



Too Much of a Good Thing? Causes and Consequences of Increases in Sugar Content of California Wine Grapes

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ABSTRACT. The sugar content of California wine grapes has increased significantly over the past 10-20 years, and this implies a corresponding increase in the alcohol content of wine made with those grapes. In this paper we develop a simple model of winegrape production and quality, including sugar content and other characteristics as choice variables along with yield. Using this model we derive hypotheses about alternative theoretical explanations for the phenomenon of rising sugar content of grapes, including effects of changes in climate and producer responses to changes in consumer demand. We analyze detailed data on changes in sugar content of California wine grapes at crush to obtain insight into the relative importance of the different influences. We buttress this analysis of sugar content of wine grapes with data on the alcohol content of wine.

Key Words: California winegrapes, sugar content, alcohol percentage, climate change, Parker effect

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Too Much of a Good Thing?

Some wine writers express their dismay
Over high alcohol cabernet
Burning coal, says Al Gore
Not the high Parker score
Is the cause of the rising baumé

Still a 15 percent chardonnay
Will be too hot to drink most would say
Lower Brix on the vine
Spinning tricks with the wine
Or a lie on the label might pay

1. Introduction

The sugar content of California wine grapes has increased significantly over the past 10-20 years, and this implies a corresponding increase in the alcohol content of wine made with those grapes. The sugar content of California wine grapes at harvest increased from 21.4 degrees Brix in 1980 (average across all wines and all districts) to 21.8 degrees Brix in 1990 and 23.3 degrees Brix in 2008.¹ Since sugar converts essentially directly into alcohol, a 9 percent increase in the average sugar content of wine grapes implies a corresponding 9 percent increase in the average alcohol content of wine (if the average in 1990 was, say, 13 percent alcohol by volume, the implied increase would be to an average of over 14 percent alcohol by volume).² These changes might have resulted from changes in climate (e.g., generally hotter weather), cultural changes in the vineyard (e.g., later harvest dates) either in response to perceived demand for more-intense or riper-flavored wines (e.g., as reflected in higher “Parker” scores) or to mitigate the effects of climate change, or some combination of the two.

¹ Degrees Brix (°Bx) is a measurement of the relative density of dissolved sucrose in unfermented grape juice, in grams per 100 milliliters. A 25 °Bx solution has 25 grams of sucrose sugar per 100 milliliters of liquid. The percentage of alcohol by volume of the finished wine is estimated to be 0.55 times the °Bx of the grape juice.

² This would represent a very substantial increase in the average alcohol content of table wine both absolutely and compared with the range of alcohol content among wines. White wines nowadays typically have 12 to 14 percent alcohol by volume and red wines typically have 13 to 15 percent alcohol by volume, with the lower-priced wines sold in larger containers often having relatively low percent alcohol, partly reflecting the differential federal excise tax rates that apply depending on the alcohol content.

In this paper we aim to develop a detailed, quantitative economic understanding of the causes and consequences of these recent changes in the sugar content of wine grapes in California. In pursuing this aim, we document the increases in the sugar content of wine grapes and their implications for the alcohol content of wine in California, and evaluate the roles of exogenous changes in climate versus human responses (both in the vineyard and the winery) to climate change and other influences in determining the changing sugar content of wine grapes.

The changes in sugar content of wine grapes have taken place in the context of other changes in the industry. In the next section of the paper (section 2) we present an overview of the California wine and winegrape industry. In addition to providing an overview of the basic trends in sugar content of wine grapes, we describe the main production patterns in terms of varieties grown, and variation in quality and price by location of production. We also provide an overview of changing technologies, market trends, government regulations, and recent changes in climate that may have had some influence on the phenomena we are studying. Vignerons have some scope to manage the balance between sugar content and other characteristics of wine grapes. Likewise, winemakers have access to technologies (i.e., the “spinning cone” technology and reverse osmosis) that may be used to remove alcohol from wine, and they can blend wines to balance characteristics. Data on the extent to which these technologies have been adopted and used to reduce the alcohol content of wine in California provides some evidence of the extent to which excess alcohol has become a nuisance by-product in the production of wine.

In section 3, we develop a model of winegrape production and quality, including sugar content and other characteristics as choice variables along with yield. Using this model we derive hypotheses about alternative theoretical explanations for the phenomenon of rising sugar content of grapes, including effects of changes in climate and producer responses to changes in

consumer demand. In section 4 of the paper, we document and describe changes in the sugar content of California wine grapes. We have assembled (from annual crush reports and various other sources) and begun to analyze a detailed data set that includes (a) annual data by variety of grapes and crush district on the average sugar content of wine grapes at crush, for 1980 through 2008, and (b) other data on yield, acreage, and production of wine grapes by variety and county. We use these data to estimate statistical models based on the ideas presented in section 3.

Detailed data on the alcohol content of California wines are not available. While every wine bottle reports a figure for alcohol content on the label, the tolerances are wide and the information content is therefore limited. Specifically, U.S. law allows a range of plus or minus 1.5 percent for wine with 14 percent alcohol by volume or less, and plus or minus 1.0 percent for wine with more than 14 percent alcohol by volume. Moreover, wineries have some incentive to deliberately distort the information because the tax rate is higher for higher alcohol wine or if they perceive a marketing advantage from keeping the stated alcohol percentage on the label within a certain range for a particular varietal or other style of wine. Consequently, label claims concerning alcohol content may be misleading. However, the Liquor Control Board of Ontario (LCBO), which has a monopoly on the importation of wine for sale in the province of Ontario, Canada, tests every wine it imports and records a number of characteristics including the alcohol content. In section 5 of the paper we present an initial analysis of the changes over time in the alcohol content of California wine tested by the LCBO. Section 6 concludes the paper.

2. A Potted History of California Wine and Wine Grape Production

During the 30 years between 1980 and 2010, California's winegrape vineyards changed dramatically. The most obvious difference was the physical expansion in total acreage and in location, as bearing acreage increased by 60%, from 278,935 acres in 1981 to 445,472 acres in

2007.³ Less obvious were the changes in the varietal composition of California's vineyards and the movement towards higher sugar concentration at harvest. None of these changes occurred smoothly over time. As growers responded to market cycles and trends, vineyard acreage evolved through phases of contraction and expansion, ultimately resulting in a varietal mix and vineyard geography in 2010 quite different from that of 1980.

Demand Drivers and Planting Cycles

Between 1980 and 2007, U.S. consumption of wine per adult (individuals over 21 years of age) increased by 15%, from 2.58 to 2.97 gallons per year, while the adult population grew by 40%, from 154 million to 216 million.⁴ Taken together, the rise in both the adult population and consumption per adult resulted in a significant increase in demand for table wine in the United States, much of which was satisfied by increases in production in California. However the change in demand was uneven over the period, especially for individual varieties, and the growth in supply was not always well matched to demand. The evolving supply and demand balance led to periodical "boom and bust" cycles that were more pronounced for particular varieties, with implications for planting and replanting. During times when prices were low, California winegrape growers set out new vineyards at a rate lower than necessary for replacement and, in some years, removed vineyards. Conversely, when grape prices were high, the grape industry attracted investment and vineyard acreage expanded.

The contraction and expansion of California vineyards is reflected both in gross acreage figures and in ratios of non-bearing acreage to bearing acreage. Assuming an economic life of 30 years for a vineyard, and that the vineyard age distribution is constant over time,

³ Acreage figures are derived from the California Department of Food and Agriculture's annual report of grape acreage. Figures for tonnage are derived from the CDFA's annual Grape Crush Report.

⁴ Population figures as well as estimates of gallons of wine per adult are taken from the Wine Market Council web site, which derived its estimates from the U.S. Census Bureau and the Adams Beverage Group. See slide 3 at http://www.winemarketcouncil.com/research_data.asp for more detail.

approximately 3.3% of vineyard acreage must be replaced each year. Given that vineyards do not become productive until the fourth year, at any given time, non-bearing acreage equal to approximately 10% of bearing acreage is required to replace aging vineyards that are soon to be grubbed out.⁵

Figure 1, panel a shows white and red non-bearing acreage as a percentage of total bearing acreage of white and red wine grapes, respectively, and the average price per ton of wine grapes in California.⁶ Two points stand out. First, during the late 1980s and again during most of the decade of the 2000s, total non-bearing acreage was less than that required for replacement, indicating periods of low profitability. Second, red and white varieties were not replaced at the same rate. In the early 1980s white non-bearing acreage was well above twice the acreage required for replacement, but has been at or below replacement rates since then. By the late 1980s, red varieties were being planted at a rate higher than needed for replacement. The replanting rate for white varieties also increased beyond that required for replacement in the second half of the 1990s, but red varieties remained the focus of the planting boom. The planting boom of the second half of the 1990s ultimately bore fruit, contributing to a “bust” in 2001 and 2002. Low grape prices led to the removal of some 90,000 acres of vineyards and non-bearing acreage fell below that required for replacement.

[Figure 1: *Nonbearing Acreage of Wine grapes as a Percentage of Bearing Acreage*
Phylloxera and Vineyard Replanting

Vineyards in California’s North Coast, and particularly in Napa and Sonoma counties, represent a special case deserving additional discussion. As seen in Figure 1, panel b, in most

⁵ Vineyards can certainly be productive for more than 30 years, but by that age, productivity declines and vineyards are often replanted. Because vineyards were often planted in cycles, vineyard age is not uniform over time and the 10% non-bearing acreage is merely a useful guideline rather than a precise figure.

⁶ These prices were deflated using the price deflator for GDP, based in 2008.

years during the two decades from 1985 to 2005, Napa and Sonoma counties had a higher percentage of non-bearing acreage than did the state as a whole. Since these counties experienced the same planting cycles and changes in consumer demand for wine, why was their percentage of non-bearing acreage higher than in other viticultural regions? The answer is that Napa and Sonoma suffered a phylloxera infestation in the 1980s and 1990s at a higher rate than surrounding regions, necessitating replanting of existing vineyards as well as new vineyard plantings to meet increased demand.

Phylloxera is a louse that attacks the roots of *Vitis vinifera*, ultimately killing its host. Since the first phylloxera epidemic of the 1860s in Europe, most viticulturists have combated phylloxera by planting rootstock bred from non-vinifera species that are resistant to phylloxera, and then grafting the desired vinifera cultivar on the rootstock. AXR was bred by the French viticulturist, Victor Ganzin, who crossed the vinifera variety, Aramon, with a *Vitis rupestris* selection. Released in 1879, AXR did not find favor in France but was used throughout the twentieth century in California, where it was considered moderately phylloxera resistant. Because of its partial vinifera parentage, AXR grafted well with vinifera scions. In addition, it propagated easily in nurseries and imparted increased vigor to vinifera scions, resulting in increased yields. During California's planting boom of the 1970s, over 200,000 acres of new vineyards were set out (Lapsley, 1996) and AXR became the rootstock variety of choice in northern California's coastal valleys, although it was not as widely adopted in the San Joaquin Valley, where phylloxera was less of a concern because its sandy soils were less conducive to phylloxera. AXR's dominance on the North Coast is reflected in the estimate of the viticulture farm advisors for Sonoma and Napa counties that approximately 42,000 acres of the two counties' total 55,616 acres in 1985 had been planted on AXR rootstock (Smith, 1998).

