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ABSTRACT. Wine is the most differentiated of all farm products, with much of the differentiation based on the location of production. In 1980 the U.S. Government created American Viticultural Areas (AVAs) as a mechanism for wine producers to signal product quality and better capture the benefits from collective reputation associated with the location of production. California, which produces about 80% of U.S. wine, has 142 AVAs of which 16 are located within the Napa Valley AVA. The objective of this study is to develop an improved understanding of the role of climate and vintage weather as they affect the quality and prices of varietal wines and hence of the potential for climate change to disrupt the role of AVAs in providing signals of varietal wine quality associated with places of production. Our analysis is based on a sample of premium wines rated by Wine Spectator magazine between 1994 and 2022 and a comparable sample of secondary market auction prices from K&L Wine Merchants, each associated with a particular AVA and matched to spatially detailed weather data from PRISM. We derive estimates of the location- and variety-specific relationship between prices (and ratings) and weather and climate, and we use the estimates to compute the implied consequences for prices resulting from projected changes in climate over the remainder of the century.

Key Words: Wine prices and ratings, climate and weather, fine varietal wine, California AVAs

JEL Codes: C23, L15, L66, Q11, Q54.

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1. Introduction

Wine is the most differentiated of all farm products, with much of the differentiation based on the combination of wine grape varieties and so-called “terroir”—reflecting the soil type, topography, and especially climate. Local climate determines the types of grapes that can be best grown and influences other choices of production technology, while weather variation introduces vintage-to-vintage quality differences. Reflecting this product differentiation, prices of wine and the grapes used to produce it vary considerably. In California, prices of wine grapes of the same variety produced in the same region in the same vintage year can vary by a factor of 50 (Sambucci & Alston 2017). Prices of wine and wine grapes also vary over time among vintage years: beneficial weather results in higher-quality wine grapes, yielding higher-quality wine that fetches a higher price (e.g., Ashenfelter 2008, Ashenfelter 2010).

This often largely uncontrolled variation in quality and prices adds to the asymmetric information or “lemons” problem that is pervasive in the market for fine wine (e.g., Livat et al. 2019). Geographical indications (GIs) for wine were first introduced 100 years ago to address this problem in France (Mérel et al. 2021). In the United States the counterpart American Viticultural Areas (AVAs) were introduced in 1980, enabling U.S. wine producers to label wine as coming from a specific AVA to exploit the “collective reputation” associated with that region of production. The purpose of associating a particular wine with an AVA is to create and capture price premia. Some recent studies have reported evidence on the value of collective reputation for wine associated with AVAs (e.g., Chandra & Moschini 2022, Chandra, Moschini & Lade 2023). However, relatively little is known about the complex relationships between prices and

appellations for wine in the context of variable weather and a changing climate, and formal evidence is scant.

The objective of this study is to develop an improved understanding of the role of climate and vintage weather as they affect the quality and prices of varietal wines, and hence of the potential for climate change to disrupt the role of AVAs in providing signals of varietal wine quality associated with places of production. Our analysis is based on a sample of 45,000 observations of ultra-premium varietal wines rated by Wine Spectator magazine, and a comparable sample of 48,000 observations of auction prices for ultra-premium varietal wines sold by K&L Wine Merchants, each associated with a particular AVA.

Using spatially detailed weather data from PRISM (800m grids) we define AVA-specific measures of attributes of weather and climate during different parts of the growing season that are hypothesized to adversely affect wine quality and prices. We derive estimates of the location- and variety-specific relationship between prices (and ratings) and weather and climate, and we explore the implications of projected changes in weather and climate for the future quality and price of ultra-premium wine from California's Napa Valley AVA.

We find that extreme temperatures result in statistically significantly lower prices for wine—especially temperatures exceeding 35ºC. Hence, absent additional adaptation and holding all else equal, future climate change will result in considerably lower prices of Cabernet Sauvignon from the Napa Valley, the premier region for Cabernet Sauvignon in California. We see a similar pattern of effects on wine rating scores: low and high temperatures are harmful and hot weather later in the growing season is especially harmful to wine quality. We also find

suggestive evidence that winemakers produce fewer cases of high-quality brands in vintage years with extreme temperatures, particularly extremely hot temperatures—at least to some extent, we surmise, as an adaptive response to maintain quality and protect brand reputation.

As well as providing insights specifically about vintage weather, climate, and wine quality, this study contributes to the broader economic literature on the effects of weather and climate on agriculture, which for the most part has focused on the effects on the yields of staple crops—annual crops for which effects on quality are less important.[1] More generally, however, farmers will be concerned about the effects of weather and climate on gross and net income, which depend not only on yield but also on quality as it affects price—and for premium wine producers quality effects predominate and can be very large. Insights gleaned from our analysis of this dimension in this case may be pertinent to other agronomic crops as well as high-valued perennials like wine grapes (e.g., Kawasaki & Uchida 2016, Dalhaus et al. 2020, Smith & Beatty 2023).

A second contribution of our study is its use of a more-nuanced representation—compared with previous work on either wine or other farm products—of relevant measures of weather and climate throughout the growing season as they affect the development of fruit yield and quality.[2] Wine quality is particularly sensitive to extreme heat, especially post-veraison—i.e., after the onset of fruit ripening. Unlike conventional measures of average heat

[1] Carter et al. (2018) review studies identifying the economic impact of climate change in agriculture.

[2] Ashenfelter & Storchmann (2016) and Jones et al. (2022) provide summaries of main points from previous work on climate change and wine.

during the growing season used in previous studies of wine or other crops, our measures capture this aspect of the relationship between vintage weather and wine quality. And we do this using spatially detailed weather data from PRISM (800m grids) to more-accurately represent the relevant concepts of weather and climate and quantify their effects on California's wine quality and price, reducing the risk of measurement error bias.[3]

2. The Setting

Grapevines are long-lived perennials, with a typical productive life of 25 years, and often longer. California wine grapes, valued at $3.6 billion in 2022-23 (CDFA 2024a), were used to produce wine with a retail value of about $20 billion at the cellar door or on supermarket shelves. California produces around 80 percent of total U.S. wine by volume (Wine Institute, 2023) in several distinct wine production regions. These regions differ in terms of terrain, soil type, and especially climate, which drives differences in the grape varieties grown and the quality of grapes and wine produced. In the hotter Southern Central Valley, wine grape production is typically high yield per acre and relatively low value per ton. The cooler areas near the coast are associated with smaller-scale production of higher-value premium wine grapes. The Napa-Sonoma region on the North Coast is especially known for Cabernet Sauvignon, which

[3] Although weather and climate can vary over relatively small distances in wine growing regions in California, previous work on wine in California uses coarsely measured weather and climate data: for example, Ramirez (2008) and Jones (2005) use one weather station for the whole of the Napa Valley and all 16 AVAs within. The resulting imprecision in the measurement of weather and climate variables for the subregions adds to challenges in estimating the true relationship between weather, climate, and wine characteristics.

is its most important variety and increasingly so, while the Central Coast region is known for cooler climate Chardonnay and Pinot Noir (Alston et al. 2015; Alston et al. 2019).

2.1. Geographical indications for wine

In 1980 the U.S. Government created American Viticultural Areas (AVAs) as a mechanism for producers to signal quality and better capture the benefits from collective reputation associated with the location of production (see U.S. Treasury/TTB, 2022; Winfree and McCluskey, 2005; and Lapsley et al. 2019). AVAs are defined geographic areas that may be quite large and cross state or county lines, or may be quite small and lie within a county or, in some cases, another AVA. In 2021, the United States had a total of 258 established AVAs of which 142 are in California and 16 are nested within the Napa Valley AVA (see U.S. Treasury/TTB, 2021). Wineries may label a wine as coming from an AVA if 85 percent of the grapes were grown in the AVA and the wine was fully finished in the state where the AVA is located. The use of an AVA label does not impose restrictions on production or winemaking practices, unlike geographical indications for wine in some other countries (for example, the Appellation d'Origine Contrôlée for French wines; see, e.g., Alston & Gaeta 2021).[4]

[Figure 1 Main wine regions in California and Napa Valley AVAs]

[4] California's wine can also be labelled as originating from a particular county or the state of California. For a wine to carry a county name on its label, at least 75 percent of the grapes must have been grown in that county and the wine must have been fully finished within California. A wine labeled with "California" must be made entirely using grapes from California and finished within California (U.S. Treasury/TTB 2020).

Prices of wine grapes vary considerably among and within AVAs, even within California (see, e.g., Alston et al. 2015; Sambucci & Alston 2017). In the 2023 California Grape Crush Report (CDFA, 2024b), prices of lots of Cabernet Sauvignon grapes from Napa County (crush district 4) ranged from as low as $200 per ton up to $67,200 per ton. Differentiation occurs along several dimensions, including wine grape varieties, terroir, vineyard management and production practices, and fruit quality attributes (e.g., sugar content).[5] Variation in wine grape prices ultimately reflects variation in the anticipated value of the wine they will be used to make, since the demand for grapes is derived from the demand for wine. The winemaking process potentially introduces additional variation in final wine quality and price. A winery's individual reputation may also play a role in price formation. For cheaper wines, price premia are more likely a consequence of collective reputation, inferred from an AVA label, rather than firm-level reputation. For more expensive wines, the premium for an individual winery's reputation is likely to be a larger component of price (Costanigro, McCluskey & Goemans 2010).

Generally speaking, as discussed by Alston & Gaeta (2021), wine prices and ratings tend to increase as we go from broader (e.g., entire country, state, or broad region within a state), to narrower and more specific sub-regions of origin (such as North Coast, or within that, Napa Valley and its sub-AVAs). For example, Bombrun & Sumner (2003) report that, after controlling for observable wine characteristics, wines using the Napa Valley AVA command a price

[5] As described by Sambucci & Alston (2017), considerable quantities of California wine grapes are not sold as such but instead are vinified by the growers (62% of Napa-Sonoma tons crushed were sold, 38% not sold). For the wine grapes that are sold, growers often contract with wineries for the sale of grapes, particularly among growers of high-quality grapes (Goodhue et al. 2003; Franken, 2014).

premium over wines labeled as from "California," and some sub-AVAs like Oakville and Howell Mountain capture even larger premia; see, also, Kwon et al. (2008). The prime purpose of creating sub-AVAs is to create and capture such premia. Hence, everything else equal, we should expect wine labeled as coming from one of the 16 sub-AVAs within the Napa Valley AVA to command a price premium over wine labeled as coming from the Napa Valley AVA (if it were not the case, winemakers might as well opt to use the broader Napa Valley AVA over the sub-AVA on the label and be freer to choose among sources for fruit to use in the blend).

2.2. Links between vintage weather, climate and wine quality

It has long been understood that weather during the growing season affects wine grape characteristics that can determine the final wine's color, aroma, tannins, and other flavor attributes, and that details of the relationship between weather and fruit quality varies among different grape varieties (e.g., see Winkler, 1962). Some studies refer to differences among grape cultivars in terms of their preferred range of average temperatures during the growing season. For example, Figure 2 (reproduced from Jones et al. 2012, see also Jones et al. 2005, and Jones 2006) depicts an optimal range of average growing season temperatures for each of the world's most common winegrape cultivars.

