit can process up to 11 tons of grapes per hour. The goal is to process the 620 tons of grapes within 12 h of arrival from the vineyard. Pumping of the must into refrigerated tanks occurs immediately after the crushing/destemming process. Measurement of the pH, titrateable acidity, and sugar content of the grape must occur during the cold soaking stage. The must is adjusted to 3.3 pH, 0.8% titrateable acidity, 24° Brix, and 50 ppm SO_2 as it reaches a 20,000-L tank. Cooling of the must to 48 °F and blanketing it with CO_2 is top priority to prevent any fermentation from occurring.

Fermentation: After cold soaking of the must for 4–5 days, transfer of the must from the 20,000 L closed tanks to the 9000 L open fermenters occurs by pumping with 3″ diameter hosing. Fermentation begins with raising the temperature of the must to room temperature and addition of Pasteur red yeast along with ample diammonium phosphate. A forklift with a stainless steel cap plunger works the cap on each fermenter at least twice per day to prevent adverse microbial infection of the fermentation. The fermentation continues until the sugar content reaches °8 Brix which occurs in approximately 1 week. The must is then pumped into one of the 4 Puleo SF-24 membrane presses where the skins, seeds, and must are removed from the wine. All wine from the membrane press leaves via 2″ diameter hosing driven by a pump. The free run wine and pressed wine should be kept separate so that flavors can be blended to perfection later in the aging. The wine pumps back into a 20,000-L tank and continues yeast fermentation while addition of the malolactic bacteria *Viniflora Oenos* begins malolactic fermentation. These fermentations continue until they naturally end or the sugar content reaches −1°Brix. Once fermentation ends, the wine is racked from the fermentation lees and rough filtered by pumping through a 40 × 40 filter frame with 40–7 μm filter pads. The rough filtered wine is then pumped back into the 20,000-L refrigeration tanks. Bentonite is added to the wine to remove excess protein (hot stabilization) while the wine is being cooled to 27 °F (cold stabilization) to precipitate out potassium bitartrate. After hot and cold stabilization, the wine is ready to go onto the aging step.

Aging: The wine is pumped from the hot and cold stabilization tanks into 2000 L maturation vessels. These vessels include an oak quick plank for smoothing of the tannins in the wine as it ages. The free SO_2 is adjusted to 50 ppm and the wine is capped with a variable capacity skin that seals the wine from free air surface. The wine is aged for 4 months and then racked off the gross lees into another 2000 L vessel. This process is repeated twice more and tested for quality at each step. This is the last chance to cure any off odors or tastes in the wine before being bottled and distributed. Once all factors are maximized, the wine is sent through medium polish and sterile filters en route to bottling.

Distribution: Once wine is stabilized, aged, fined, and filtered it is ready for distribution to the drinking public. The wine is sent to the bottling and corking unit which minimizes time the wine spends with oxygen. After this point the bottle is labeled,

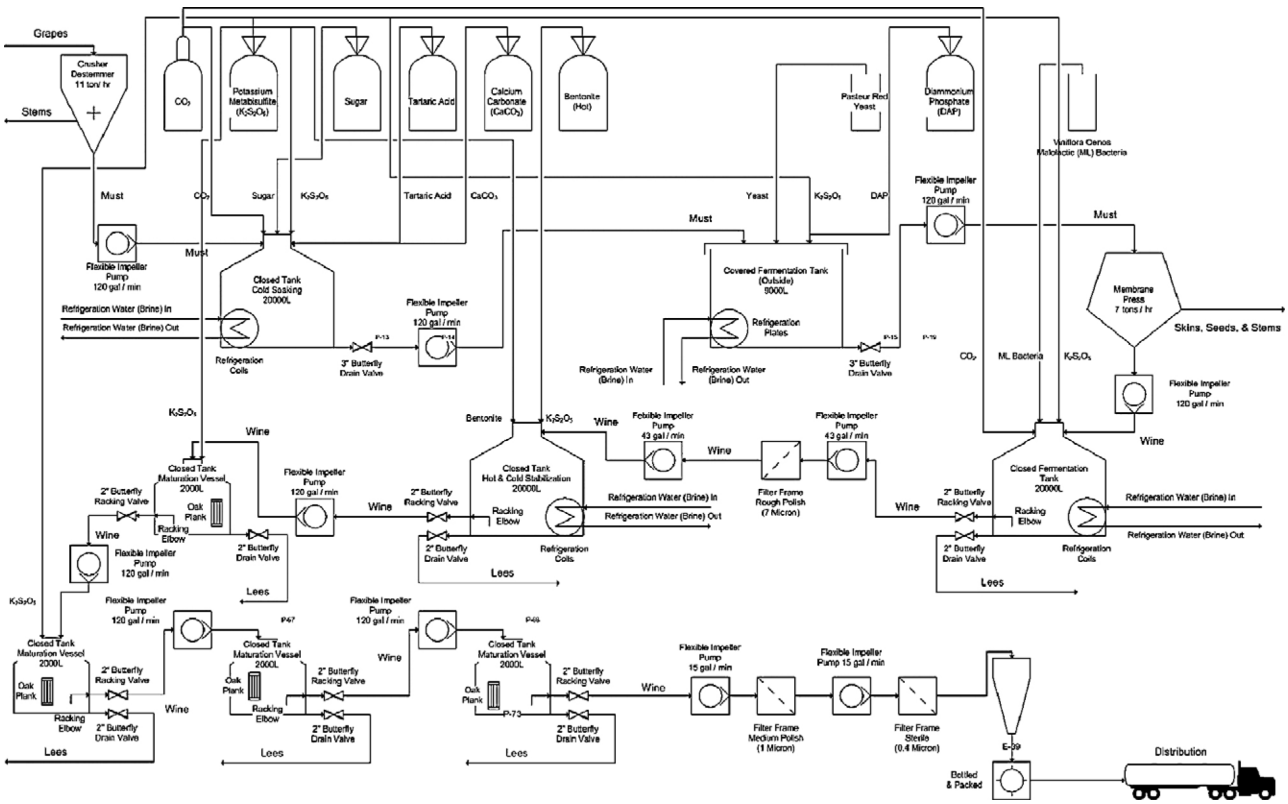

Fig. 32. Process flow diagram for a winery.

sealed with a capsule, and packaged into cases. The cases sit in storage for about another 3 months before being shipped to the distributor.

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