In 1983, the first signs of vineyard failure attributable to phylloxera were observed in Napa, and by 1985 vineyard owners in Sonoma were reporting problems. By 1989, the University of California no longer recommended the use of AXR as a rootstock (Sullivan, 1996), and replanting began, which continued through the 1990s. Although costly in materials and lost harvest revenue, the replanting roughly coincided with the red wine boom of the 1990s and allowed vineyard owners to convert their vineyards to red varieties while adopting higher planting densities and new trellising systems. The switch to Cabernet Sauvignon and Merlot was especially dramatic. In 1985, Napa and Sonoma had 11,800 acres of the two varieties, accounting for just over 21% of the grape acreage. By 2005 the acreage had more than tripled to 43,200 acres, which comprised just under 44% of Napa and Sonoma vineyard acres.

Change in Varietal Mix

Changes in consumer demand for wine type and variety drove changes in vineyard composition. The boom in wine consumption of the 1970s had been primarily in white wine, at a time when California vineyards were predominantly planted to red varieties. This demand led to relatively higher prices for white varieties and sparked the planting trend seen in Figure 1. In 1981, white varieties accounted for approximately 38% of the 278,935 bearing acres of wine grapes in California. By 1984, white varieties represented more than 50% of all acreage and white varieties remained dominant until 1998, when red varieties accounted for 50.7 percent. The trend toward red varieties has continued and in 2007 red varieties claimed just under 62% of all California winegrape acreage.

During this period, wine consumers in the United States increasingly chose varietally labeled wine, leading to the dominance of varieties such as Chardonnay, Cabernet Sauvignon, Zinfandel, and Merlot. In 1985, only 19% of California table wine carried a varietal label, but

within 15 years, by 2000, varietally labeled wine accounted for 71% of all California table wine by volume (Shanken, 2001, p. 97).⁷ Chardonnay was the first varietal to benefit from this trend. In 1981, 13,670 acres, or 13% of California's white wine acreage, was planted to Chardonnay. By 1990 Chardonnay acreage was 23% of white wine acreage, growing to 49% in 2000, and increasing to 55% in 2007 and 94,282 acres. Among red varieties, Cabernet Sauvignon and Merlot emerged as the dominant varieties for red wine production. In 1981, 21,447 bearing acres of Cabernet existed in California, accounting for 12.3% of all red variety acreage. By 2007, Cabernet acreage had more than tripled to 74,643 acres, or 27.1% of all red wine acreage. Merlot, starting from a much smaller base, also benefited from consumer interest in red wine in the 1990s. In 1990, with 4,010 planted acres, Merlot represented just over 3% of all red wine acreage. By 2007 Merlot acreage had grown 12-fold to 48,648 acres and claimed 17% of red wine acreage.

The variety Zinfandel requires more discussion. Although a red grape variety, the vast majority of its fruit is used to produce white Zinfandel, so it perhaps should be classified as a "white" grape variety.⁸ White Zinfandel gained popularity in the 1980s and has remained so, although its market share has declined somewhat in the past decade. From 26,652 acres or 15.3 percent of total red wine acreage in 1981, Zinfandel acreage grew to 20.3% of red acreage in 1990, and expanded further to 23% of red acreage in 2000. In 2007, at 49,061 acres, it represented 17.8 percent of red grape acreage, slightly more than Merlot.

[Figure 2: *Varietal Mix of California Wine Grape Production, 1980, 1990, and 2008*]

⁷ Under U.S. law, varietally labeled wine must contain at least 75% of the named variety.

⁸ According to Shanken (2001, p. 98), 21 million cases of California white Zinfandel were sold in the United States in 2000, equivalent to 49,896,000 gallons which, at 165 gallons of finished wine per ton, would require approximately 302,000 tons of Zinfandel if the wine were 100% varietal. This does not account for any white Zinfandel exported. In 1999 (the year that would have produced grapes made into wine and sold in 2000) 324,397 tons of Zinfandel were crushed. By this estimate 75% of Zinfandel grapes are used for the production of white Zinfandel.

Geographic Location

Just as the varietal mix changed within California's winegrape vineyards, so did the location of California's vineyards. In 1981 slightly more than 50% of California's winegrape acreage was located in the southern San Joaquin Valley but by 2008, this percentage had fallen to slightly more than 33% of acreage. While total California winegrape vineyard acreage had expanded by 164,756 acres (a 59% increase), San Joaquin Valley acreage had increased by only 12,422 acres, or 8.5%. For the present purpose, we have divided California into five viticultural areas: (1) the "North Coast," including Napa, Sonoma, Mendocino, Lake and Marin counties; (2) the "Central Coast," including Monterey, San Benito, San Luis Obispo, and Santa Barbara counties; (3) the "Delta," which includes the northern portion of San Joaquin County and southern portions of Yolo and Sacramento counties adjacent to California's delta; (4) the "San Joaquin Valley," comprising southern San Joaquin County, Stanislaus, Merced, Madera, Fresno, Tulare, Kings and Kern counties; and "Other" which includes the Sierra foothills, southern California, and the northern Sacramento Valley (in aggregate the "Other" area comprises approximately 6% of vineyard acreage and 3.5% of total tonnage). As is seen in Figure 3, the areas experiencing the greatest percentage growth in acreage were the Delta, which grew by 185% from 17,355 acres in 1981 to 49,558 acres in 2008; the North Coast, which expanded by 128% from 55,474 acres in 1981 to 87,726 acres in 2008; and the Central Coast, which doubled in size from 41,015 acres in 1981 to 82,600 acres in 2008.

[Figure 3: *Regional Distribution of California Winegrape Acreage, 1981 and 2008*]

[Figure 4: *Regional Distribution of California Winegrape Acreage, by Variety, 2008*]

Price Patterns by Variety and Location

California's vineyard regions differ significantly in yield and in perceived quality, which is reflected in the average price per ton paid for grapes from different regions. Figure 5 shows

the average price per ton for Cabernet Sauvignon and Chardonnay wine grapes for five California viticultural areas in 2008. The price ranged from an average price of \$4,648 a ton for Cabernet Sauvignon grown in Napa County, to a low of \$363 a ton for the same variety grown in district 14, which is located at the southern end of the San Joaquin Valley. The higher prices paid for Cabernet from Napa and Sonoma counties reflect the very real compositional differences, such as higher acidity, deeper color, and greater intensity, relative to grapes grown in California's warm interior valley. To some extent the prices also are indicative of yield. In 2008, Napa County vineyards delivered 2.4 tons of Cabernet per acre, and neighboring Sonoma County yields were only a bit higher at 2.8 tons. In the warm interior valley, Delta vineyards produced 7.6 tons per acre of Cabernet while district 14 yielded 15.1 tons per acre. Monterey and San Benito counties in California's Central Coast, yielded 4.4 tons per acre.

[Figure 5: *Price of Cabernet Sauvignon and Chardonnay in Various Districts, 2008*]

Cabernet Sauvignon shows the greatest price variation among regions, but the reality of lower yields and higher prices in the coastal areas and lower prices and significantly higher yields in California's Central Valley is seen in Figure 6. Panel a shows the percentage of tons by region while Panel b displays the percentage of value by region. The North Coast, which accounts for just less than 10% of all grapes crushed, commands over 38% of all revenue. It is followed by the Central Coast, which grew 9.4% of all tons crushed and claimed 18.8% of revenue. The Delta, the coolest area of California's interior valley, delivered 17.1% of all grapes crushed and received 13.5% of the revenue. The southern San Joaquin Valley, responsible for producing 61% of California's harvest, received just under 27% of the revenue. Clearly growing grapes is a significantly different business in Napa than in the San Joaquin Valley.

[Figure 6: *Total Tons Harvested and Value in 2008 by Region*]

Sugar Content of Grapes

The expansion of California's vineyards since 1980 was readily apparent to even a casual observer and the change in the mix of varieties within the vineyards could be discerned by a trained viticulturist. What was not easily observed was a third change: The increase of sugar concentration at harvest. On average, sugar at harvest for all crushed grapes increased from 21.2 degrees Brix for the period 1980–1984, to 23.8 degrees Brix for the period 2005–2007, almost a 10% increase.⁹ The extent of change varied by variety and growing region, as well as over time, but it is clear that a shift towards higher sugar at harvest became evident in the mid 1990s and through the first decade of the 21st century. White varieties, which are generally picked at lower sugar than are red grapes, increased sugar at harvest by just under 12%, moving from an average sugar at harvest of 20.7 degrees Brix in the years 1980–1984, to 23.2 degrees Brix for the period 2005–2007. Red grapes increased from 22.2 to 24.3 degrees Brix for the same time period. Average degrees Brix at harvest for red varieties, as a single category, was reduced by the inclusion of Zinfandel, a red variety that is generally harvested at low sugar for the production of White Zinfandel. Indeed, average sugar at harvest barely changed for Zinfandel, rising from 22.0 only to 22.6 degrees Brix between 1980–1984 and 2005–2007. In contrast, Cabernet Sauvignon increased from 22.8 degrees Brix in 1980–1984 to 25.0 in 2005–2007. Figure 7 charts the rise of sugar at harvest for California as a whole.

[Figure 7: *Trends in Sugar Content (Degrees Brix) of California Wine Grapes, 1980-2008*]

Cabernet Sauvignon, the most widely planted red variety used for red wine in California, exhibits a dramatic increase in sugar at harvest, beginning in the second half of the 1990s, with differences among regions. For the period 1980–1984, average degrees Brix at harvest for

⁹ These are averages of averages, that is, the total of weighted average degrees Brix per vintage, added over several vintages and divided by the number of vintages. This was done in order to reduce the effects of normal fluctuations between years.

Cabernet was quite similar among regions, with the lower San Joaquin Valley harvesting at 22.6 degrees Brix and the coastal regions picking at around 23.0 degrees Brix.¹⁰ For the period 2005–2008, degrees Brix at harvest were 25.0 or above for all regions except the San Joaquin Valley, which averaged 24.5. The upward movement began in the second half of the 1990s, increased during the first five years of the 2000s, and peaked in the second half of the decade, with Napa and Sonoma showing the highest average degrees Brix at harvest. Other varieties exhibit increasing concentration of sugar at harvest as well, although not quite to the same extent as Cabernet Sauvignon. For example in 2008, Pinot Noir, a variety grown in cooler areas to enhance its varietal character, was picked at an average of 24.4 degrees Brix in Napa and Sonoma, while prior to 2000 it had been picked at below 23.0 degrees Brix. For the last two years of our data, Chardonnay grown in the Delta averaged 24.1 degrees Brix at harvest, in contrast to an average of 23.2 degrees Brix during the decade of the 1990s.

Alcohol Removal

It is unclear why sugar has increased at harvest and there are no doubt numerous contributing factors. Global warming is often mentioned. For instance, average minimum temperatures in the San Joaquin Valley rose by about 2.5 degrees Fahrenheit (almost 1.4 °C) from the 1930s to the first years of the 21st century, and most of that increase became apparent during the most recent 20-30 years (Bar-Am 2009; see also Weare 2009).

Denser coastal vineyard plantings and new trellising systems are also often cited. Some winemakers point to the new rootstock/scion interactions that were introduced following the collapse of AXR to phylloxera, indicating that these new vineyards achieve sugar ripeness prior

¹⁰ The San Joaquin Valley data combines crush districts 12, 13 and 14; the North Coast is districts 3 and 4 (Sonoma Marin and Napa counties); the Central Coast is districts 7 and 8 (San Benito, Monterey, San Luis Obispo, Santa Barbara, and Ventura counties); and the Delta is district 11, comprising the northern portion of San Joaquin County and the southern portion of Sacramento County.

to reaching phenolic maturity, making it necessary for the grapes to “hang” longer than in the past. Still others claim that higher sugar at harvest is simply a style choice, with no underlying physiological reason to be found in the vineyard. Whatever the case, it is clear that higher sugar grapes, if fermented to dryness, result in higher alcohol wines.