[Figure 2 Optimal average growing season temperature range by grape variety]

It is widely understood that weather during the vintage year can cause significant vintage-to-vintage variation in the quality and prices of bottled wine, and this popular perception is supported by formal evidence. But some of the evidence is unexpected. While recent discussions emphasize the potentially damaging consequences of hotter temperatures

for wine quality, most of the econometric studies of the effects of vintage weather on wine prices have found the converse, whether with reference to New World or the Old World regions. In various studies, Orley Ashenfelter and colleagues found that warmer and drier vintages resulted in higher prices for Bordeaux wines (Ashenfelter, Ashmore, & Lalonde 1995, Ashenfelter 2008, Ashenfelter 2010) and for Australia's famous Penfold's Grange Hermitage (Byron & Ashenfelter 1995), as well as for Riesling from the Mosel Valley (Ashenfelter & Storchmann 2010) where such a finding is more clearly to be expected. Similarly, Ramirez (2008) found that relatively cool and wet winters with dry, warm summers tend to result in higher prices for Cabernet Sauvignon wines from the Napa Valley. In contrast, Haeger & Storchmann (2006) found that, for Pinot Noir in the United States, general temperature increases are not beneficial and growing-season temperature increases above the optimum could entail a drop in suggested retail prices, though the statistical relationship was not strong.[6]

These studies all use aggregated measures of weather during the growing season, such as growing-season average temperature and growing-season total precipitation, but variations in wine quality can be linked to various other aspects of weather, including exposure to high temperatures and frost (Jones et al. 2005; Jones & Goodrich, 2008; Davis et al. 2019). Timing of weather events also matters, as illustrated by Jones et al. (2012, p. 111) in their Figure 7.1 (Figure 3). For example, in the case of Burgundy wines, rainfall is beneficial to quality if it occurs during the bud-break period but detrimental if it occurs during the ripening phase (Davis et al. 2019). However, previous studies typically have not allowed specifically for the timing of heat

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[6] Ashenfelter & Storchmann (2016) review these and other studies. See also Oczkowski (2016).

during the growing season, and none has accounted for sustained periods of extreme heat, especially later in the growing season, which has been identified as a crucial factor for vintage quality.[7]

[Figure 3 Weather and climate influences on grapevine development and phenological growth]

Since the 1950s, grape growing regions in California have experienced warmer growing seasons on average, largely driven by an increase in minimum (i.e., overnight) temperatures, which has reduced the occurrence of frost days (Jones, 2004).[8] Nemani et al. (2001) and Gambetta & Kurtural (2021) suggest that wine quality in California appears to have largely benefitted from this warming. However, warming trends have coincided with notable trends in the supply of and demand for wine that make it difficult to disentangle the effect of warming from other factors.

In this context, secular trends or cycles in total demand for wine and demand for wine with specific attributes are confounding factors for econometricians.[9] Wine markets are

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[7] Wine grape yields also can be affected by weather. Exposure to extreme temperatures (i.e., frost or extreme heat) reduces yields while exposure to moderate temperatures, particularly overnight, increases yields (Cahill et al. 2007; Lobell et al. 2006; White et al. 2006). However, in the premium wine market higher yields are not always seen as advantageous and the implications for value of the crop are not always clear. In Europe PDO rules impose yield restrictions, and in California even though they are not required to do so growers are known to restrict yields aiming thereby to increase quality and obtain higher prices.

[8] While warming trends reduced the number of frost days they also caused earlier bud break, which lengthened the window of time when vines were at risk of frost damage, offsetting some of the benefit of fewer frost days.

[9] Over recent decades, trends in total demand for wine have reflected effects of both increases in per capita income and in the total wine-consuming population, to some extent at least offset by falling per capita consumption—especially in traditional wine-consuming countries of Europe; meanwhile, we have also seen increases in relative demand for higher-priced wines (see, e.g., Alston et al. 2018; Anderson et al. 2018). Today's global wine market "crisis" in which the worldwide wine market is awash, especially with lower-priced wine, is the long-term result of slow adjustment by producers in the face of persistent and somewhat predictable long-term trends in overall demand, compounded by more-recent relative shifts in demand for certain types of wine.

notorious for patterns of shifting demand for different styles of wine (e.g., red, white, pink, sparkling) for different varietal wines (e.g., the “Sideways effect” on Pinot Noir versus Merlot) or with different other attributes (e.g., higher or lower %ABV, natural, organic)—akin to the demand for other consumption goods subject to “fashion” and fads. To some extent these shifts may be affected by influencers including wine writers such as Robert Parker (see, for example, Hilger et al. 2011). It is widely held that Parker’s high rating points for wines of that type contributed to a shift toward big, powerful, “fruit forward” wines that tended also to have more alcohol and less cellaring potential. But it is difficult to tell whether those observed changes were entirely an intended response by grape growers and winemakers to a perceived shift in demand or to some extent the result of changes in climate.[10] Adding to this identification challenge, technological advancements in viticulture and winemaking and improved vineyard management have allowed producers to create more consistent, high-quality wine from a given vintage, and to better mitigate the effects of undesirable vintage weather (Jones et al. 2005).

Producers can potentially mediate the effect of weather (high temperatures) and climate change (rising temperatures) in several ways. One (longer-run) response is to relocate wine grape production from warm regions to cool regions, such as towards the poles or to higher elevation areas. Several studies predict a decline in areas of vineyards acreage in key

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[10] Alston et al. (2011) found that increased heat during the growing season contributed to a statistically significant but small increase in sugar content of wine grapes grown in California over the period 1990–2008. However, rather than a climate effect, they concluded that most of the observed upward trend in sugar content (and associated increases in alcohol percentage) must be attributed to other factors including changes in vineyard management such as longer hang times. Using their estimated model parameters, even a substantial rise in average temperatures would have had only a modest effect on sugar content of wine grapes.

production regions (for example, southern Europe) because the regions are projected to become too hot to produce quality wine (Moriondo et al. 2013; Hannah et al. 2013; Webb et al. 2007). However, these studies generally underestimate or ignore adaptive responses that may help preserve production in wine-growing regions that are currently culturally and economically important.

Grape varieties are diverse in their phenology and other traits related to climate and weather. As climate changes, growers may opt to plant a different variety that is more suited to their new climate (Wolkovich et al. 2018). However, despite the availability of more than 1,000 commercial varieties, most wine grape regions grow the same 12 varieties. In fact, the mix of wine grape varieties is becoming less differentiated in the United States, especially in California (Alston et al. 2015) and Australia (Puga et al. 2022), and instead these regions are becoming more similar to France and the rest of the world as a whole. Traditional French varieties such as Cabernet Sauvignon, Chardonnay, Merlot, Sauvignon Blanc, Pinot Noir, and Syrah (or Shiraz) are increasingly predominant in California in places that are becoming increasingly less-favored for growing those varieties. California growers have been very slow to adopt varieties from Italy or Spain that may be better suited to hotter places.

Varietal adaptation in California and elsewhere is hampered by the long productive life of vineyards as well as historical associations of high-quality wines from particular regions with particular varieties.[11] Changing the location of production or varieties grown can be seen as

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[11] Such slowness to adapt is particularly pronounced in many European regions where a wine cannot bear a geographical indication as coming from a specific PDO unless it is made using particular varieties or blends of varieties that are permitted by the PDO rules; and these rules themselves are slow to change.

long-run, disruptive responses that essentially forsake the established identity of production that reflects the association of particular wines produced in particular places using particular varieties—at the terroir-varietal-GI nexus.

Other, shorter-run responses can be undertaken seeking to preserve that identity. Specifically, producers can manage weather shocks (or trends) by adapting their growing practices, such as harvest date, canopy structure, and irrigation (van Leeuwen et al. 2024). For example, Webb et al. (2009) found that smaller damages from 2009 heatwave in South-Eastern Australia were associated with irrigation prior to the heatwave event, and good canopy growth that protects fruit from direct radiation. Other adjustments can be made in the winery. Producers can blend fruit from different locations to mitigate vintage weather effects and can opt to produce smaller quantities or none of particular brands if fruit of the required quality is not available in sufficient quantity; indeed, some iconic wines are only produced in vintage years that are good enough. So one measure of weather effects on quality of a vintage is the relative quantity of higher-quality blends, an aspect that may be missed by studies that consider only prices or rating scores for given brands.

2.3. Conceptual Model

Previous studies have modeled the effects of weather and climate on various economic outcomes for wine producers, including variables such as revenue and yield per acre or cost per ton of grapes, as well as price per ton of fruit, per bottle of wine, or other measures of quality such as rating scores or %ABV (Ashenfelter & Storchmann 2016). Here, like the majority of

studies, we are primarily interested in quality of wine as measured by price per bottle, though we also have data on rating scores and volume of production.

The stereotypical study includes, as explanatory variables, relatively simple measures of weather during the growing season (typically April–October in the northern hemisphere) such as total rainfall or average growing-season temperature, and perhaps these same variables squared (Ashenfelter & Storchmann 2016).[12] While the average of daily average temperatures over key growing months is easy to measure and interpret, this measure could conceal large differences in exposure to extreme temperatures that matter for fruit quality. For example, two growing seasons may have the same average temperature, but one may exhibit significantly more exposure to extreme temperatures if hot and cold temperatures average out.

Indeed, we find no relationship between wine prices and temperature when using a simple quadratic function of growing season average temperatures (see Appendix 7.1).[13, 14] We take this stereotypical model as a point of departure and propose a more nuanced representation of the complex relationship between weather and climate and wine quality,

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[12] Jones et al. (2005) estimated a quadratic-in-temperature specification on Sotheby's vintage ratings in wine regions across the world and found no effect of temperature on U.S. wine quality. Ramirez (2008) found that weather variability affects Napa wine quality and prices, but their results indicated that "warmer summers tend to be associated with lower, not higher, quality ratings, a result that does not coincide with expectations."

[13] The timing of veraison varies from year to year, variety to variety, and place to place in response to the weather variables whose effects we are trying to model, so it would be particularly advantageous to observe veraison and account for that in the definition of the timing intervals.

[14] In addition to the linear and squared measures of weather variables, we also included linear and squared measures of magnitudes of deviations from average weather or climate. These different elements were included to allow us to better account for differences between short-run (within places) versus longer-run (among places) effects of particular weather patterns on wine quality, where growers in different places have adopted different technologies optimized for their expected weather or climate and their vintage quality depends on deviations from their local optimum as well as deviations from the long-run global optimum optimorum. A similar approach was employed by Mérel & Gammans (2021) applied to US corn and soybean yields and French wheat and barley yields.

allowing for varying effects in different parts of the growing season, especially for heat. Specifically, instead of the total number of degree days during the growing season we include measures of degree days in each of five temperature intervals (< –2ºC; –2ºC to 10ºC; 10ºC to 30ºC; 30ºC to 35ºC; > 35ºC) for each of three time intervals across the growing season (February–October, April–July, August–October), with our choice of temperature and time intervals motivated by Jones et al. (2012), see also Figure 3.[15] This specification is designed in particular to identify the effects of cold weather around bud-break and the effects of sustained periods of extreme heat, especially post-veraison. Since we do not observe veraison directly, as an approximation we presume veraison occurs around the end of July.