Higher alcohol in wines may or may not be a desired outcome of increased sugar. The presence of more alcohol can contribute to a perception of “hotness” for some consumers, while for others higher alcohol may add a sense of sweetness to the wine. However, under the United States tax system, wines above 14% alcohol by volume are taxed at \$0.50 a gallon more than are wines with a concentration of less than 14%. The demand to reduce alcohol concentrations has given rise to a new business in California, alcohol reduction. Currently two firms, Wine Secrets and ConeTech, specialize in alcohol removal. Wine Secrets uses reverse-osmosis filtration to separate alcohol and water, while ConeTech employs a patented low temperature distillation system. In both cases, a portion of the wine to be treated will be shipped to the processing facility where significant amounts of alcohol are removed, perhaps reducing the alcohol concentration from 16% to 5%. The low alcohol fraction is then shipped back to the contracting winery, where it is blended back into the main lot, thus lowering the total blend. Use of such technology indicates a demand to reduce the alcohol content of wine. Based on its production of “proof gallons,” we estimate that ConeTech alone treated roughly 3.3 million gallons of wine per year for the four years 2005–2008, which represents a finished amount of approximately 16.5 million gallons (assuming 20% of a lot would be treated), or about 3% of California’s annual wine production. (A “proof gallon” is a gallon of 50% alcohol, so one proof gallon represents the lowering of 50 gallons of wine by 1% alcohol.) ConeTech indicates that they have sold their technology to several large California wineries, but declined to name their clients.

3. A Simple Model of Determinants of Sugar in Wine Grapes

In this section of the paper we develop a model of winegrape production and quality, including sugar content and other characteristics as choice variables along with yield, which we can use to derive hypotheses about alternative theoretical explanations for the phenomenon of rising sugar content of grapes. The model details reflect the fact that winegrape yields, quality, and prices vary significantly among regions within California, and within regions depending on weather, varieties grown, cultural techniques, and other management practices.

Vineyard Economics

Growers' variable profit per acre of wine grapes of variety v grown in crush district d in year t is equal to gross revenue per acre (yield in tons per acre, Y_{vdt} times the price per ton, P_{vdt}) minus variable costs (the quantity of variable inputs used per acre, X_{vdt} times the price per unit of inputs, v_i).¹¹ That is:

$$\pi_{dvt}^G = P_{dvt} Y_{dvt} - v_i X_{dvt}. \quad (1)$$

The price of wine grapes varies, depending on their sugar content, B (in degrees Brix) and other physical quality characteristics, Q (such as acidity), as well as the variety, V , the district, D , and the year, Y (reflecting market conditions).¹² Thus:

$$P_{dvt} = p(B_{dvt}, Q_{dvt}, D_d, V_v, T_t). \quad (2)$$

The yield of wine grapes varies among crush districts, varieties, and years, and with changes in the quantity of variable inputs, X ; it also depends on weather conditions during the growing season in the crush district, W_{dt} (a complex of rainfall and temperature variables), and management practices applied to the particular variety, M_{dvt} . The yield relationship may also

¹¹ It might be useful to disaggregate into several categories of inputs for some purposes but for now we treat it as a scalar aggregate.

¹² The district itself might have a direct value, as an influence over price, as well as serving as a proxy for certain quality characteristics of the wine produced.

vary over time reflecting year-to-year and secular changes in technology that are not captured in the weather and management variables (e.g., because of changes in climate, rootstocks, pest and disease prevalence, or other factors), and the variable T_t is included to represent these aspects.

$$Y_{dvt} = p(X_{dvt}, W_{dt}, M_{dvt}, D_d, V_v, T_t). \quad (3)$$

The sugar content of wine grapes (B) and other quality characteristics (Q) depend on the same factors that affect yield.

$$B_{dvt} = b(X_{dvt}, W_{dt}, M_{dvt}, D_d, V_v, T_t). \quad (4)$$

$$Q_{dvt} = q(X_{dvt}, W_{dt}, M_{dvt}, D_d, V_v, T_t). \quad (5)$$

Winery Economics

Winemakers' variable profit per gallon of bulk wine (or equivalent quantity of wine grapes) produced using variety v grown in crush district d in year t is equal to gross revenue per gallon, G_{dvt} minus (a) the cost of excise taxes per gallon, E , which depend on the alcohol content of the wine, A_{dvt} , (b) the cost of the wine grapes, (c) variable costs of winemaking (the quantity of variable inputs used per gallon, Z_{vdt} times the price per unit of inputs, r_t), and (d) expenditure on removal of alcohol from wine, S_{vdt} .¹³ That is:

$$\pi_{dvt}^W = G_{dvt} - E(A_{dvt}) - P_{dvt} Y_{dvt} - r_t Z_{vdt} - S_{vdt}. \quad (6)$$

The value of wine per gallon depends on its alcohol content, A , other physical quality characteristics, K , as well as the variety, V , the district, D , and the year, Y (reflecting market conditions).

$$G_{dvt} = g(A_{dvt}, K_{dvt}, D_d, V_v, T_t). \quad (7)$$

¹³ It might be useful to disaggregate into several categories of winemaking inputs for some purposes but for now we treat Z as a scalar aggregate, as we did with X for grape production.

The alcohol content of the wine depends on the sugar content of the wine grapes, but can be modified by the expenditure of effort, S .

$$A_{dvt} = a(B_{dvt}, S_{dvt}). \quad (8)$$

Other quality characteristics of the wine depend on the same variables, as well as the quality characteristics of the wine grapes, Q , the quantity of winemaking inputs, Z , and oenological management practices in the winery, O .

$$K_{dvt} = k(Q_{dvt}, O_{dvt}, B_{dvt}, S_{dvt}, A_{dvt}, D_d, V_v, T_t). \quad (9)$$

Hypotheses about Increases in Brix in California

Equations (1) through (9) incorporate the linkages between exogenous factors—such as weather and changes in consumer demand—and the joint determination of winegrape yield, quality, and sugar content, along with wine quality, price, and alcohol content. We have these linkages in mind informally in developing hypotheses about the exogenous causes of changes in sugar content of California wine grapes.

We propose two main hypotheses about the sources of the rise in sugar content of wine grapes in California. In each case the increase in sugar content of grapes is seen as an unsought consequence of other factors. The first hypothesis is that exogenous changes in the weather, with generally rising average temperatures, implied increases in sugar content of grapes even without any changes in management of the vineyard by growers.¹⁴ Profit-maximizing responses of growers and wineries to such changes could mitigate the implications for sugar content of grapes but should not be expected entirely to eliminate their impact.

¹⁴ A literature is developing on the implications of climate and climate change for the wine industry, and some of that specific to California. Examples include Nemani et al. (2001), Tate (2001), Jones (2005, 2006, 2007), Jones et al. (2005), Webb et al. (2005), White et al. (2006), and Jones and Goodrich (2007). Issues addressed include various aspects of wine quality, yield, and the optimal location of production. Published work to date has not quantified the impacts on sugar content of grapes that are the subject of our work.

The second hypothesis is that the trend was caused by a market demand (perceived or real) for wines with ripe flavors and lower tannin levels, attributes associated with grapes that are picked at higher degrees Brix. Under this hypothesis, profit-maximizing responses of wineries and growers to changes in demand for quality characteristics of wine required changes in viticultural practices that resulted in unsought increases in sugar content of grapes.¹⁵ For instance, extending the “hang time” and picking the grapes later than they would do otherwise is likely to result in higher sugar content if only because the grapes are more dehydrated. To some extent vignerons can independently manage the sugar content of grapes and other quality characteristics, but an increase in intensity and ripeness of fruit is likely to come to some extent at the expense of a reduction in tons per hectare and an increase in degrees Brix.¹⁶

If climate change were the primary cause, we might expect to see different patterns of change among different regions and varieties, depending on the extent to which the climate had changed and the susceptibility of the variety in a given region to the changes. That is, we could attribute the observed patterns primarily to biophysical determinants; any human behavioural elements would be serving to mitigate the consequences of the exogenous change (e.g., to mitigate the increase in sugar content of grapes, to remove alcohol from wine, or to blend wine to balance alcohol content). What would be different if the primary cause was industry responses to increased consumer demand for more-intense, riper flavoured wines, and not

¹⁵ More-specifically, it has been suggested that influential wine writers, such as Robert Parker of the *Wine Advocate* or James Laube of the *Wine Spectator*, have encouraged the production of wines with strong, intense, riper fruit flavors, by giving very favorable ratings for such wines. This argument applies more directly to ultra-premium wines than to the large volume end of the market that is not subject to wine ratings, and probably more to red wines than white wines. However, changes in the ultra-premium end of the market might have led to similar subsequent movements in wines in the lower price categories. In addition, however, it has been suggested that some of the market growth of moderately priced wines has been facilitated by an emphasis on similar styles of wine that are attractive to less experienced wine consumers.

¹⁶ A literature on the economic effects of weather and climate on wine quality has developed over the past 20 years, with contributions such as Ashenfelter, Ashmore and Lalonde (1993), Ashenfelter and Byron (1995), Jones et al. (2005), Ashenfelter (2008), and Ashenfelter and Storchmann (2010).

climate change? It is difficult to derive crisp testable hypotheses that can be refuted unequivocally.

One contrast between the two theories is that warming temperatures would tend to imply increases in Brix correlated with earlier harvest dates, whereas later harvest dates would be correlated with demand-driven increases in Brix. There may be corollary differences in implications for yield (if climate change implies higher yields while delayed harvest implies lower yields). Perhaps detailed location-specific data on the nature and timing of changes in climate relevant to grape production might permit more precise hypothesis tests to be developed. Similarly, detailed location-specific data on the nature and timing of changes in harvest dates or other cultural practices might allow for more-powerful tests, but care will still be necessary.

Even if the observed increases in sugar content of wine grapes are primarily attributable to producer responses to changes in demand, vignerons and winemakers might be taking action to mitigate an unsought increase in sugar content of grapes or to remove alcohol from wine. One indicator is the extent of the use of technology to remove unwanted alcohol from wine. But any effects of changes in either demand or climate have been to some extent pervasive and cumulative, and changes from either source may have elicited similar behavioural responses. For instance, the incentive effects of the rising scale of per unit taxes on alcohol mean that regions producing lower-priced wines have a stronger incentive to mitigate increases in sugar content, regardless of whether the fundamental source of the increases was a change in supply or a change in demand. In addition, we should be conscious of other potential causes, possibly interacting with consequences of changes in climate, changes in demand, or both. For instance, during the late 1980s and early 1990s, many California vineyards were succumbing to Phylloxera and were consequently replanted, beginning on the North Coast. It has been

informally observed by some growers that the new planting systems and rootstocks seem to have produced grapes with a different composition at a given sugar maturity than under the old system—hence leading to delayed harvest and increased sugar content.

4. Changing Sugar Content of California Wine Grapes

In this section of the paper, we document and describe the changes in the sugar content of California wine grapes. We have assembled (from annual crush reports and various other sources) and begun to analyze a very detailed data set that includes (a) annual data by variety of grapes and crush district on the average sugar content of wine grapes at crush, extending from 1980 through 2008, (b) other data on yield, acreage, and production of wine grapes by variety and county, and (c) daily data on temperatures by crush district. Using these data alone we explore whether the changes in sugar content have varied systematically among varieties and across production regions in ways that allow us to discriminate between alternative theories about the sources of changes.

Statistical Model of Changes in Brix in California, 1990–2008

We have data for the years 1980–2008 on average degrees Brix for over 200 varieties in 17 crush districts. (The number of varieties reported changes from year to year and from district to district. Varieties include wine, table, and raisin grapes.) Table 1 reports average annual growth rates over the longer period 1980–2008 as well as 1990–2008, for a selection of important varieties, as well as for all red, all white, and all varieties, in each of the main production regions and for California as a whole. The data in the table are suggestive of the possibility that growth rates may have differed systematically among regions and varieties, an issue that we examine next. The statistical analysis that follows uses only the data for the more

recent period, 1990–2008, for which the data are more consistent and more complete, and the estimated relationships are more likely to be stable and meaningful.

[Table 1: *Trends in Sugar Content (Degrees Brix) of California Wine Grapes, 1990–2008*]

We estimated variants of the following model to examine the extent of changes in degrees Brix (*BRIX*) over time among crush districts and varieties:

$$BRIX_{dvt} = \beta_0 + \beta_h H_{dt} + \sum_{j=1}^V \nu_j VAR_{vj} + \sum_{i=1}^D \delta_i DIST_{di} + \tau_0 T_t + \sum_{j=1}^V \tau_j^v (VAR_{vj} \times T_t) + \sum_{i=1}^D \tau_i^d (DIST_{di} \times T_t) + \varepsilon_{dvt} \quad (11)$$

In this model, H_{dt} is a weather variable, the “heat index” for crush district d during the growing season in year t .¹⁷ The other variables are dichotomous dummy (or indicator) variables such that $VAR_{vj} = 1$ if $j = v$, 0 otherwise, and $DIST_{di} = 1$ if $i = d$, 0 otherwise). In this model, a statistically significant value for τ_0 implies annual growth at that rate in degrees Brix per year for the default variety in the default region. The coefficients on the dummy variables modify this rate such that the corresponding growth rate for variety j in district i is $\tau_0 + \tau_j^v + \tau_j^d$.

We tried this model with different aggregations of varieties and districts in preliminary analysis. To reduce the dimensions of the problem of reporting and interpreting results we opted to aggregate crush districts into four larger regions based on the average price of wine grapes in 2008. Table 2 shows the districts as classified. Similarly, rather than model individually every winegrape variety we included various aggregates such as “red” versus “white,” and “premium” versus “non-premium” varieties, where “premium” included Cabernet Sauvignon, Merlot, and Chardonnay (we tried including Pinot Noir as well, but the results were not affected much).

¹⁷ The daily measure of growing degrees (GDs) is equal to the average of the daily minimum and daily maximum temperature minus a base temperature of 50 °F. The growing season for wine grapes is defined as extending over the six months April through September. The accumulated total of growing degree units (GDUs) is the sum of GDs accumulated during the season. We use a growing season heat index, H defined as the average daily GDs during the growing season, equal to the accumulated GDUs divided by the total number of days. We also experimented with the same variable applied to different periods (e.g., the entire year or particular months). We thank Professor Andrew Walker from the Department of Viticulture and Enology at UC Davis for advising us about the appropriate choice of a heat index for our purpose.

[Table 2: *Definition of Districts*]

Each of the four columns in Table 3 refers to a different variant of the model in equation (12). We estimated each model by ordinary least squares (OLS) but where possible we used Newey-West robust standard errors for hypothesis testing rather than the conventional OLS robust standard errors. As well as estimating each model using conventional OLS we also estimated each model using weighted regression, where the data from each crush district were weighted according to shares of California's total production.¹⁸ The rationale for using a weighted regression is that the data we are using are themselves annual averages for particular varieties within individual crush districts, with very different numbers of observations contributing to the average, depending on the volume of the crush. We prefer the estimates from the model using weighted regression, as reported in Panel a of Table 3. The results from the same models using the unweighted data are also presented for comparison in Panel b of Table 3.

[Table 3: *Brix Regression Results, Annual Observations 1990-2008*]

In Table 3, Panel 1, column (1) includes the results from a regression of Brix against trend for all varieties and regions. The model predicts that on average, sugar content of California wine grapes increased by 0.14 degrees Brix over the years 1990–2008 from a base of 21.7 in 1989, a predicted increase of 2.5 degrees Brix, or 11.6 percent over the period. In column (2) the model is augmented with a weather variable (the heat index for the growing season), and various dummy variables for Variety and Region, retaining the assumption of a single trend growth rate applying to all varieties and regions. The trend growth rate in this model is slightly lower, 0.10 rather than 0.14 degrees Brix per year.

¹⁸ The weights were calculated using STATA's "aweight" option, with the weights for particular observations equal to the corresponding observation-specific tons crushed as a share of total California tonnage in the same year.

The coefficient on the heat index is positive and statistically significant indicating that a 1 degree increase in the index would result in a 0.04 degrees Brix increase in the sugar content of wine grapes. This is a comparatively small effect, since a 1 degree increase in the heat index requires a large temperature increase.¹⁹ The first Variety dummy is set equal to 1 for “red” varieties (including Zinfandel, although significant quantities of Zinfandel are used to make White Zinfandel). The second Variety dummy is set equal to 1 for “premium” varieties (Cabernet Sauvignon, Merlot, or Chardonnay). Regional dummies represent the “fine,” “premium,” and “ultra premium” regions as defined in Table 2 such that the default region is “ordinary.” The coefficients on all of the dummy variables for Varieties and Regions are positive and statistically significant (with the marginal exception of the “fine” region), indicating that red varieties, and premium varieties, and grapes from districts commanding price premia could be expected to have higher sugar content at crush compared with the default category.

In this case we interpret the intercept (18.8) as applying to the default category of “non-premium,” “white” varieties from the “ordinary” region (crush districts 12, 13, and 14 in the southern San Joaquin Valley). The counterpart for red varieties is higher by 0.96 degrees Brix, the estimated dummy variable coefficient, and the counterpart for premium varieties is higher by 1.89 degrees Brix. It can be seen that compared with the default region (“ordinary”) the other regions have higher degrees Brix associated with higher prices for wine grapes: by 0.28 degrees Brix for the “fine” region, 1.71 degrees Brix for the “premium” region and 1.34 degrees Brix for the “ultra premium” region. These results are consistent with the idea that higher sugar content and higher alcohol content are less desirable in lower-priced wine grapes, possibly because of the additional \$0.50 cents per gallon tax on wine with more than 14 percent alcohol by volume.

¹⁹ For instance, an increase by 1 degree Fahrenheit in both the average daily minimum and the average daily maximum temperature throughout the six-month growing period would imply 1 degree increase in the index.

The model in columns (3) augments the model in column (2) with variables that interact the time trend with the dummy variables for varieties and regions. In this model the coefficient on the heat index indicates that a 1 degree increase in the index would result in a 0.08 degrees Brix increase in the sugar content of wine grapes, twice that in the model without interaction terms, but the coefficient on the time trend (the growth rate for the default category) and several of the coefficients on the dummy variables for Varieties and Regions are no longer statistically significant. Still, premium varieties (but no longer red varieties) and grapes from the premium and fine districts (but not the ultra-premium district) could be expected to have higher sugar content at crush compared with the default category.

The interaction terms indicate significantly faster growth rates in sugar content for red varieties and premium varieties, and for grapes from the premium and fine regions, compared with the default; they indicate a slower growth rate for the ultra-premium region. The coefficients on the interaction terms represent the additional growth in degrees Brix per year for the dummy category relative to the default. The default category is non-premium, white varieties in the ordinary wine region, for which the trend growth rate is 0.02 degrees Brix per year from a base of 19.25 degrees Brix. Thus, for instance, for a premium white variety in the premium region, the corresponding estimate is a trend growth rate of 0.16 ($0.02 + 0.09 + 0.05$) degrees Brix per year from a base of 22.30 ($19.25 + 2.25 + 0.80$) degrees Brix.

Column (4) of Table 3 represents the same model as in column (3) augmented with lagged values of the dependent variable. We experimented with the number of lags of the dependent variable to include. The adjusted R-squared is maximized and the Akaike Information Criterion (AIC) is minimized when three lags are included, so that is the model we are reporting. In models with lagged dependent variables we could not compute Newey-West measures and so we

report the OLS robust standard errors. Notably the coefficients on all three lagged-dependent variables are individually statistically significant, and diminishing with lag length, and they sum to 0.93, which means that in this model shocks have very persistent effects on the dependent variable. In addition, the long-run impact of a shock is on the order of 10-20 times its initial impact. This implication of the model might not be equally plausible for all types of shocks. Otherwise, this model is to be preferred, on grounds of its superior statistical performance, to the one in column (3) that omits the lagged values of the dependent variable.

The pattern of the coefficients for this model is generally plausible, and they are largely consistent with those of the variant in column (3). The coefficient on the heat index indicates that a 1 degree increase in the average degree day index would result in a 0.03 degrees Brix increase in the sugar content of wine grapes in the current year. Taking the lagged dependent variables into account, a permanent increase in the heat index by 1 degree Fahrenheit would imply a 0.43 degrees Brix increase in the sugar content of wine grapes in the ultimate long run.²⁰ Compared with the default variety, non-premium white, for red varieties sugar content is higher by 0.19 degrees Brix and for premium varieties it is higher by 0.36 degrees Brix. As in the other models, compared with the default region (“ordinary”) the other regions have higher degrees Brix associated with higher prices for wine grapes: by 0.18 degrees Brix for the “fine” region, 0.50 degrees Brix for the “premium” region and 0.40 degrees Brix for the “ultra premium” region. Importantly, none of the coefficients on interactions of trend with region, or trend with red varieties, is statistically significant. For these categories the coefficient on the trend is the same as for the default category, 0.01 degrees Brix per year. Only for premium varieties is the trend growth rate significantly different: it is higher by 0.02 degrees Brix per year.

²⁰ The long-run multiplier for a permanent increase is equal to the short-run multiplier, divided by one minus the sum of the coefficients on the lagged dependent variable: $1 - 0.93 = 0.07$.

Of particular interest here is the relative importance of the heat index as an explanation of the rise in Brix. Across all the models, the results suggest that even a substantial rise in average temperature (or the average of the daily maximum and minimum temperatures) during the growing season would have had only modest effects on the sugar content of wine grapes. In fact, however, our data do not show a substantial rise in temperature between 1990 and 2007, as measured by the heat index. Table 4 includes two measures of the average trend rate in the index for each crush district: (a) the simple average of the annual proportional growth rates as measured by the logarithmic difference, and (b) the trend growth rate, from a regression of the logarithm of the index against a time trend. The estimates are expressed as annual percentage growth rates, and they include a mixture of small positive and negative numbers, none of which is statistically significantly different from zero. This outcome reflects the fact that the year-to-year movements in the index are large relative to any underlying trend that can be discerned. This aspect is revealed clearly in Figure 8, which represents the weighted heat index for California, in which the district-specific indexes are weighted according to the district shares of the total tonnage produced.