3. Data

We compiled data on prices and expert rating scores for California's wines from the Wine Spectator magazine and K&L Wine Merchants and matched these to relevant measures of weather and climate from PRISM. Figure 4 summarizes the key datasets and how they were merged.

[Figure 4 Diagram of key datasets and links between datasets]

[15] While we use a relatively flexible representation of effects of temperature on wine quality, compared with previous studies by economists, we acknowledge that it is nonetheless simplified along other dimensions. For example, wine quality might be affected by the diurnal temperature range—the difference between the daily minimum and maximum temperatures (see, e.g., Byron & Ashenfelter 1995)—or other more complicated aspects of temperature variation that are not captured by our measures of degree days. But including additional measures of temperature may absorb some of the explanatory power of our degree day variables and make it difficult to interpret our key estimates. We plan to explore these complications, working with viticulturists and enologists, in extensions of this study.

3.1. PRISM data and weather variables

We used spatially detailed weather data from PRISM (PRISM Climate Group, Oregon State University, 2020) to represent regional weather and climate. PRISM interpolates daily minimum and maximum temperatures and precipitation to 800m-by-800m grids, taking into account elevation, coastal proximity, and aspect.

Matching weather data (daily by 800m grid) to wine data (vintage by region) requires both temporal and spatial aggregation. Starting with spatial aggregation, we first identified every 800m PRISM grid that intersects with each wine region using the AVA boundaries taken from the American Viticultural Areas Digitizing Project Team (2021) produced by the UC Davis Library and UC Davis DataLab. They publish "spatial data from each of official American Viticultural Areas boundary descriptions which are accepted and published by the Alcohol and Tobacco Tax and Trade Bureau." For regions that intersect with multiple PRISM grids, we calculated a single observation for the region by taking a weighted average of weather and climate variables across grids. Each grid's weight is equal to the share of the region's grape acreage within the grid in 2021, calculated using the USDA's Cropland Data Layer (USDA NASS, 2022). Grids that were not associated with any grape acreage were assigned a weight of zero and did not contribute to the weighted average.

To temporally aggregate PRISM grids to wine regions, we defined our temperature variables in terms of degree days in selected temperature intervals, which measure how long and by how much temperatures exceed (i.e. >) the lower bound of a temperature interval $\underline{h}$

without exceeding (i.e., ≤) an upper bound $\overline{h}$ (Snyder 1985; Ortiz-Bobea 2021), during specific parts of the growing season for winegrapes in each region.

We first translated daily minimum and maximum temperatures into measures of temperature exposure. This involved fitting a sinusoidal curve between daily minimum and maximum temperatures and integrating under the curve to estimate how many hours were spent in each 1°C temperature interval indexed by *j*. We then calculated degree-day variables following Equation (1), based on the temperature interval thresholds and timing thresholds as shown in Figure 5.

$$DD_{rmv,[\underline{h},\overline{h}]} = \sum_{j=\underline{h}}^{\overline{h}-1} x_{rmv,j} \times (j - \underline{h} + 1), \tag{1}$$

where $DD_{rmv,[\underline{h},\overline{h}]}$ is the number of degree days between $\underline{h}$°C and $\overline{h}$°C for region *r* in months *m* in vintage year *v*, and $x_{rv,j}$ is the number of days spent between *j*°C and $j+1$°C in region *r* in months *m* of vintage year *v*.

[Figure 5 Grapevine growth stages and definition of degree-day variables]

Specifically, during the period February–October freezing temperatures (≤ -2°C) are expected to have a negative influence on vegetative growth, berry development and fruit quality; during the growing season, April–October, compared with cooler temperatures (–2°C to 10°C) and hotter temperatures (> 35°C), warm temperatures (10°C to 30°C) are favorable to berry development and quality (Jones et al. 2012, see Figure 3). However, sustained periods of

hot temperatures (30ºC to 35ºC), especially post-veraison, are damaging to wine grape quality because they cause reduced photosynthesis, color development, and anthocyanins; and moreso extremely hot temperatures (> 35ºC). Wines made with grapes exposed to exceedingly hot temperatures often possess high alcohol and low acidity, as well as undesirable aromatic and flavor components (Pons et al. 2017). Table 1 includes summary statistics on the weather for premium wine-grape growing regions of California.

[Table 1 Weather Variables by Location]

3.2. Wine Spectator data

We compiled data on prices and expert rating scores for California's wines from the Wine Spectator (WS) magazine and matched these to relevant measures of weather and climate from PRISM. The WS publishes information on recommended retail prices, expert ratings, and other information about many wines from around the world in each of its monthly issues; WS editors blind taste and rate over 15,000 wines per year. We collected information on wines from California published in the WS between January 1994 and December 2022 (see Appendix 0). For each wine, we recorded its brand or producer, region (including AVA), vintage year, rating, suggested retail price, wine grape variety, wine type, and number of cases made. We focused on varietal wines produced using five grape varieties that are predominant in California wine production and that together account for the lion's share (71%) of the wines for which we recorded information from the WS: Cabernet Sauvignon (29 percent of wine observations for the five varieties), Chardonnay (23 percent), Merlot (8 percent), Pinot Noir (28 percent), and Zinfandel (12 percent). Vintage is the year in which the grapes used to produce

the wine were grown. We kept data on vintages between 1991 and 2020, with other vintages being too infrequently sampled to be included in our analysis.

Across the 28 years of WS magazines from which we collected data, some price variation reflects changes in the purchasing power of money. We converted suggested retail prices into equivalent 2022-dollar values using the Consumer Price Index (CPI) for the corresponding issue year (the year in which the wine rating was published by the WS) (U.S. Bureau of Labor Statistics 2023, specifically, the annual average of the CPI for all urban consumers, series number CUUR0000SA0). The average suggested retail price is $73 per bottle in our sample. These wines are high priced compared not only with California wines generally, but also compared with the premium wine brands produced within the regions that they predominately represent.

Wine ratings reported by WS are ostensibly on a scale of 0–100 points but in practice for premium wines the typical range is 85–95 points, with exceptional wines scoring more than 95 points. Wines are rated blind, meaning information about the winery or wine (including its price) is unknown to the taster during the tasting. In our sample, wine scores increased from an average of 85 points in 1991 to 90 points in 2020, and variation around the average declined over the decades shown in Figure 6. Wine prices also increased in real terms from $35 per bottle in 1991 to more than $80 per bottle by the mid-2010s (all in 2022 dollars). These trends in the complete sample are reflected in scores and prices for each variety (Appendix 7.3).

[Figure 6 Wine Spectator wine scores, prices and number of observations by vintage, all]

Table 2 includes summary statistics on the price, WS score, and number of cases made for each wine; the corresponding wine-specific measures of the weather variables, and the numbers and proportions of the 44,570 observations associated with the various grape varieties and regions. Appendix 7.4 shows disaggregated details.

[Table 2 Summary Statistics, All Varieties and Regions]

3.3. K&L Wine Merchants Data

K&L Wine Merchants, based in California, bring together independent buyers and sellers of fine wines. Sellers present bottles of wine to K&L who inspect all items for authenticity and quality. K&L then lists the “auction lot” consisting of one or more bottles of wine on its website. Buyers may bid on an auction lot over a seven-day auction period. Upon the completion of the auction period, the highest bidder pays the hammer price and receives the auction lot while the seller receives the hammer price minus fees charged by K&L. Unlike the Wine Spectator magazine which publishes recommended retail prices as declared by the winery, K&L prices represent actual sales of fine wine.

K&L publishes information on past auction lots, including the winery, wine type, vintage year, number of bottles in the lot, hammer price, and end-date of bidding on the auction lot. We collected K&L auction data for wines from California wineries, summarized in Table 2. We focused on standard-sized 750mL bottles of varietal wine for the same five grape varieties as for the WS data. Compared with the WS sample the shares were different: Cabernet Sauvignon (64 percent of wine observations), Chardonnay (13 percent), Merlot (2 percent), Pinot Noir (18 percent), and Zinfandel (3 percent). We excluded auction lots that comprised a mix of wines

from different vintages or different regions (for example, vertical or horizontal tasting lots) since we are seeking to link price to vintage- and region-specific weather. We kept data on vintages between 1981 and 2020, leading to a dataset of 47,842 observations.

[Figure 7 K&L wine prices (2022 dollars/bottle) by vintage, excluding outliers, all varieties]

Table 2 includes summary statistics on the price, wine age at the time of the auction, and numbers of observations associated with the various grape varieties and regions. In our sample, the average auction lot contains 2.6 bottles of the same wine. For lots of multiple identical bottles, we calculated price per bottle by dividing the hammer price by the number of bottles. The average price is $244 per bottle in 2022 dollars. The standard deviation is relatively large at $475 per bottle, as many bottles were priced into the thousands of dollars. Appendix 7.4 shows disaggregated details by wine grape variety and region.

4. Statistical analysis of vintage weather effects on prices and ratings

In what follows, using data from the WS or K&L, we estimate statistical models of prices of varietal wines as a function of measures of weather for each of the main varieties (and for the WS data we also estimate models of ratings and total cases). The goal of this analysis is to estimate vintage effects arising from temperature variation around the regional norm. Since wine grape varieties (Cabernet Sauvignon, Chardonnay, Merlot, Pinot Noir, and Zinfandel) have distinct optimal climates, as well as a model pooling data across varieties, we estimate a separate model for each variety. The model has the same general form for all the regressions. The only substantive difference is a small one: for the WS data we use the year of publication whereas with the K&L auction data we use the year of the auction to identify the timing of the

observation. We report detailed results for models estimated for a particular variety, Cabernet Sauvignon produced in a particular place, the Napa Valley AVA and its various sub-AVAs, which encompasses more than half of the entire dataset. The other results provide contrast.