[Table 4: *Trends in the Heat Index by Crush District and for California, 1990–2008*]

[Figure 8: *Growing Season Heat Index, California Weighted Average, 1990–2008*]

Combining the negligible trend in the heat index with its low coefficient in the model, our results imply that warming average temperatures in the growing season did not contribute substantially or significantly to the increase in sugar content of California's wine grapes during the almost twenty-year period 1990–2008. Other factors in the model do account for much of the rise in sugar content, including changes in the varietal mix and location of production. Some is attributed statistically to underlying trends that are not captured by specific variables in the

model and might reflect elements of climate change not well represented by our heat index. Regardless of the cause, the rise in sugar content of grapes implies increases in alcohol content of wine that might not be desired by winemakers or consumers.

5. Changes in Alcohol Content of Wine: Too Much of a Good Thing?

Detailed data on the alcohol content of California wines are not available. While every wine bottle reports a figure for alcohol content on the label, the tolerances are wide and the information content is therefore limited. Specifically, U.S. law allows a range of plus or minus 1.5 percent for wine with 14 percent alcohol by volume or less, and plus or minus 1.0 percent for wine with more than 14 percent alcohol by volume. Moreover, wineries have incentives to deliberately distort the information because the tax rate is higher for higher alcohol wine. Consequently, label claims concerning alcohol content may be misleading. However, the Liquor Control Board of Ontario (LCBO), which has a monopoly on the importation of wine for sale in the province of Ontario, Canada, tests every wine it imports and records a number of characteristics including the alcohol content. We have obtained access to 18 years of (LCBO) data comprising information on a total of 129,123 samples composed of 80,421 red wines and 46,985 white wines. For each sample a number of measures are reported including the label claim of alcohol content and the actual alcohol content.

Here we report some preliminary analysis. Table 5 shows the average alcohol content of red wine, white wine, and both red and white wine from California tested by the LCBO in 1990 and in 2008. The data show that the average alcohol percentage increased by 0.30 percent, with a larger increase for white wine (0.38 percent) than for red wine (0.25 percent). This increase in alcohol percentage is consistent with an increase in the sugar content of the grapes used to make that wine of 0.55 degrees Brix, on average. Such an increase in degrees Brix over a 10 year

period, while substantial, implies a relatively small growth rate compared with the actual growth. Further work remains to be done to examine the other characteristics of the wine tested.

[Table 5: *Alcohol Percentage of California Wine Measured by the LCBO: 1990 versus 2000*]

The LCBO also records the alcohol percentage claimed on the wine label. We compared the true alcohol percentage and the label claims and found some remarkable discrepancies. On average across 7,920 observations of California wines, the actual alcohol percentage (13.35 percent by volume) exceeded the declared alcohol percentage (12.63 percent by volume) by 0.72 percent by volume. Further work is needed to examine more fully the nature of this discrepancy before we can evaluate causes. It seems unlikely that wineries are making consistent errors of this magnitude in measuring the true alcohol content of the wine. One possibility is that wine producers may be attempting to avoid tax, given that tax rates vary with alcohol percentage; another is that there may be marketing advantages from having label claims of alcohol percentages that are consistent with consumers' expectations for given types of wine.

6. Conclusion

The work in this paper has documented a substantial rise in the sugar content of wine grapes in California since 1980, and we have analyzed in detail patterns since 1990. All regions of production and all varieties grown have experienced some increase. We investigated the pattern among varieties and regions to try to shed light on the role of nurture, in terms of management choices by vignerons, versus nature, in terms of climate change as factors contributing to this growth. It is difficult to devise clean, definitive tests of these competing possibilities, given the complex relationships involved and the many dimensions for responses and interactions. However, we were able to distinguish some interesting patterns.

Previous studies have shown some increase in measures of temperature in California over the longer term, which may have contributed to changes in winegrape characteristics including sugar content at harvest. We used a measure of heat during the growing season for wine grapes to attempt to account for any direct effect of climate change. This measure itself exhibits large year-to-year swings making it difficult to discern clear trends in it. The variable contributed statistically significantly to the models, and showed that an increase in heat during the growing season would contribute to an increase in the sugar content of grapes. However, the heat index did not exhibit any statistically significant growth during the growing season and, in any event, its coefficient was small. Hence, this variable did not account for much of the growth of the average sugar content of grapes, compared with the other variables in the model.

Sugar content of grapes at harvest was relatively high for red varieties and premium varieties, and for grapes from ultra-premium and premium regions. The same categories tended to show evidence of faster growth rates in sugar content as well, but here the story is a little mixed, depending on the details of the model. In all of the models, however, the analysis shows a higher propensity for growth in sugar content for premium varieties, compared with non-premium varieties, even though premium varieties had higher sugar content to begin with. This feature and the patterns of the level of sugar content among regions and varieties could be consistent with a “Parker effect” where higher sugar content is an unintended consequence of wineries responding to market demand and seeking riper flavoured more intense wines through longer hang times. A similar story holds for red (versus white varieties) in the models without lagged dependent variables, but not in the models with lagged dependent variables.

Regional patterns are important in relation to the level of the average sugar content of grapes, but less so with regard to trends in sugar content. Using a definition of regions based on

the average price of wine grapes, we found that the region with the lowest price of wine grapes (under \$500 per ton) had significantly lower average degrees Brix at crush compared with all other regions. This finding is consistent with the idea that sugar content is being managed in the vineyard, perhaps with a view to avoiding taxes that are disproportionately high on lower valued wine.

Preliminary analysis of data from the Liquor Control Board of Ontario (LCBO) indicates that the alcohol content of California wine has risen in concert with the rise in sugar content of wine grapes, although possibly not to the same extent. This result is consistent with the fact that significant effort is being spent in wineries to remove alcohol from wine, which suggests that to some extent at least alcohol is a nuisance by-product in some wines; possibly because of tax implications. The finding that label claims appear systematically to understate the alcohol content of California wine sampled by the LCBO may reflect a perception that higher alcohol content diminishes the consumer value of certain wines.

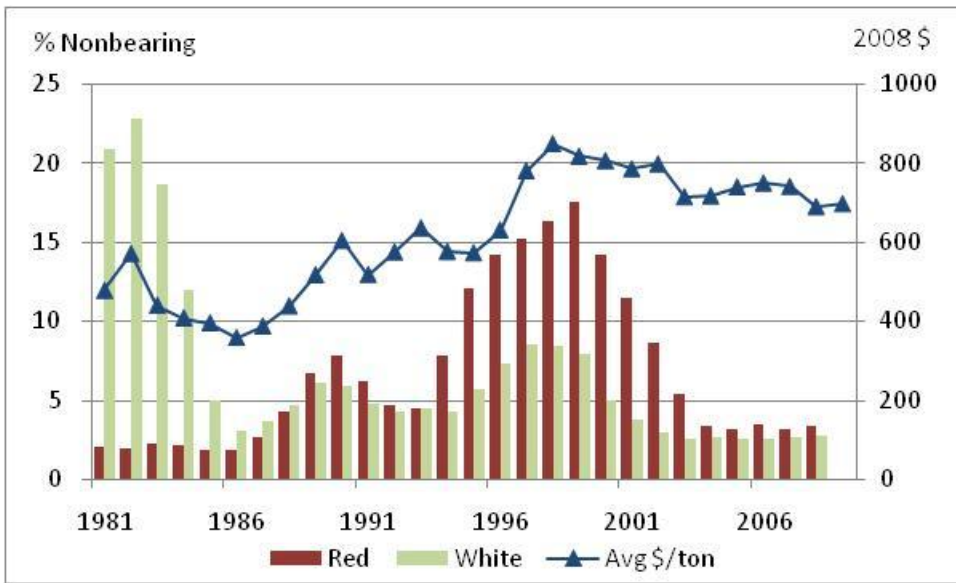
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Figure 1: *Nonbearing Acreage of Wine grapes as a Percentage of Bearing Acreage*

Panel a:



Panel b:

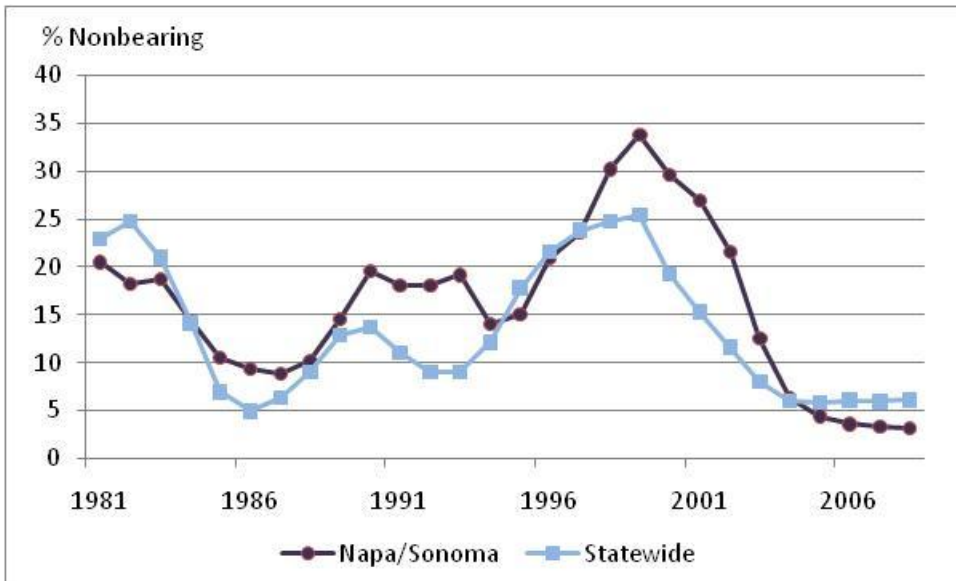


Figure 2: Varietal Mix of California Winegrape Production, 1980, 1990, and 2008

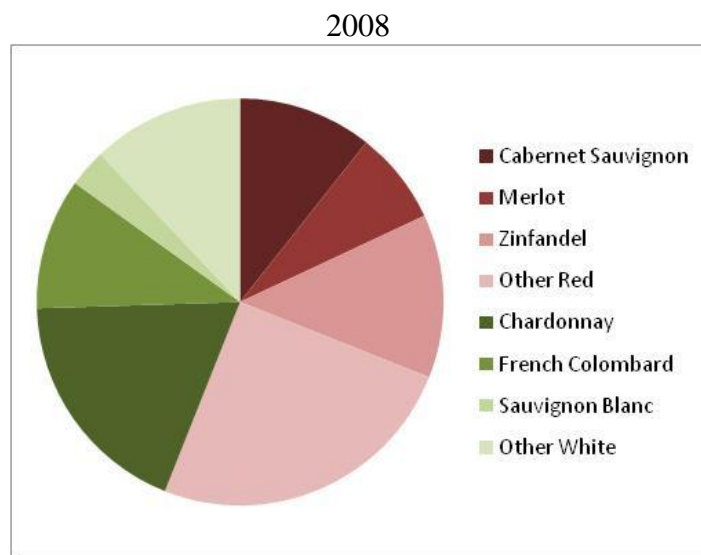
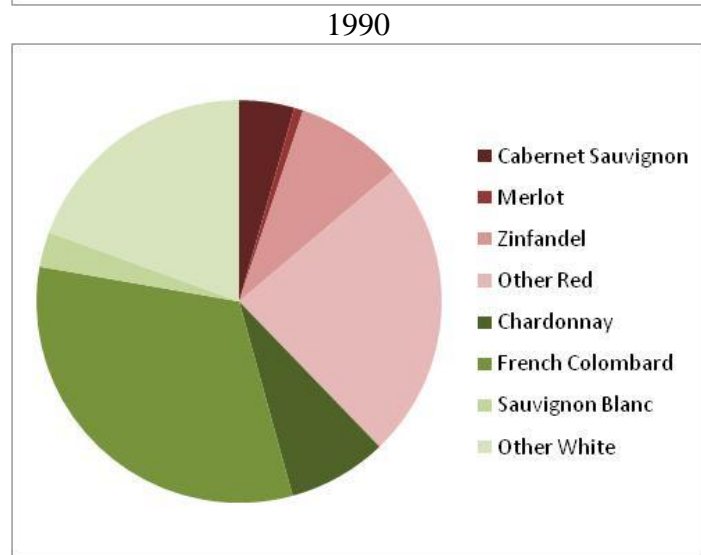
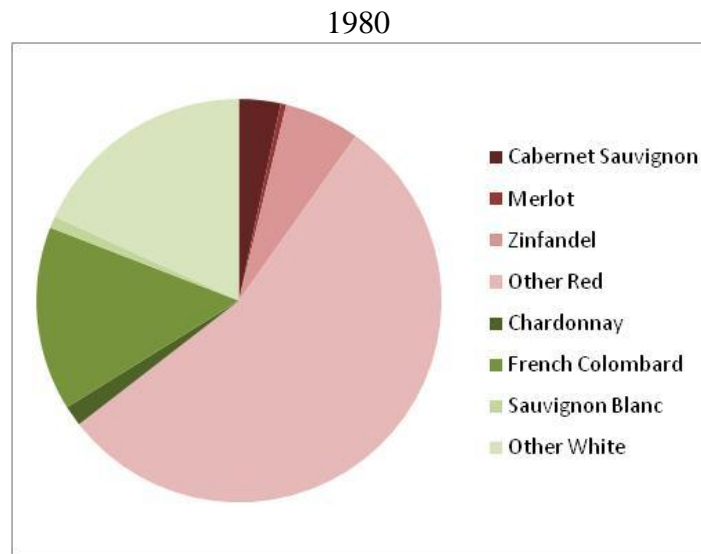


Figure 3: *Regional Distribution of California Winegrape Acreage, 1981 and 2008*

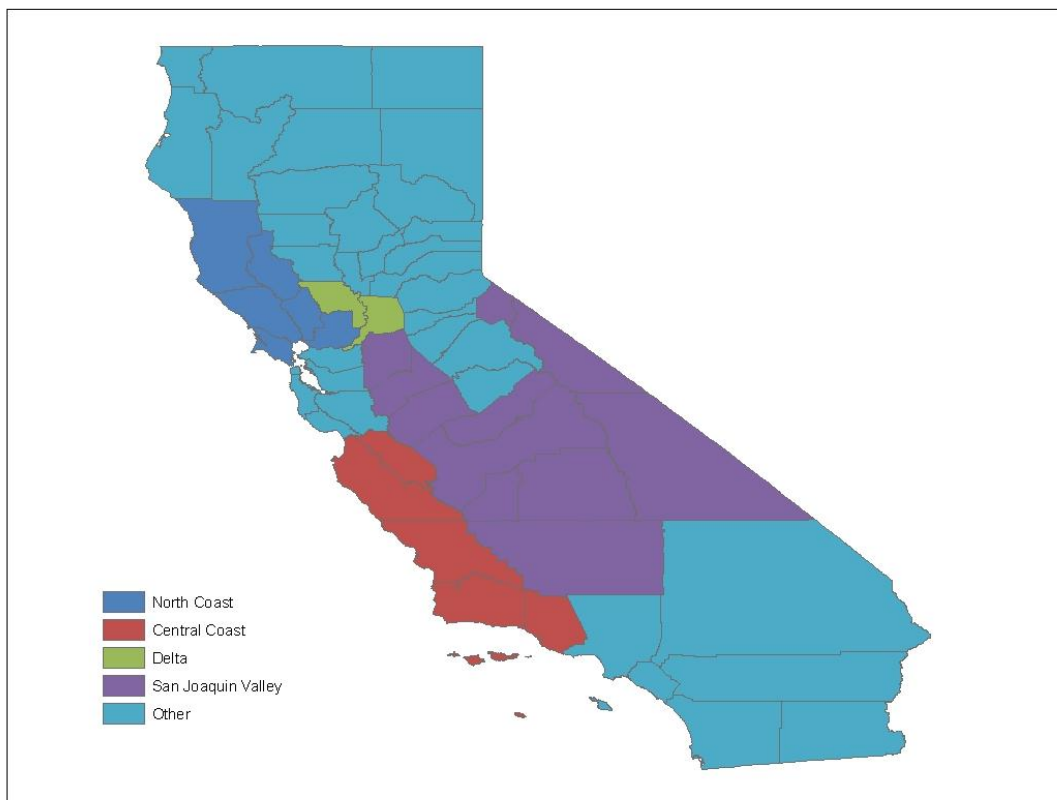
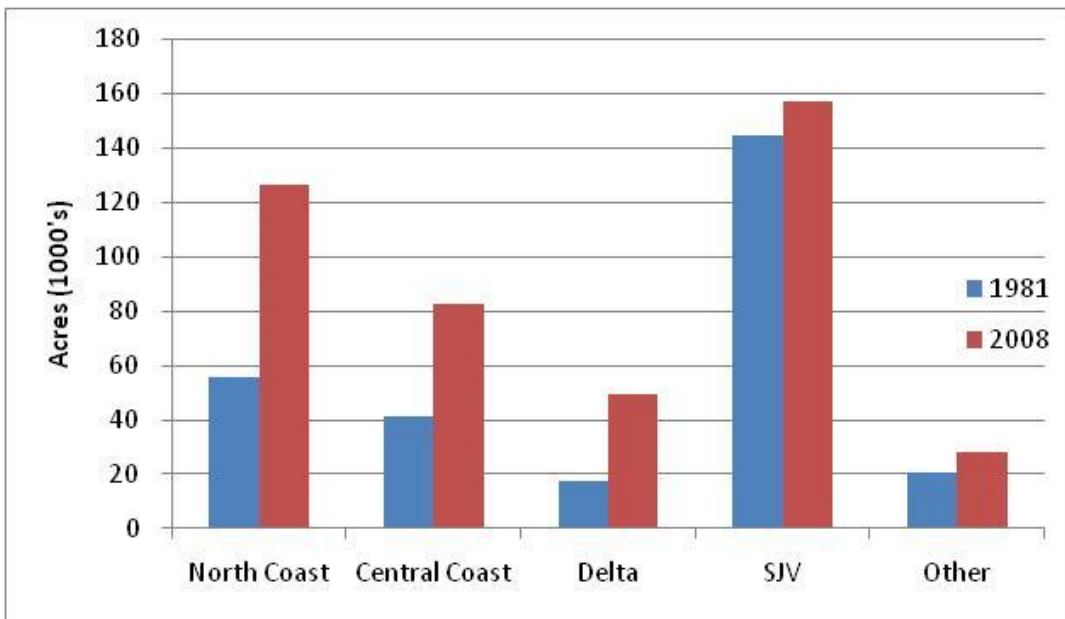
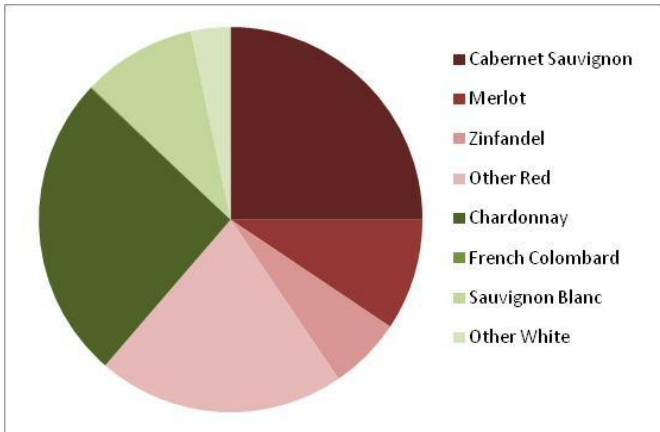
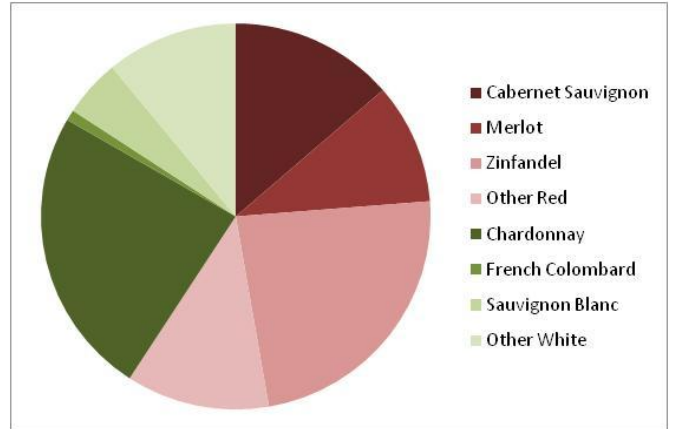


Figure 4: *Regional Distribution of California Winegrape Acreage, by Variety, 2008*