4.1. Regression models

Using K&L price data we estimated the following model for each of the five varieties:

$$ln(Price_{wrvt}) = \alpha_{wr} + \sum_{d=1}^{D} \beta_d DD_{drv} + \rho_1 ppt_{rv} + \rho_2 ppt_{rv}^2 +$$

$$\delta_1 \, wine \; age_{wrvt} + \delta_2 wine \; age_{wrvt}^2 + \theta_1 v + \theta_2 v^2 + \psi_t + \epsilon_{wrvt}$$

(2)

where $\ln(Price_{wrvt})$ is the natural logarithm of price for wine from winery *w* using grapes grown in region r in vintage year *v* observed in auction year *t*. We took the natural logarithm to reduce the skewness evident in prices. DD_{drv} is the degree-day variable *d* for region r in vintage year *v.* We included six degree-day variables: DD < –2°C February–October; DD –2°C to 10°C February–October; DD 30°C to 35°C April-July; DD 30°C to 35°C August–October; DD > 35°C April–July; DD > 35°C August–October. Exposure to moderate temperatures, DD 10°C to 30°C served as the comparison category. We included a quadratic function of precipitation during the growing season ppt_{rv} summed from April to October. We controlled for the "age" of the wine at the time of the auction by including a quadratic function of $wine\ age_{wrvt}$ which is equal to the number of years between the year of the auction *t* and the vintage of the wine *v*. To account for technological advancements and other uncontrolled factors such as trends in

demand, we included a linear and quadratic vintage-year trend *v*. We included a dummy variable for the auction year ψ_t to control for the market conditions when the wine was auctioned. We included winery-by-region fixed effects α_{wr} to absorb time-invariant characteristics of the winery and region. By using a semilog specification, we estimated the proportional effect of weather variables and controls on price. The errors were heteroskedastic robust and clustered by region.

We estimated similar statistical models of three variables reported by Wine Spectator magazine—varietal wine prices, scores, and the number of cases made. As noted, the model is the same as that used for the K&L price data except that now instead of the year of auction we have the year of publication, and the "age" of the wine is equal to the difference between the year of publication and the year of the vintage. And the right-hand side of the model is the same whether the dependent variable is the recommended retail price, the rating score of the wine or the number of cases made.

Considering the different data sources and many varieties and regions we have numerous models and diverse results to consider. To make the task more manageable, we are opting to focus on a subset of the total. First, we focus initially and mainly on the results from using K&L auction price data. We compare these with the results from using the WS price data to illustrate the implications of using suggested retail prices rather than actual transactions prices. And we use the results from the models using the WS data on rating scores and quantities produced to draw out other angles on the main story revealed using the K&L price data. Second, we focus mainly on the analysis of data for one variety Cabernet Sauvignon (which comprises 64 percent of the total K&L sample) and especially on production of that

variety from the Napa Valley and its sub-AVAs. We use the results for the other varieties mainly to illustrate the range of results and for contrast, as a loose robustness check.

The full statistical results for all the various models of interest are reported in Appendices. Here we summarize the findings from the models in terms of the parameters on the various measures of temperature (degree days in specific temperature intervals in different parts of the growing season). Table 3 includes the estimated marginal effects—percentage change in the outcome caused by a one standard deviation increase in the explanatory variable—for the models by variety, estimated for the full sample (i.e., pooling data across all regions). Corresponding tables for models by sub-region by variety are included in Appendix 7.5.

[Table 3 Estimated effect of degree days indices on natural logarithm of wine prices from K&L]

4.2. Overview of estimates

In Table 3, the results in the first column are for the model estimated using the K&L price data for all five varieties across all growing regions. The results are broadly consistent with our expectations. Specifically for the variables included primarily as controls, the vintage year trend follows an inverted-U shape with prices peaking in 1993 and vintages post-2006 experience a price penalty. We find that prices of wine tend to decrease with the "age" of the wine at the time of the auction equal to the number of years between the auction year and vintage. These somewhat counterintuitive results could be a consequence of the high negative correlation between wine age and vintage year trend (correlation coefficient of -0.93).

In this analysis we are focusing on the effects of a specific aspect of climate: temperature. We include measures of precipitation as controls rather than to measure the effects of precipitation on wine quality. Nonetheless we were disappointed to find that the estimated effects of precipitation on wine prices and quality did not clearly make sense. Part of the problem here is that we do not observe irrigation, which can be used to some extent to mitigate the effects of variation in precipitation. Also, the correlation between seasonal patterns of precipitation, other aspects of climate, and soil types that matter for wine quality may be having some influence on these estimates. Our use of an annual—rather than season-specific—measure of precipitation and its square might not capture these complicated aspects of the relationship well but we hope, nonetheless, it is helpful as a control.

We are mostly interested in the effects of temperature. The estimated coefficients represent the marginal effects of changes relative to a default category of temperatures in the range of 10ºC to 30ºC. Most of the estimated marginal effects of the degree-day variables are estimated precisely, indicating that extreme temperatures result in statistically significantly lower prices for wine—especially temperatures exceeding 35ºC.

The results in the second column—for Cabernet Sauvignon wines that comprise more than 60 percent of the total K&L sample—are quite similar to those for the full sample across the five varieties. The next four columns represent the results from the corresponding models for Chardonnay, Pinot Noir, Merlot, and Zinfandel, respectively. In these models, too, the point estimates of the parameters are similar to those in the model for "All varieties" in the first column, but the statistical significance is generally lower, reflecting the effect of smaller sample sizes, especially for Merlot and Zinfandel (see Appendix 7.6). In what follows we focus on the

results for Cabernet Sauvignon, which are illustrative of the results, generally. We characterize the marginal effects in terms of the elasticities shown in curly brackets.

The results indicate that cool temperatures cause Cabernet Sauvignon prices to fall. A one-standard deviation increase in DD –2ºC to 10ºC (i.e., an increase in the number of days in the range of –2ºC to 10ºC and a corresponding reduction in the number of days in the range of 10ºC to 30ºC) would cause Cabernet Sauvignon prices to decline by 2%. We found that a one-standard deviation increase in DD < –2ºC (i.e., an increase in the number of days in the range of < –2ºC and a corresponding reduction in the number of days in the range of 10ºC to 30ºC) would cause Cabernet Sauvignon prices to decline by a less statistically significant and slightly smaller 1.1%.

Lower prices for Cabernet Sauvignon are also associated with hot temperatures during particular stages of the growing season. We found that increases in DD 30ºC to 35ºC in April-July did not cause a significant decline in price, which is consistent with wine grapes being able to withstand moderately hot temperatures prior to veraison. However, significantly lower prices are associated with increases in DD 30ºC to 35ºC later in the growing season. Extremely hot temperatures DD >35ºC are damaging both pre- and post-veraison. A one-standard deviation increase in DD >35ºC in April-July would cause prices to fall by 2.4% and a one-standard deviation increase in DD >35ºC in August to October would cause prices to fall by 1.3%.

Climate varies in the cross-section, making it difficult to disentangle its effects from those of other time-invariant characteristics of regions, such as soil type and typography. When modelling prices using Equation (2), we estimated winery-by-region fixed effects that captured

time-invariant characteristics of the winery and region, such as wine brand reputation and aspects of the region's terroir including soil type and climate. In Figure 8, we show the relationship between winery-by-region fixed effects from the regression of K&L Cabernet Sauvignon prices against climate, measured as the growing season average temperature between April and October, averaged over 1981–2020. We found that the relationship between price and climate follows an inverted-U shape for Cabernet Sauvignon. While not causal, this result suggests that wines from regions with warmer (>19ºC) or cooler climates (<18ºC) tend to be priced lower. This analysis offers a more nuanced view of climate than prior work which suggests a wide optimal climate band for premium Cabernet Sauvignon wine—around 16.5ºC to 20.2ºC (Jones et al. 2012, see also Figure 2).

[Figure 8 Distribution of winery-by-region fixed effects for Cabernet Sauvignon prices by regional climate]

As noted, the results for the other varieties are generally similar albeit with some variation and less precision in the case of the varieties for which the sample is comparatively small. The results by sub-region and variety (see Appendix 7.5 Table 3a to Table 3e for details) illustrate the trade-offs in pooling across places and varieties. The estimates for Cabernet Sauvignon are relatively precise for Napa AVAs because it is a relatively homogeneous category (compared with the full sample which includes prices for wines from varieties other than Cabernet Sauvignon, made from grapes grown not just in the Napa AVA but also in other AVAs having less similar climate and other elements of terroir) with a relatively large number of observations. But for Cabernet Sauvignon in every model whether for all premium wine-

growing regions of California or particular major regions producing premium wine, we see statistically significant negative effects of extremely cold or hot weather on prices.

Later in the paper, in the context of our analysis of the implications of climate change in Section 4.3, we express those findings in more natural units for understanding the importance of the effects. Before doing that we consider the results from the analysis using data from the Wine Spectator magazine. Table 4 includes the results for the models of WS prices, which are directly analogous to the results in Table 3 for the models of K&L prices. While the general pattern of the signs of the coefficients on the rainfall and temperature variables is similar to the counterparts for the models using K&L prices, in the models using WS prices the coefficients and the implied elasticities are generally much smaller and mostly not statistically significantly different from zero. This reflects the fact that the WS prices are producers' suggested retail prices for wines, at release, whilst the K&L prices are secondary market auction prices for aged wines. We suspect that suggested retail prices tend to be stickier and much less reflective of inter-vintage variation in quality compared with auction market prices, so any vintage weather effects on quality are likely to be muted in the prices reported by WS.

[Table 4 Estimated effect of degree-days indices on natural logarithm of wine prices from Wine Spectator]

This conjecture appears to be supported by the results from the counterpart models of wine rating scores (in Table 5) and models of the number of cases produced (in Table 6) using data from WS on the same wines. In the models of wine rating scores the measured effects of extreme weather are statistically significant and consistent with priors: low and high

temperatures are harmful and hot weather later in the growing season is especially harmful to wine quality.

[Table 5 Estimated effect of degree-days indices on natural logarithm of wine scores from Wine Spectator]

One of the short-run adaptive responses available to winemakers, to maintain quality and protect the brand, is to produce smaller quantities of higher-quality brands in vintages with less favorable weather. The estimates in Table 6 are somewhat consistent with the idea that extreme weather harms quality and winemakers are exercising discretion in this way—if quality is generally down a smaller share of the total quantity of wine grapes will be good enough for the signature wines that are especially important for a winery's reputation. Hence, for Cabernet Sauvignon we observe a statistically significant reduction in the total number of cases produced of a particular wine label if the vintage weather was extremely cold or extremely hot, though we see a seemingly anomalous increase in cases produced associated with an increase in the number of cooler days (i.e., days in the range of –2°C to 10°C). They could also reflect a simple yield effect of weather, but that seems less likely in the case of fine wines for which growers are carefully managing yield and mostly preventing it from being too high.

[Table 6 Estimated effect of degree-days indices on natural logarithm of cases made from Wine Spectator]

4.3. Implications of climate change

Climate change will cause warming in key wine-grape growing regions around the world. Table 7 shows the 10-year average values of our measures of temperature and degree-day variables for Napa Valley AVA during two historical periods: 2001–2010 and 2011–2020, and

two projected periods: midcentury 2041–2050 and end of century 2091–2100. We use projected temperatures from global climate model EC-Earth3 for emissions scenario SSP2-4.5, a middle-of-the-road global emissions scenario. The average growing season temperature in the Napa Valley is projected to increase from 18ºC in 2001–2010 to almost 22ºC by the end of the century. Focusing on average temperature hides even larger projected increases in exposure to hot and very hot temperatures as measured by our degree-day variables. The measure of degree days 30ºC to 35ºC during August to October is expected to double by end of century, and the measure of degree days above 35ºC is expected to increase by a factor of five.

[Table 7 Observed and projected (EC Earth3 SSP2-4.5) average temperature and degree day variables in Napa Valley AVA]

How might future climate change affect wine prices? We did two back-of-the-envelope calculations of the effect of changing temperatures on wine prices using the modeled relationship between observed temperature and prices. To do so, we made several assumptions. First, we did not allow for any additional adaptation (or maladaptation) other than the adaptation already implicitly embedded in the model parameters calibrated to technologies and strategies used during our period of analysis (1981–2020). We made no allowances for climate-mitigating innovations in production systems—for example, the development and adoption of varieties better adapted to hotter weather (which is not so relevant in the analysis of variety-specific prices) or viticultural practices (e.g., pruning, irrigation, or cover crops) or winemaking technologies. Second, we did not consider other potential pathways through which climate change (and its causes) may affect wine grape yield

and quality, such as higher concentrations of atmospheric carbon dioxide or increased pest or disease pressure. Third, we did not model other potential changes in price that may coincide with changing temperatures, for example changes to the reputation premium or changes in price from adjustments in the demand or supply of wine both in California and globally. In particular, to the extent that climate change is having significant effects on the supply and quality of fine wine from California it will surely be having effects on the supply and quality of competing wine from other countries or other parts of the United States.

With these caveats in mind, we estimated the effect of observed and projected changes in degree days in the Napa Valley AVA on Cabernet Sauvignon wine prices (Table 8). We estimated that less time spent at cool temperatures below 10ºC will cause Cabernet Sauvignon wine prices to increase. However, this will be more than offset by a decline in prices caused by increasing numbers of degree days 30ºC to 35ºC and degree days above 35ºC, particularly during August to October. We estimate that, absent additional adaptation and all else equal, as a result of projected changes in temperatures relative to 2001–2010, Napa Valley Cabernet Sauvignon prices will decrease by 26% by midcentury and by 41% by the end of the century. However, the extent to which these effects will be realized will depend on how grape growers and winemakers adapt.

[Table 8 Estimated percentage change in Cabernet Sauvignon prices relative to 2001–2010 caused by observed and projected changes in degree days in Napa Valley AVA]

In the second back-of-the-envelope calculation, we assigned Napa Valley the climate of Fresno County—a grape-growing region of California that is warmer than Napa Valley's current climate. Table 9 summarizes observed average temperature and degree days for the Napa

Valley AVA and Fresno County for vintages between 1981 and 2020. Fresno County's climate is remarkably similar to the climate projected for the Napa Valley AVA at the end of the century. Our results imply that assigning Napa Valley the climate of Fresno would cause prices of Napa Valley Cabernet Sauvignon wine to decline by 40%, absent additional adaptation and holding all other factors constant.

[Table 9 Observed temperature in Napa Valley AVA and Fresno County, 1981–2020]

5. Conclusion

Previous studies have represented the effects of vintage weather and climate on wine quality and prices with relatively simple measures of temperature, such as average daily temperature during the growing season. However, our results show that what matters for wine grape quality, and therefore wine prices, is not average temperature throughout the growing season but, rather, extreme temperatures at particular times within the growing season. We find that exposure to extreme temperatures, measured in degree days, during key stages of the growing season causes significant changes in quality and prices of premium wine produced in California. Our findings on this aspect parallel findings in studies of effects of weather and climate on agriculture, including effects on farmland values (Schlenker et al. 2006), crop yields (Schlenker & Roberts 2009, Gammans et al. 2017) and quality (Kawasaki & Uchida 2016, Smith & Beatty 2023) of other agricultural crops.

Extremely hot weather causes wine quality and prices to decline, particularly if high temperatures occur post-veraison. These effects can be economically significant. Models of future climate project significant increases in average temperatures in California, but much

more profound increases in the prevalence of extreme heat. The average growing season temperature in the Napa Valley is projected to increase from 18ºC in 2001–2010 to almost 22ºC by the end of the century, but the measure of degree days 30ºC to 35ºC during August to October is projected to double by end of century, and the measure of degree days above 35ºC is projected to increase by a factor of five. Consequently, we estimate that, absent additional adaptation and holding all else equal, as a result of projected changes in temperatures relative to 2001–2010, Napa Valley Cabernet Sauvignon prices will decrease by 26% by midcentury and by 41% by the end of the century. The implication is that producers will feel strong pressures to adapt their methods of production both in the vineyard and the winery to preserve quality and premia associated with production of this signature variety in the Napa Valley. Models using average temperatures to represent heat effects would not capture this effect—indeed, earlier work found no effect or counter-intuitive effects of heat on quality and price of Napa Valley wine (Jones et al. 2005, Ramirez 2008).

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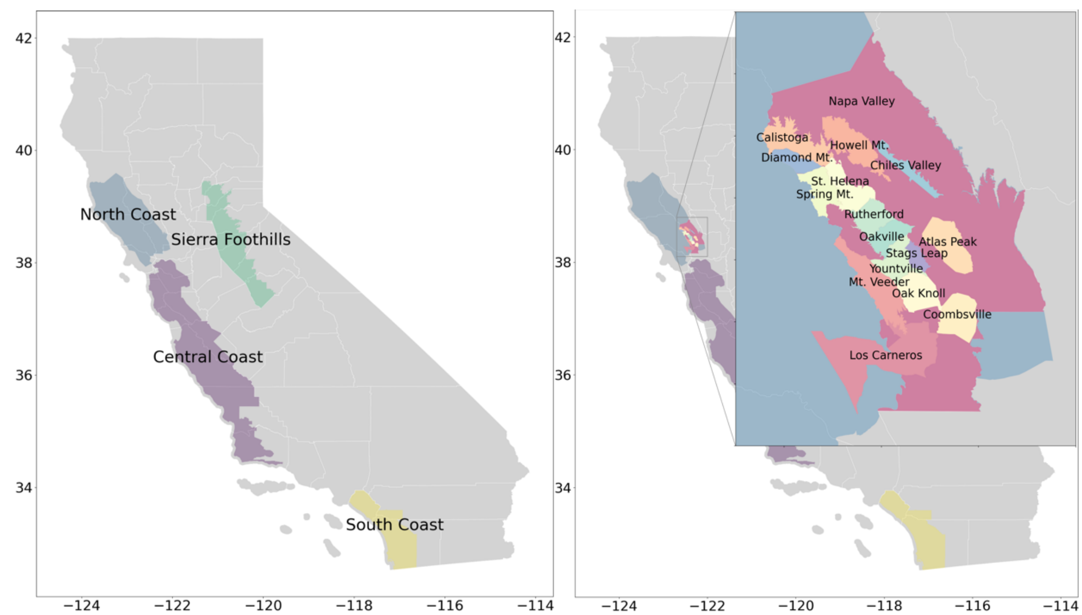


Figure 1 Main wine regions in California and Napa Valley AVAs

Source: Generated by the authors using AVA boundaries from American Viticultural Areas Digitizing Project Team (2021).

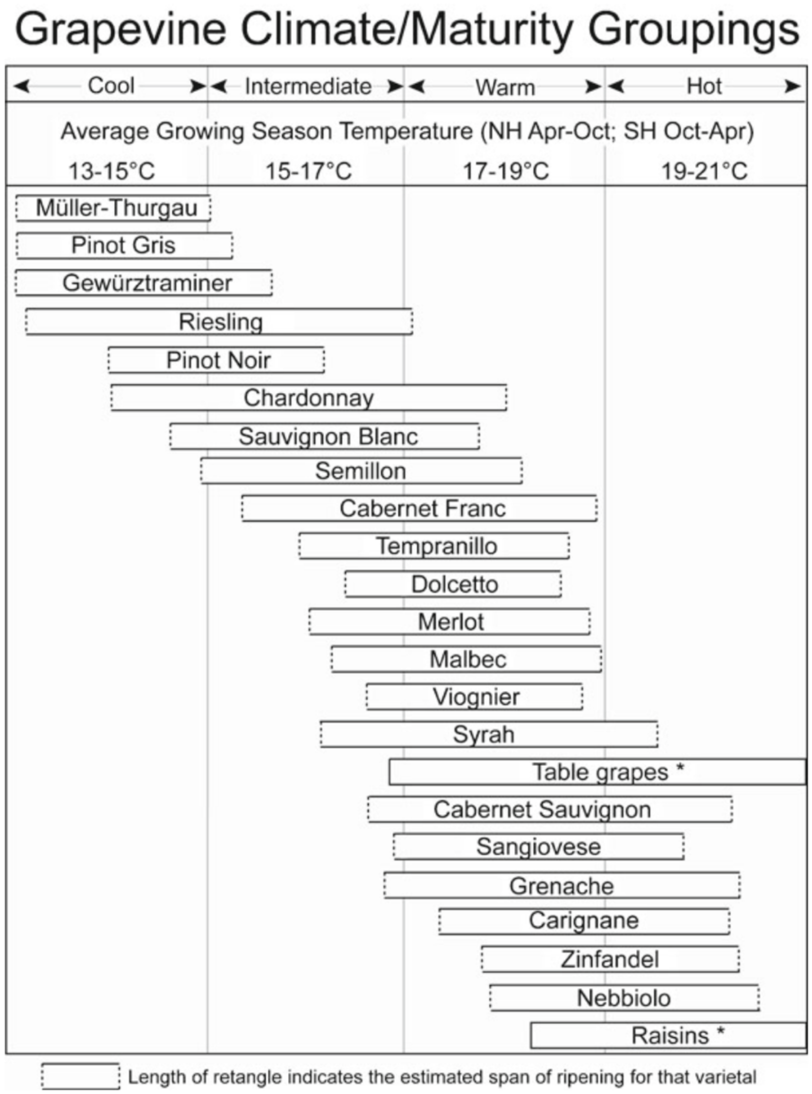


Figure 2 Optimal average growing season temperature range by grape variety

Source: Jones et al. (2012, p. 116), Figure 7.3

Note: The original caption in Jones et al. (2012) reads “Climate-maturity groupings based on relationships between phenological requirements and growing season average temperatures for high- to premium-quality wine production in the world’s benchmark regions for many of the world’s most common cultivars. The dashed line at the end of the bars indicates that some adjustments may occur as more data become available, but changes of more than ±0.2–0.5°C are highly unlikely (Jones 2006)”