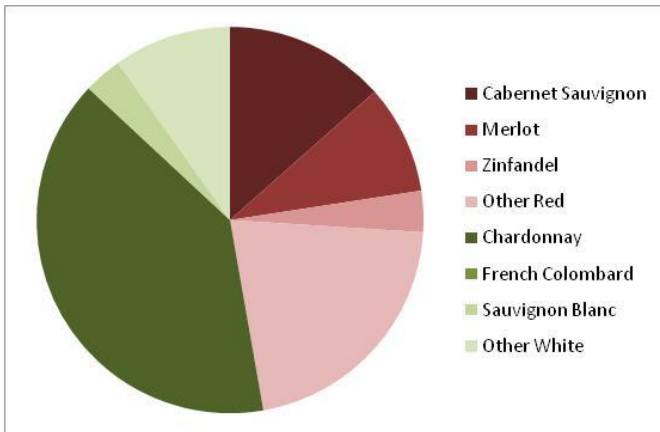
North Coast



Delta



Central Coast



San Joaquin Valley

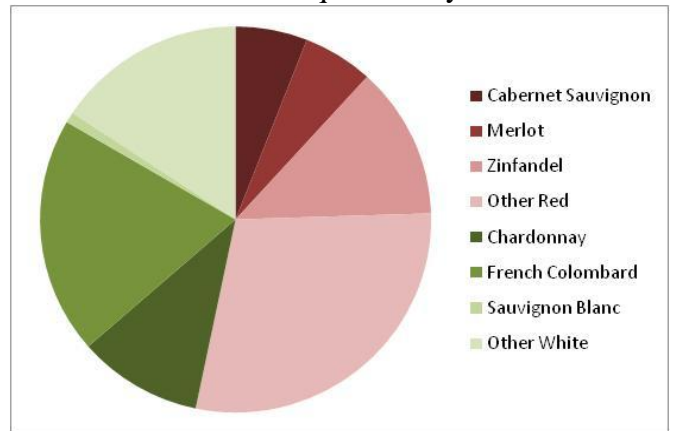


Figure 5: Price of Cabernet Sauvignon and Chardonnay in Various Districts, 2008

\$/ton

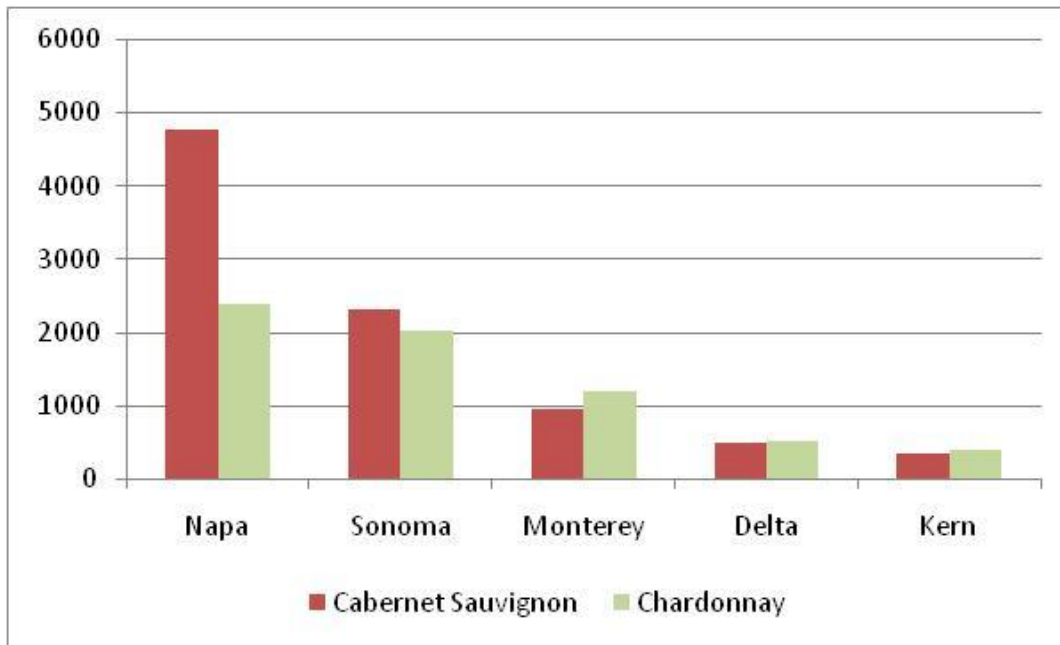


Figure 6: Total Tons Harvested and Value in 1980 and 2008, by Region

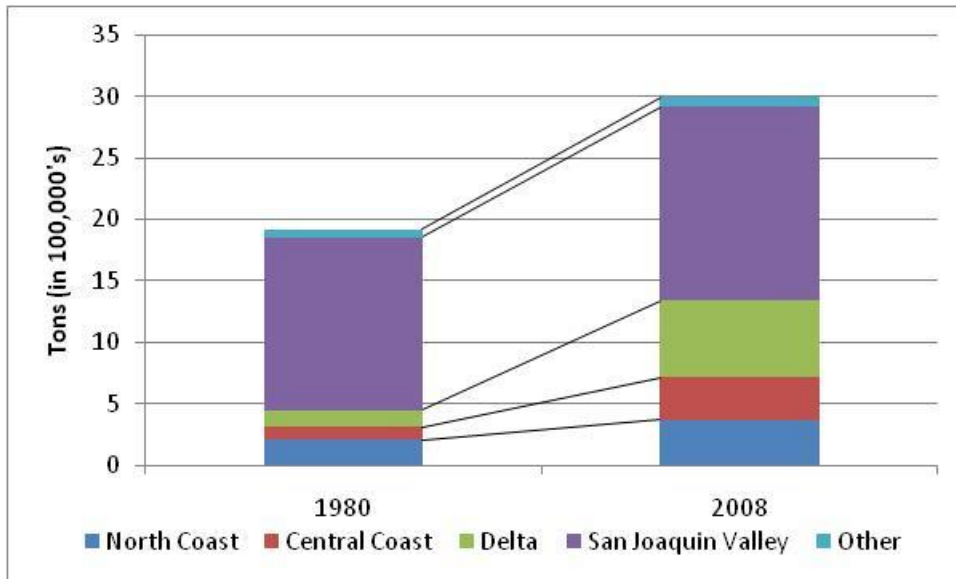
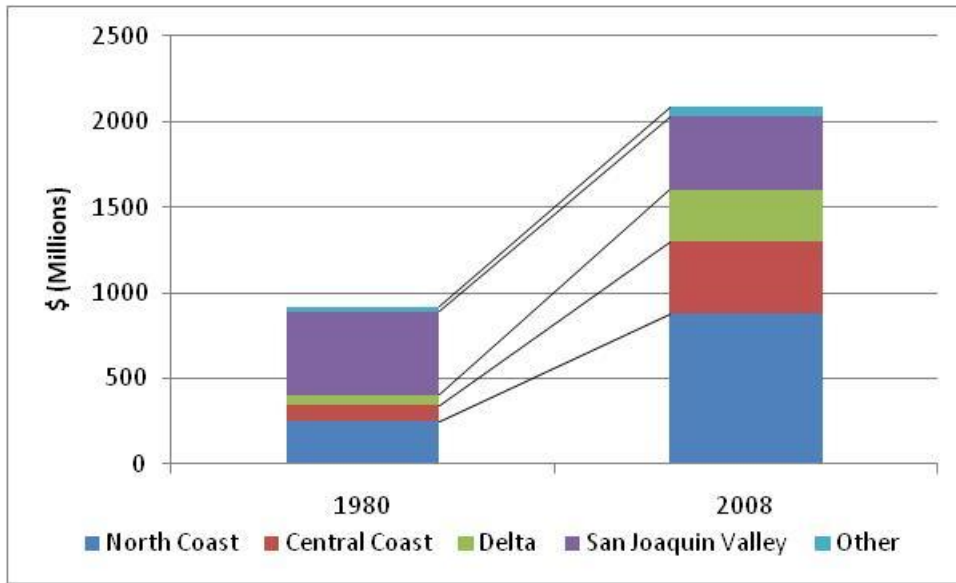


Figure 7: Trends in Sugar Content (Degrees Brix) of California Wine Grapes, 1980-2008

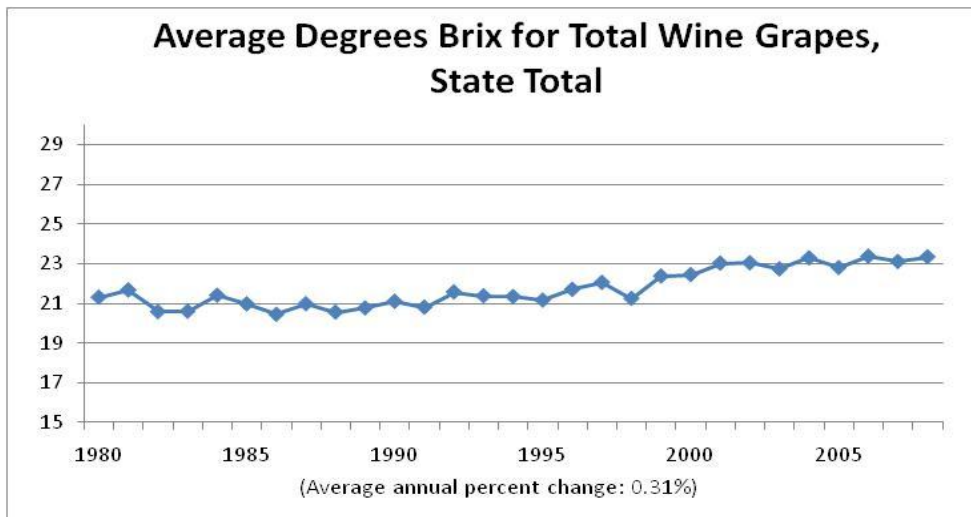
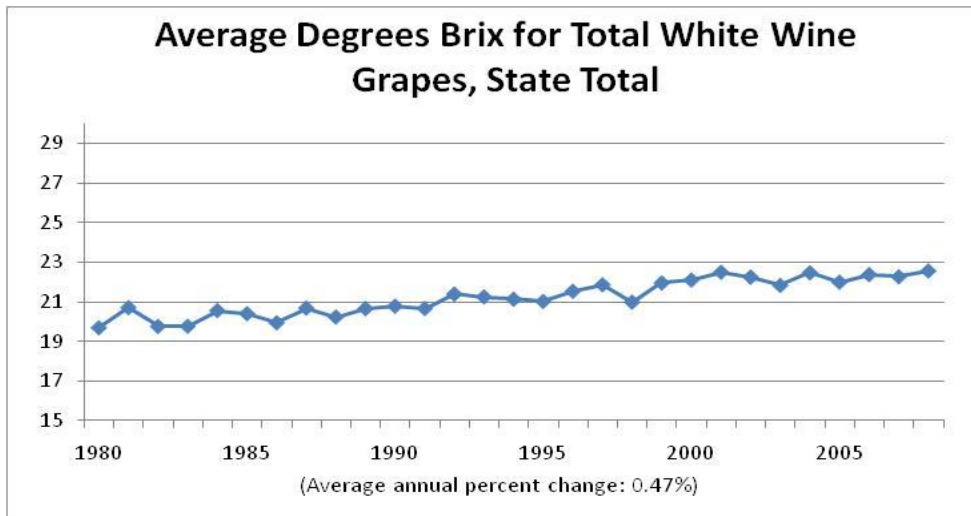
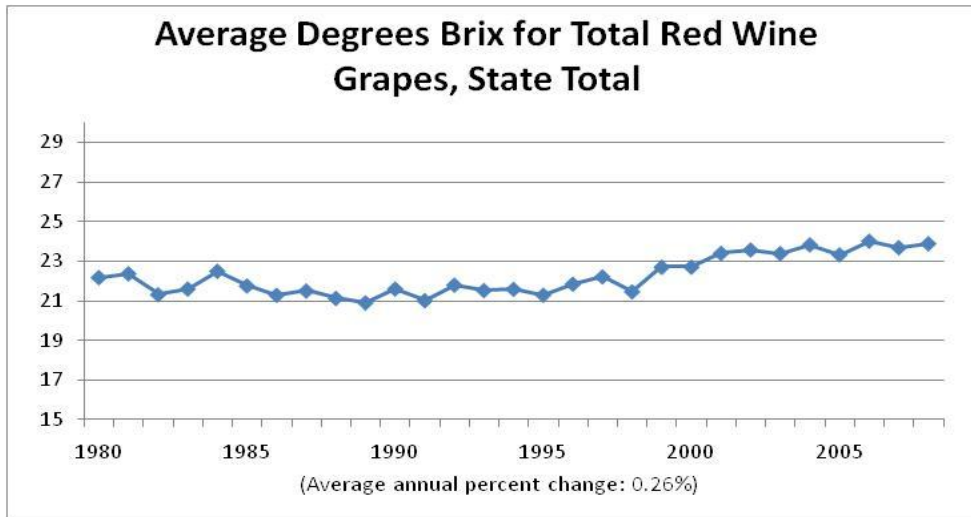
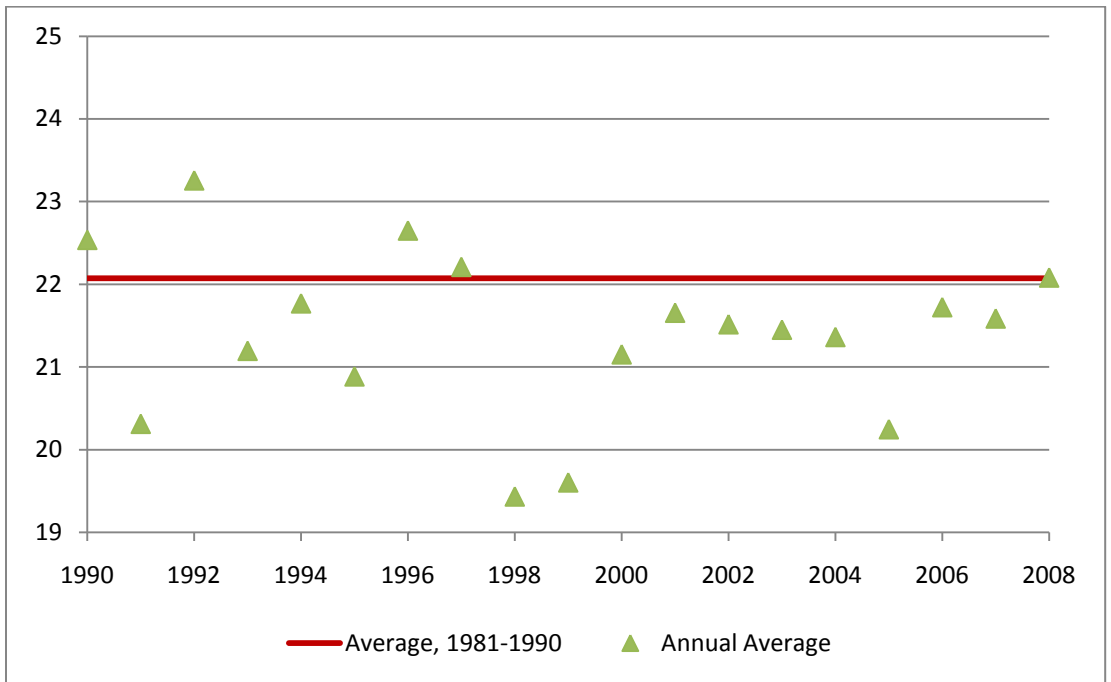