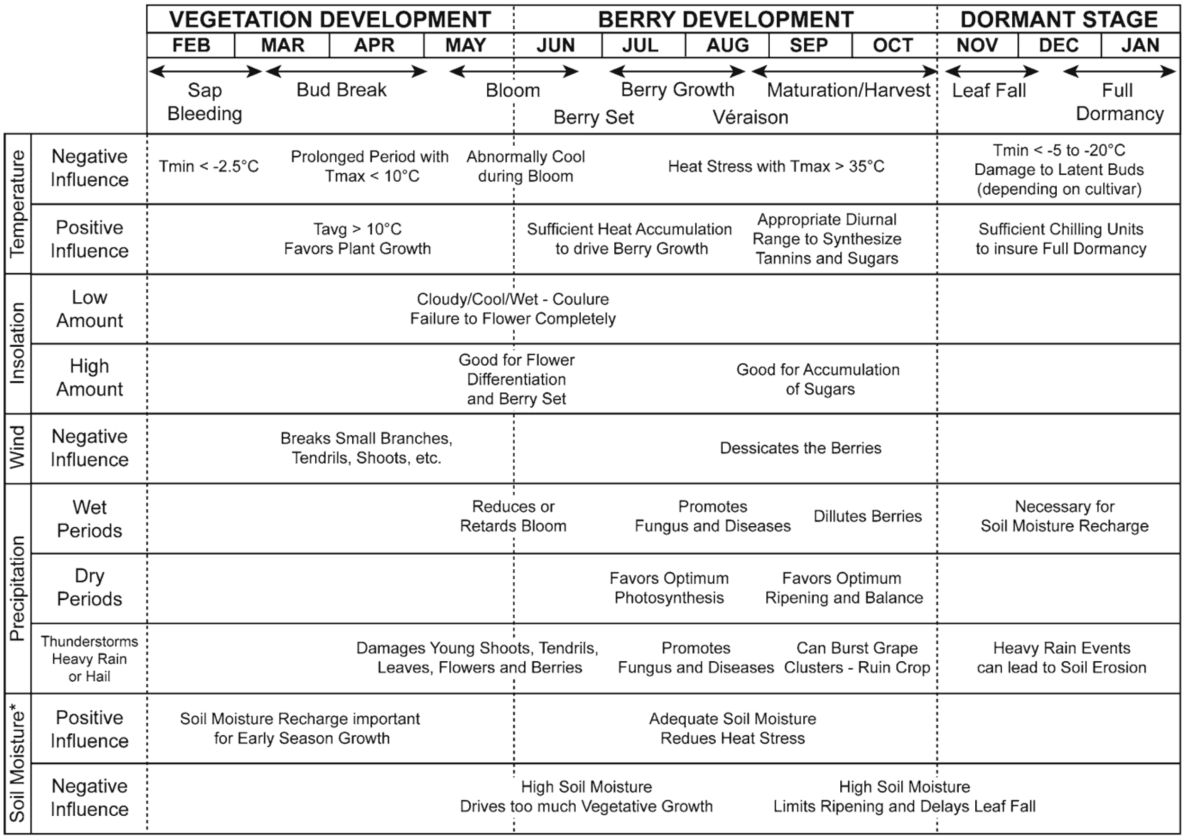


Figure 3 Weather and climate influences on grapevine development and phenological growth stages

Source: Jones et al. (2012, p. 111), Figure 7.1

Note: The original caption in Jones et al. (2012) reads: “Weather and climate influences on grapevine development and phenological growth stages (Crespin et al. 1987; Jones 1997).”

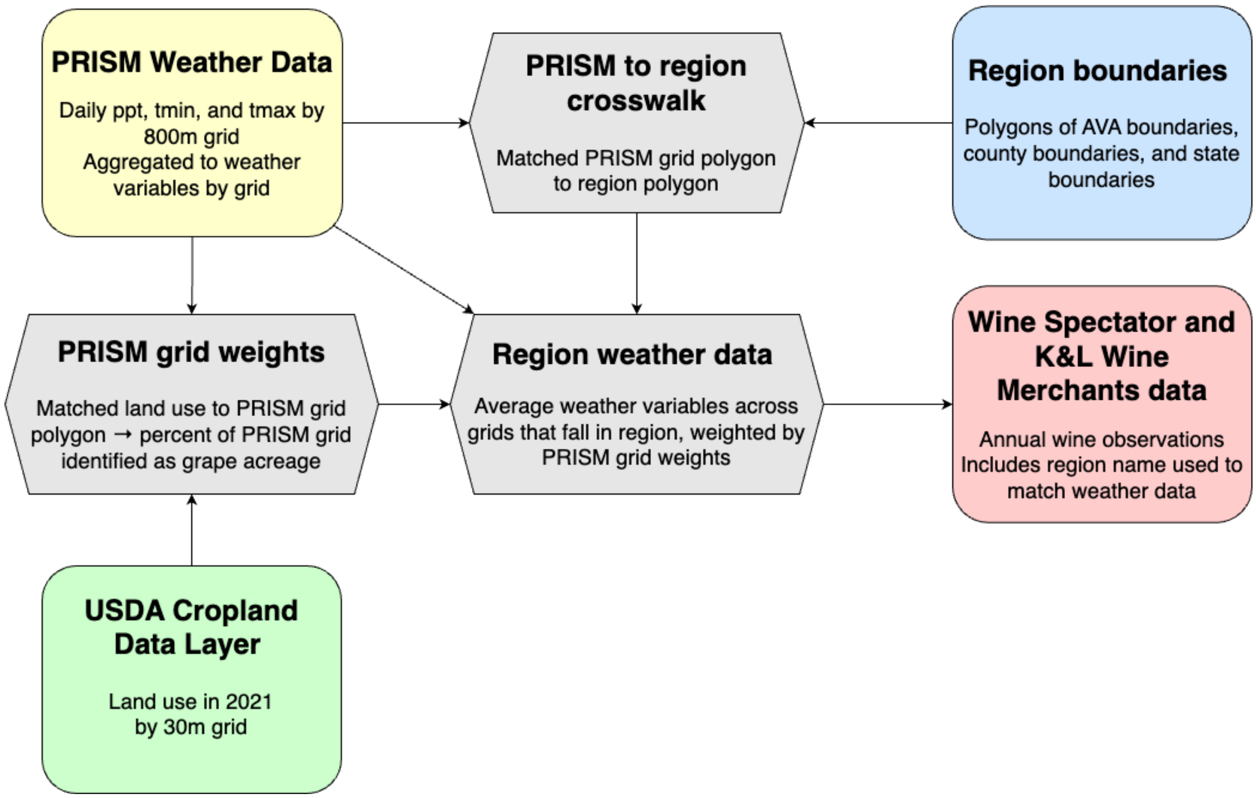


Figure 4 Diagram of key datasets and links between datasets

Source: Created by the authors.

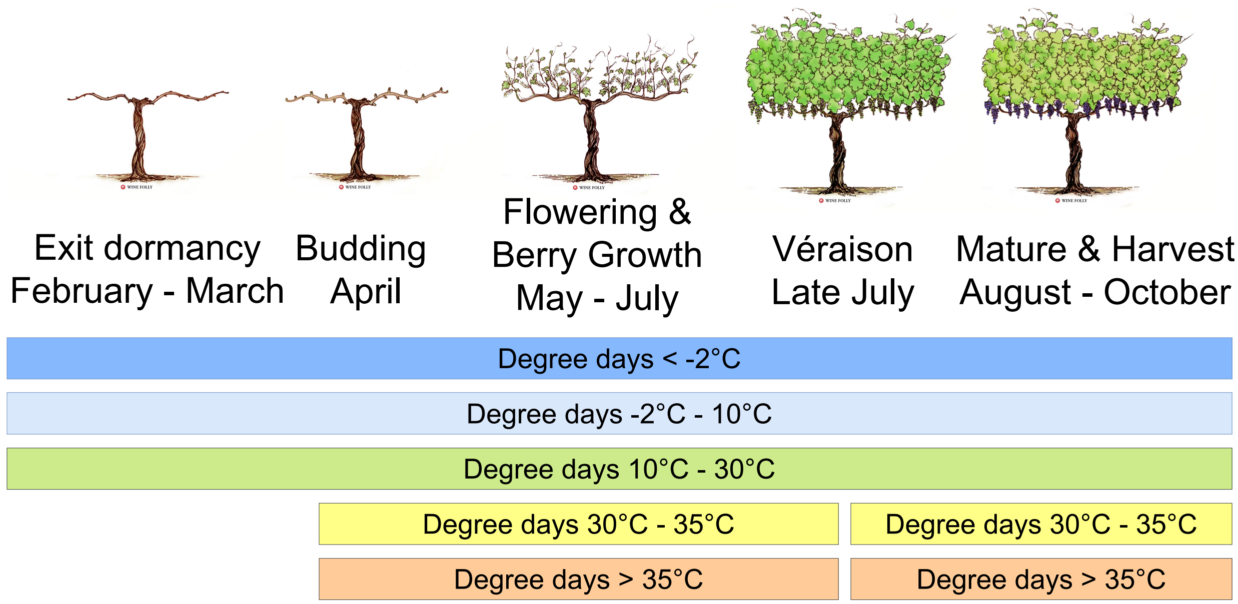


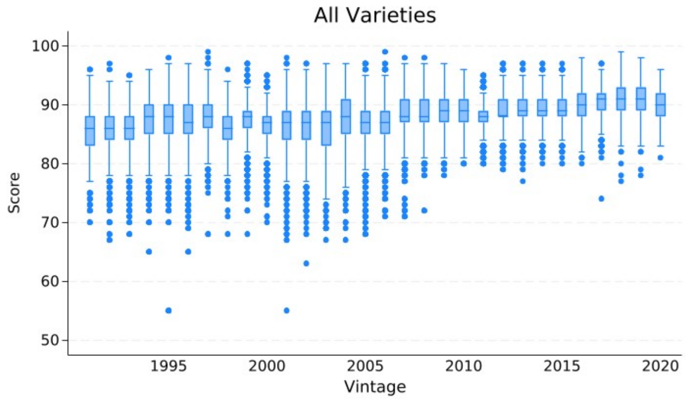
Figure 5 Grapevine growth stages and definition of degree-day variables

Source: Created by the authors, drawing on Snyder (1985), Jones et al. (2012) and Ortiz-Bobea (2021).

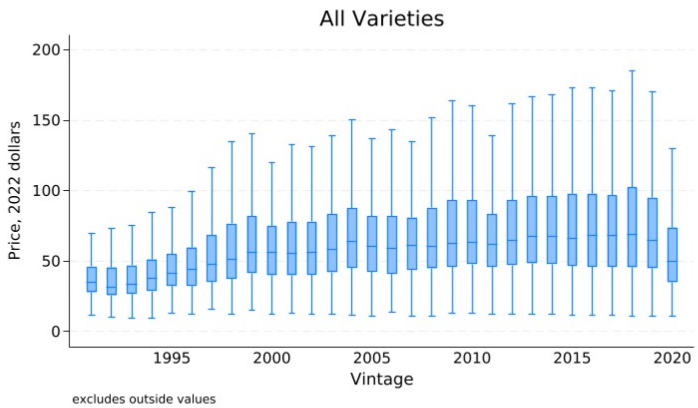
Table 1 Weather Variables by Location

Region	Temp. (°C) Apr–Oct		Precip. (mm) Apr–Oct		Feb–Oct < 2°C	Feb–Oct –2°C to 10°C	Feb–Oct 10°C to 30°C	Apr–Jul 30°C to 35°C	Aug–Oct 30°C to 35°C	Apr–Jul > 35°C	Aug–Oct > 35°C
	Mean	*S.D.*	*Mean*	*S.D.*				*Degree Days*			
North Coast AVAs	**17.9**	**0.6**	**136.8**	**66.0**	**0.1**	**147.2**	**2,238.7**	**19.0**	**19.6**	**3.6**	**3.6**
Napa Valley AVAs	18.4	0.6	125.3	61.3	0.0	138.0	2,309.9	22.1	21.4	4.4	3.9
Oakville	18.5	0.7	124.4	62.1	0.0	131.7	2,345.4	26.8	22.5	5.8	4.7
Rutherford	18.6	0.6	126.6	64.4	0.0	126.7	2,363.5	27.2	23.3	6.1	5.0
Howell Mountain	18.2	0.8	164.4	81.5	0.1	206.9	2,271.5	20.4	19.0	2.3	1.8
Stags Leap District	18.3	0.6	115.1	56.4	0.0	127.6	2,323.7	21.1	20.4	3.7	3.3
St Helena	19.2	0.6	134.4	68.5	0.0	113.3	2,451.8	29.3	26.6	6.6	6.0
Mt Veeder	18.4	0.6	138.9	66.2	0.0	130.6	2,308.6	18.5	20.1	3.0	3.1
Other NV sub-AVAs	18.8	0.6	144.2	72.0	0.0	136.3	2,385.1	25.9	25.4	5.3	5.1
Napa Valley	18.4	0.6	123.8	60.5	0.0	133.7	2,325.5	22.8	22.3	4.7	4.3
Sonoma Coast AVAs	17.3	0.6	151.9	72.0	0.1	159.4	2,133.9	14.3	16.6	2.4	2.9
Russian River Valley	17.0	0.6	157.1	74.3	0.1	170.4	2,083.1	12.4	15.0	2.0	2.5
Sonoma Valley	17.3	0.6	118.0	55.2	0.0	142.5	2,122.4	11.2	14.2	1.6	1.9
Dry Creek Valley	18.2	0.6	168.1	82.7	0.1	150.9	2,299.0	24.1	24.4	4.9	5.4
Alexander Valley	18.2	0.6	164.6	80.2	0.1	145.6	2,300.2	23.1	23.9	4.5	5.1
Other SC sub-AVAs	18.2	0.6	179.9	88.0	0.1	143.8	2,272.2	21.0	22.5	4.0	4.6
Sonoma Coast	17.0	0.6	140.7	65.4	0.1	160.8	2,082.6	11.4	14.1	1.7	2.2
Other NC AVAs	17.7	0.6	172.7	81.9	0.1	174.4	2,175.8	18.9	22.4	4.2	4.9
Anderson Valley	17.5	0.5	169.0	78.8	0.0	161.8	2,127.1	14.7	18.5	2.6	3.8
Central Coast AVAs	**17.5**	**0.6**	**81.4**	**50.2**	**0.1**	**139.5**	**2,124.1**	**12.5**	**16.0**	**3.2**	**4.2**
Sta. Rita Hills	17.3	0.6	59.7	48.2	0.0	109.7	2,100.5	4.5	9.4	0.5	1.2
Sta. Lucia Highlands	16.8	0.7	53.1	32.6	0.0	129.3	2,003.6	6.3	10.1	0.8	1.5
Paso Robles	19.0	0.6	57.5	39.3	0.4	180.0	2,348.3	38.1	39.4	16.1	17.7
Other CC AVAs	17.5	0.6	97.0	56.8	0.1	142.0	2,123.4	11.7	15.0	2.4	3.3
All Coastal Regions	**17.9**	**0.6**	**129.8**	**64.0**	**0.1**	**146.2**	**2224.3**	**18.2**	**19.1**	**3.6**	**3.7**

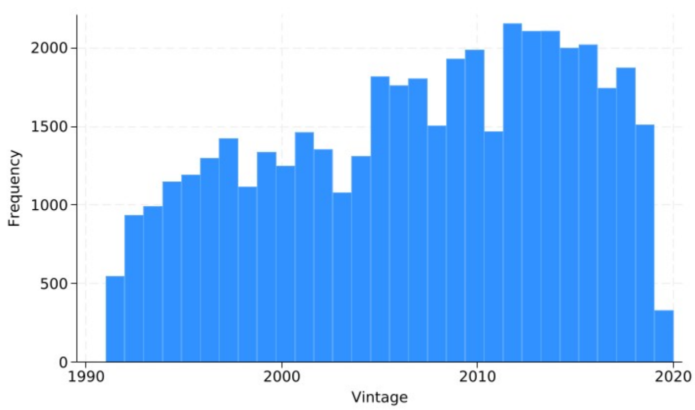
Notes: Averages for individual regions are simple averages across vintages. Averages for multiple regions are weighted by shares of the total number of observations in sub-regions across all five varieties from K&L and WS and all vintages.



(a) Score



(b) Price (2022 dollars/bottle)



(c) Frequency histogram of number of Wine Spectator observations by vintage

Figure 6 Wine Spectator wine scores, prices and number of observations by vintage, all varieties

Table 2 Summary Statistics, All Varieties and Regions

Variety or Region	Average Temp. Apr–Oct	WS No. of Obs.	WS Average Price	WS Average Score	WS Cases Made	WS Average "Age"	K&L No. of Obs.	K&L Average Price	K&L Average "Age"
	°C	*Count*	*$/bottle*	*points*	*Average*	*Years*	*Count*	*$/bottle*	*Years*
All Varieties	**17.9**	**44,570**	**72.5**	**88.2**	**4,406**	**2.9**	**47,842**	**244.0**	**11.9**
Cabernet Sauvignon	18.3	12,811	114.4	88.8	5,236	3.7	30,836	320.5	14.1
Chardonnay	17.5	10,313	51.4	88.4	6,756	2.3	6,139	121.5	6.3
Pinot Noir	17.1	12,436	64.2	88.2	2,155	2.5	8,695	105.3	7.9
Zinfandel	18.0	5,450	44.6	87.4	1,847	2.7	1,358	49.6	10.0
Merlot	18.2	3,560	54.7	86.4	5,657	3.0	814	78.0	15.2
All Regions	**17.9**	**44,570**	**72.5**	**88.2**	**4,406**	**2.9**	**47,842**	**244.0**	**11.9**
North Coast AVAs	17.9	36,718	76.9	88.4	3,977	3.0	44,039	250.3	11.8
Napa Valley AVAs	18.4	19,238	93.6	88.5	4,433	3.3	28,363	328.3	13.7
Sonoma Coast AVAs	17.5	15,558	59.5	88.4	3,006	2.7	15,422	109.9	8.4
Other NC AVAs	17.7	1,922	49.6	87.1	7,269	2.6	254	65.5	8.1
Central Coast & Santa Cruz AVAs	17.5	7,852	52.2	87.3	6,414	2.5	3,803	171.2	12.7

Notes: Summary statistics for premium growing regions in California using PRISM data for average temperature, and winery-vintage observations for Wine Spectator data for vintages between 1991 and 2020 and for K&L data for vintages between 1981 and 2020. Averages are simple averages across the relevant sample—so effectively weighted by shares of observations in sub-regions or shares of varieties.

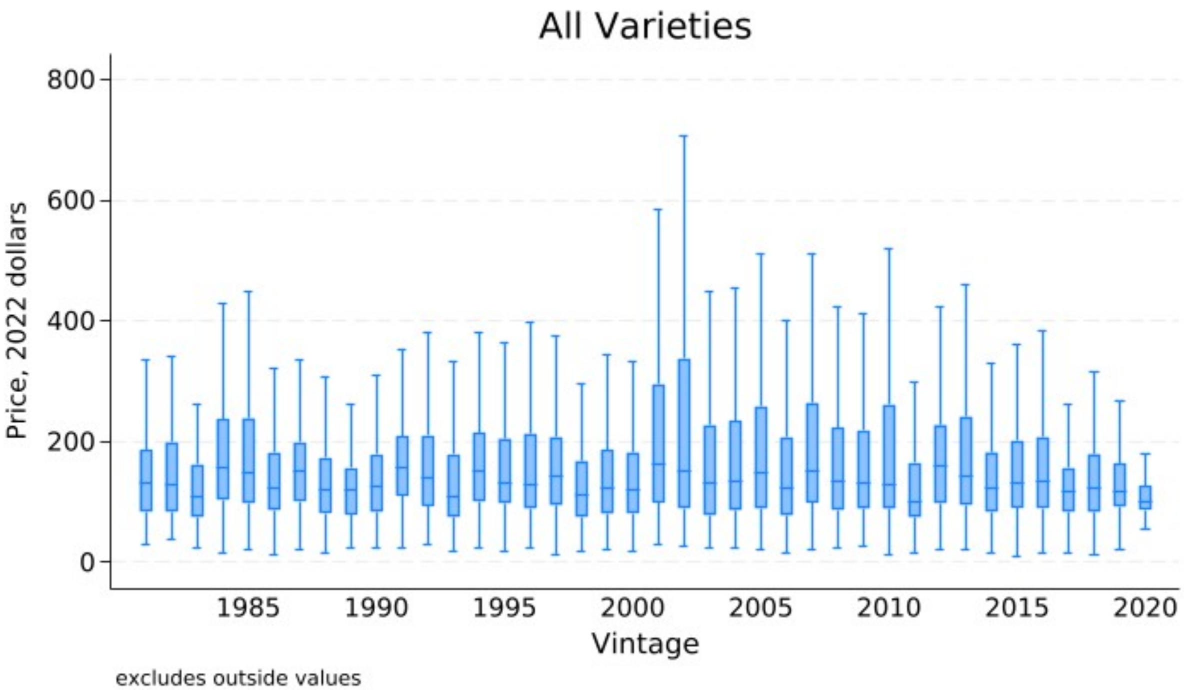


Figure 7 K&L wine prices (2022 dollars/bottle) by vintage, excluding outliers, all varieties

Table 3 Estimated effect of degree days indices on natural logarithm of wine prices from K&L