Figure 8: *Growing Season Heat Index, California Weighted Average, 1990–2008*



Notes: The annual heat index is a weighted average across crush districts where the weights are tons crushed in the respective districts as a share of the total California tonnage.

Table 1: Trends in Sugar Content of California Wine Grapes (Degrees Brix), by Variety and Region

(a) 1980-2008

Variety	Region					
	North Coast	Central Coast	Delta	San Joaquin Valley	Southern California	California
	<i>average annual percentage change</i>					
Sauvignon Blanc	-0.02	0.11	0.05	0.51	0.20	0.16
French Colombard	-0.12	--	0.25	0.22	--	0.20
Chardonnay	0.18	0.32	0.29	0.37	0.19	0.18
Chenin Blanc	0.05	0.29	0.30	0.33	-0.11	0.29
All White Varieties	0.30	0.42	0.68	0.40	0.61	0.47
Cabernet Sauvignon	0.30	0.25	0.33	0.23	0.38	0.25
Merlot	0.15	0.32	0.38	0.10	--	0.19
Zinfandel	0.37	0.17	0.07	-0.29	0.07	-0.16
Pinot Noir	0.39	0.30	--	0.72	--	0.42
All Red Varieties	0.36	0.35	0.27	0.17	0.18	0.26
All Varieties	0.34	0.38	0.34	0.22	0.30	0.31

(b) 1990-2008

Variety	Region					
	North Coast	Central Coast	Delta	San Joaquin Valley	Southern California	California
	<i>average annual percentage change</i>					
Sauvignon Blanc	0.18	0.39	0.08	0.37	0.42	0.21
French Colombard	-0.05	--	0.19	0.04	--	0.04
Chardonnay	0.35	0.49	0.39	0.22	0.00	0.32
Chenin Blanc	0.12	0.72	0.23	0.16	0.07	0.20
All White Varieties	0.36	0.63	0.69	0.26	0.25	0.43
Cabernet Sauvignon	0.50	0.49	0.46	0.29	0.53	0.42
Merlot	0.44	0.55	0.44	0.18	0.35	0.40
Zinfandel	1.11	1.01	1.02	0.33	0.60	0.55
Pinot Noir	0.88	0.63	0.75	1.49	0.26	0.87
All Red Varieties	0.72	0.75	0.96	0.31	0.49	0.53
All Varieties	0.57	0.69	0.85	0.36	0.43	0.53

Notes. Entries in this table are average annual percentage changes, computed as $\ln(\text{final value}) - \ln(\text{initial value})$ divided by the number of years and multiplied by 100. For some years and some varieties, records are unavailable. In the table, this is indicated by “--.”

Table 2: *Definitions of Regions*

Region (average winegrape price in 2008)	Includes Crush Districts
Ultra-premium (> \$2,000/ton)	3 (Sonoma) 4 (Napa)
Premium (\$1,000 – \$2,000/ ton)	1 (Mendocino) 2 (Lake) 6 (San Francisco area) 7 (Monterey, San Benito) 8 (Santa Barbara area) 10 (Sierra Foothills area) 15 (Los Angeles, San Bernardino) 16 (San Diego area)
Fine (\$500 – \$1,000/ ton)	5 (Solano) 9 (Northern California area) 11 (San Joaquin, part of Sacramento) 17 (parts of Yolo, Sacramento)
Ordinary (<\$500/ ton)	12 (Merced area) 13 (Fresno area) 14 (Kern, parts of Kings, Tulare)

Table 3: *Brix Regression Results, Annual Observations 1990-2008*

a: Weighted Observations

Regressor	(1)	(2)	(3)	(4)
Constant	20.91** (0.107) [0.187]	18.79** (0.447) [0.649]	19.25** (0.418) [0.616]	0.58** (0.424)
Trend	0.14** (0.011) [0.020]	0.10** (0.009)	0.02 (0.011) [0.018]	0.01** (0.007)
Variety				
Red		0.96** (0.087) [0.156]	0.22 (0.158) [0.274]	0.19** (0.091)
Premium		1.89** (0.072) [0.123]	2.25** (0.119) [0.200]	0.36** (0.100)
Region				
Ultra-premium		1.34** (0.121) [0.189]	0.48 (0.176) [0.290]	0.40** (0.116)
Premium		1.71** (0.206) [0.302]	0.80* (0.215) [0.336]	0.50** (0.140)
Fine		0.28 (0.137) [0.241]	-0.91* (0.265) [0.463]	0.18** (0.154)
Heat Index (Growing Season Average Degree Days)		0.04* (0.018) [0.027]	0.08* (0.017) [0.025]	0.03** (0.010)
Trend x Region				
Ultra-Premium			-0.03** (0.014) [0.023]	-0.01 (0.009)
Premium			0.09** (0.013) [0.021]	-0.00 (0.009)
Fine			0.10** (0.023) [0.040]	0.00 (0.013)
Trend x Variety				
Red			0.12** (0.015) [0.025]	0.00 (0.008)
Premium			0.05** (0.011) [0.019]	0.02** (0.008)
Brix(Year-1)				0.35** (0.030)
Brix (Year-2)				0.41** (0.029)
Brix(Year-3)				0.17** (0.033)
<i>Adjusted R²</i>	0.14	0.49	0.52	0.91
RMSE	1.94	1.49	1.45	0.63

OLS robust standard error in parentheses. Newey-West robust standard error in square brackets.

**, * Significant at the 1% and 5% levels, respectively, using Newey-West except in column (4). 13,379 observations.

Table 3: *Brix Regression Results, Annual Observations 1990-2008***b: Unweighted Observations**

Regressor	(1)	(2)	(3)	(4)
Constant	21.87** (0.032) [0.049]	18.62** (0.121) [0.173]	20.35** (0.140) [0.206]	3.69** (0.371)
Trend	0.14** (0.003) [0.004]	0.13** (0.003) [0.004]	0.09** (0.008) [0.013]	0.03** (0.007)
Variety				
Red		1.05** (0.031) [0.048]	0.77** (0.063) [0.093]	0.21** (0.078)
Premium		0.52** (0.026) [0.039]	0.90** (0.049) [0.072]	0.18** (0.059)
Region				
Ultra-premium		1.28** (0.060) [0.091]	1.00** (0.117) [0.174]	0.50** (0.127)
Premium		1.25** (0.057) [0.085]	0.97** (0.091) [0.139]	0.58** (0.088)
Fine		0.74** (0.057) [0.090]	0.38* (0.107) [0.166]	0.41** (0.104)
Heat Index (Growing Season Average Degree Days)		0.02** (0.005) [0.006]	0.02** (0.005) [0.006]	0.02** (0.004)
Trend x Region				
Ultra-Premium			0.03 (0.010) [0.015]	0.01 (0.010)
Premium			0.03* (0.008) [0.012]	0.00 (0.007)
Fine			0.03* (0.010) [0.015]	-0.01 (0.009)
Trend x Variety				
Red			0.03** (0.006) [0.008]	-0.01 (0.006)
Premium			-0.02** (0.005) [0.006]	-0.02** (0.005)
Brix(Year-1)				0.35** (0.032)
Brix (Year-2)				0.28** (0.036)
Brix(Year-3)				0.17** (0.020)
<i>Adjusted R²</i>	0.14	0.26	0.27	0.61
RMSE	1.83	1.69	1.68	1.20

OLS robust standard error in parentheses. Newey-West robust standard error in square brackets.

**, * Significant at the 1% and 5% levels, respectively, using Newey-West except in column (4). 13,379 observations.

Table 4: *Trends in the Heat Index by Crush District and for California, 1990–2008*

Crush District	Annualized Average Change (%)	100*Slope from Regression of $\ln(\text{Heat})$ on Trend
	<i>percent per year</i>	
1	-0.30	-0.23 (0.357)
2	-0.18	0.11 (0.722)
3	0.58	0.75 (0.007)
4	0.01	0.20 (0.374)
5	0.03	-0.01 (0.979)
6	-0.50	-0.16 (0.600)
7	-0.69	-0.55 (0.271)
8	-0.60	-0.05 (0.919)
9	0.02	0.14 (0.445)
10	0.85	1.01 (0.004)
11	-0.19	-0.09 (0.725)
12	-0.19	-0.09 (0.725)
13	0.22	0.25 (0.224)
14	0.22	0.26 (0.312)
15	0.04	0.27 (0.249)
16	-0.31	-0.83 (0.033)
17	0.07	0.28 (0.195)
State Average (Weighted)	0.06	0.12 (0.405)

Notes: The weather station is the same for Districts 11 and 12. The annual heat index is a weighted average across crush districts, where the weights are tons crushed in the respective districts as a share of the total California tonnage.

Table 5: *Alcohol Percentage of California Wine Measured by the LCBO: 1990 versus 2000*

		Red Wine	White Wine	All Wine
1990	Number of Observations	329	152	481
	Mean	13.14	13.04	13.10
	(Standard deviation)	(0.65)	(0.96)	(0.77)
2000	Number of Observations	115	171	286
	Mean	13.39	13.41	13.40
	(Standard deviation)	(1.44)	(0.84)	(1.12)
Average Difference in Means (Standard error)		0.25 (0.10)	0.38 (0.10)	0.30 (0.07)
t ₁ (equal variances)		-2.51**	-3.83**	-4.36**
t ₂ (unequal variances)		-1.81*	-3.79**	-3.97**
F		0.21**	1.32*	0.47**

** , * Significant at the 1 percent and 10 percent levels of significance, respectively.

t₁ and t₂ report the results of t-tests for a paired comparison under assumptions of equal and unequal variances, respectively.

F is the F-value for a test of equal variances.