	(1) All varieties	(2) Cabernet Sauvignon	(3) Chardonnay	(4) Pinot Noir	(5) Merlot	(6) Zinfandel
DD <-2°C Feb-Oct	-0.0380	-0.0928*	-0.1152	0.0009	0.0007	-0.2072***
	(0.0483)	(0.0490)	(0.1828)	(0.0308)	(0.0854)	(0.0209)
	[-0.092]	[-0.171]	[-0.331]	[0.003]	[0.002]	[-1.074]
	{-0.434}	{-1.053}	{-0.680}	{0.011}	{0.012}	{-2.709}
DD -2°C to 10°C Feb-Oct	-0.0007***	-0.0006***	-0.0011**	-0.0006**	-0.0019***	0.0002
	(0.0001)	(0.0001)	(0.0005)	(0.0003)	(0.0003)	(0.0004)
	[-10.377]	[-8.902]	[-17.224]	[-10.798]	[-26.938]	[3.148]
	{-2.291}	{-2.037}	{-3.714}	{-2.022}	{-5.671}	{0.682}
DD 30°C to 35°C Apr-Jul	-0.0001	-0.0007	0.0008	0.0015	0.0122***	-0.0026
	(0.0007)	(0.0007)	(0.0029)	(0.0031)	(0.0029)	(0.0034)
	[-0.256]	[-1.311]	[1.313]	[1.755]	[23.497]	[-5.035]
	{-0.078}	{-0.388}	{0.361}	{0.620}	{6.254}	{-1.253}
DD 30°C to 35°C Aug-Oct	-0.0036***	-0.0062***	-0.0040*	0.0012	0.0079	-0.0017
	(0.0009)	(0.0009)	(0.0022)	(0.0033)	(0.0047)	(0.0022)
	[-6.595]	[-12.089]	[-6.664]	[1.661]	[14.944]	[-3.370]
	{-1.682}	{-2.819}	{-1.963}	{0.542}	{3.320}	{-0.826}
DD >35°C Apr-Jul	-0.0068***	-0.0089***	-0.0035	-0.0104*	-0.0090	0.0032
	(0.0015)	(0.0018)	(0.0063)	(0.0055)	(0.0052)	(0.0027)
	[-2.228]	[-3.543]	[-0.798]	[-1.442]	[-3.256]	[1.458]
	{-1.644}	{-2.354}	{-0.628}	{-1.736}	{-2.089}	{1.175}

DD >35°C Aug-Oct	-0.0056***	-0.0056***	-0.0070***	0.0059	-0.0249**	-0.0011
	(0.0019)	(0.0020)	(0.0014)	(0.0050)	(0.0094)	(0.0033)
	[-1.680]	[-1.795]	[-2.066]	[1.234]	[-6.802]	[-0.479]
	{-1.332}	{-1.268}	{-2.068}	{1.169}	{-4.906}	{-0.353}
Precipitation	-1.2986***	-2.0282***	-0.5690*	0.5186	-0.3090	-0.0910
	(0.3415)	(0.2285)	(0.3046)	(0.3064)	(0.8403)	(0.7623)
	[-9.819]	[-11.118]	[-6.175]	[10.413]	[-3.573]	[-1.269]
	{-4.889}	{-5.489}	{-3.007}	{5.244}	{-1.542}	{-0.598}
Precipitation squared	2.5670***	4.4249***	0.1241	-0.9402*	1.0578	-0.8322
	(0.7921)	(0.7428)	(0.7542)	(0.4881)	(2.9361)	(1.9642)
	[28.267]	[171.318]	[0.340]	[-1.895]	[4.163]	[-1.566]
	{29.073}	{166.165}	{0.356}	{-1.994}	{3.590}	{-1.498}
Wine age	-0.0409***	-0.0246***	-0.0604***	-0.0546***	-0.0623**	-0.0433***
	(0.0072)	(0.0069)	(0.0083)	(0.0033)	(0.0223)	(0.0090)
	[-47.592]	[-34.303]	[-37.021]	[-42.199]	[-91.809]	[-42.189]
	{-24.932}	{-16.962}	{-19.800}	{-20.488}	{-45.045}	{-24.707}
Wine age squared	0.0009***	0.0005***	0.0019***	0.0007***	0.0008***	0.0012***
	(0.0001)	(0.0001)	(0.0003)	(0.0001)	(0.0002)	(0.0002)
	[18.259]	[14.508]	[10.959]	[5.724]	[26.132]	[18.823]
	{20.045}	{14.123}	{14.568}	{6.971}	{22.868}	{24.543}
Vintage trend	0.0102*	0.0022	0.1031***	-0.0491***	0.0074	0.0102
	(0.0058)	(0.0063)	(0.0286)	(0.0117)	(0.0200)	(0.0269)
	[27.057]	[5.246]	[350.883]	[-144.043]	[17.144]	[29.151]

	{6.363}	{1.506}	{36.709}	{-18.482}	{5.525}	{5.952}
Vintage trend squared	-0.0004***	-0.0002	-0.0018***	0.0001	-0.0006***	-0.0005
	(0.0001)	(0.0001)	(0.0004)	(0.0003)	(0.0001)	(0.0004)
	[-34.128]	[-11.408]	[-192.975]	[11.455]	[-39.242]	[-45.575]
	{-12.367}	{-5.136}	{-35.611}	{2.574}	{-20.443}	{-14.772}
Constant	5.9206***	5.9413***	3.9399***	6.2910***	5.1910***	4.3725***
	(0.0927)	(0.1886)	(0.5228)	(0.1408)	(0.8537)	(0.4547)
	[.]	[.]	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}	{.}	{.}
R^2	0.810	0.820	0.614	0.569	0.603	0.400
Winery fixed effects	✓	✓	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓	✓	✓
Observations	47662	30649	6123	8688	805	1350

Notes: Each column shows the results from a separate regression model for the varietal wine identified in the column header, using winery-vintage observations from all premium growing regions in California from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in parentheses are heteroskedastic robust and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * p<0.05, ** p<0.01, *** p<0.001.

Table 4 Estimated effect of degree-days indices on natural logarithm of wine prices from Wine Spectator

	(1) All varieties	(2) Cabernet Sauvignon	(3) Chardonnay	(4) Pinot Noir	(5) Merlot	(6) Zinfandel
DD <-2°C Feb-Oct	-0.0841***	-0.1022**	-0.0459	-0.1059**	-0.1947***	-0.0836***
	(0.0163)	(0.0394)	(0.0449)	(0.0519)	(0.0254)	(0.0142)
	[-0.181]	[-0.188]	[-0.085]	[-0.217]	[-0.325]	[-0.326]
	{-0.531}	{-0.672}	{-0.199}	{-0.441}	{-1.062}	{-0.830}
DD -2°C to 10°C Feb-Oct	0.0002*	0.0001	0.0003***	0.0002	0.0002	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0001)
	[3.027]	[0.751]	[5.099]	[2.460]	[2.648]	[1.254]
	{0.448}	{0.111}	{0.642}	{0.306}	{0.370}	{0.166}
DD 30°C to 35°C Apr-Jul	0.0004	-0.0002	0.0004	-0.0007	0.0001	-0.0003
	(0.0003)	(0.0006)	(0.0006)	(0.0008)	(0.0007)	(0.0005)
	[0.694]	[-0.543]	[0.490]	[-0.788]	[0.183]	[-0.511]
	{0.178}	{-0.108}	{0.124}	{-0.227}	{0.038}	{-0.103}
DD 30°C to 35°C Aug-Oct	-0.0010*	0.0008	-0.0026***	0.0006	-0.0010	0.0009
	(0.0006)	(0.0010)	(0.0007)	(0.0008)	(0.0010)	(0.0009)
	[-1.827]	[1.649]	[-4.328]	[0.887]	[-2.120]	[1.932]
	{-0.393}	{0.267}	{-0.950}	{0.238}	{-0.317}	{0.328}
DD >35°C Apr-Jul	-0.0023***	-0.0011	-0.0028	-0.0019	-0.0013	0.0002
	(0.0008)	(0.0008)	(0.0018)	(0.0013)	(0.0019)	(0.0006)
	[-0.777]	[-0.528]	[-0.685]	[-0.322]	[-0.599]	[0.102]
	{-0.537}	{-0.256}	{-0.477}	{-0.304}	{-0.315}	{0.064}

DD >35°C Aug-Oct	0.0001	-0.0006	0.0030***	0.0002	-0.0012	-0.0007
	(0.0006)	(0.0008)	(0.0011)	(0.0014)	(0.0013)	(0.0006)
	[0.050]	[-0.256]	[0.937]	[0.042]	[-0.516]	[-0.357]
	{0.036}	{-0.153}	{0.668}	{0.036}	{-0.275}	{-0.216}
Precipitation	-0.0278	-0.5061***	0.0175	0.2901**	0.1278	0.1686
	(0.0783)	(0.1168)	(0.0836)	(0.1240)	(0.1546)	(0.1057)
	[-0.354]	[-5.123]	[0.222]	[4.219]	[1.731]	[2.724]
	{-0.137}	{-1.724}	{0.078}	{1.662}	{0.595}	{0.962}
Precipitation squared	-0.0038***	-0.0016	-0.0063	-0.0305***	-0.0104***	-0.0020**
	(0.0010)	(0.0009)	(0.0046)	(0.0029)	(0.0032)	(0.0008)
	[-3.883]	[-2.732]	[-3.669]	[-20.469]	[-9.961]	[-1.703]
	{-5.855}	{-3.805}	{-1.473}	{-12.347}	{-5.928}	{-2.988}
Wine age	-0.0409***	-0.0246***	-0.0604***	-0.0546***	-0.0623**	-0.0433***
	(0.0072)	(0.0069)	(0.0083)	(0.0033)	(0.0223)	(0.0090)
	[-47.592]	[-34.303]	[-37.021]	[-42.199]	[-91.809]	[-42.189]
	{-24.932}	{-16.962}	{-19.800}	{-20.488}	{-45.045}	{-24.707}
Wine age squared	0.0009***	0.0005***	0.0019***	0.0007***	0.0008***	0.0012***
	(0.0001)	(0.0001)	(0.0003)	(0.0001)	(0.0002)	(0.0002)
	[18.259]	[14.508]	[10.959]	[5.724]	[26.132]	[18.823]
	{20.045}	{14.123}	{14.568}	{6.971}	{22.868}	{24.543}
Vintage trend	0.1066***	0.0959***	0.0189	0.0833***	0.0361**	0.0874***
	(0.0071)	(0.0083)	(0.0222)	(0.0130)	(0.0174)	(0.0172)
	[190.387]	[169.603]	[31.307]	[163.592]	[49.716]	[145.618]

	{12.548}	{16.618}	{0.842}	{4.954}	{2.246}	{8.568}
Vintage trend squared	-0.0030***	-0.0022***	-0.0006	-0.0023***	-0.0010*	-0.0024***
	(0.0002)	(0.0002)	(0.0007)	(0.0004)	(0.0006)	(0.0005)
	[-105.556]	[-76.557]	[-19.943]	[-91.131]	[-24.076]	[-74.963]
	{-10.368}	{-10.760}	{-0.964}	{-4.980}	{-1.846}	{-6.125}
Constant	3.6801***	3.6992***	3.4375***	3.1539***	3.3007***	3.1529***
	(0.0517)	(0.0759)	(0.0792)	(0.0802)	(0.1014)	(0.0774)
	[.]	[.]	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}	{.}	{.}
R^2	0.802	0.784	0.808	0.720	0.823	0.734
Winery fixed effects	✓	✓	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓	✓	✓
Observations	44570	12609	10020	12253	3350	5311

Notes: Each column shows the results from a separate regression model for the varietal wine identified in the column header, using winery-vintage observations from all premium growing regions in California from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in parentheses are heteroskedastic robust and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * p<0.05, ** p<0.01, *** p<0.001.

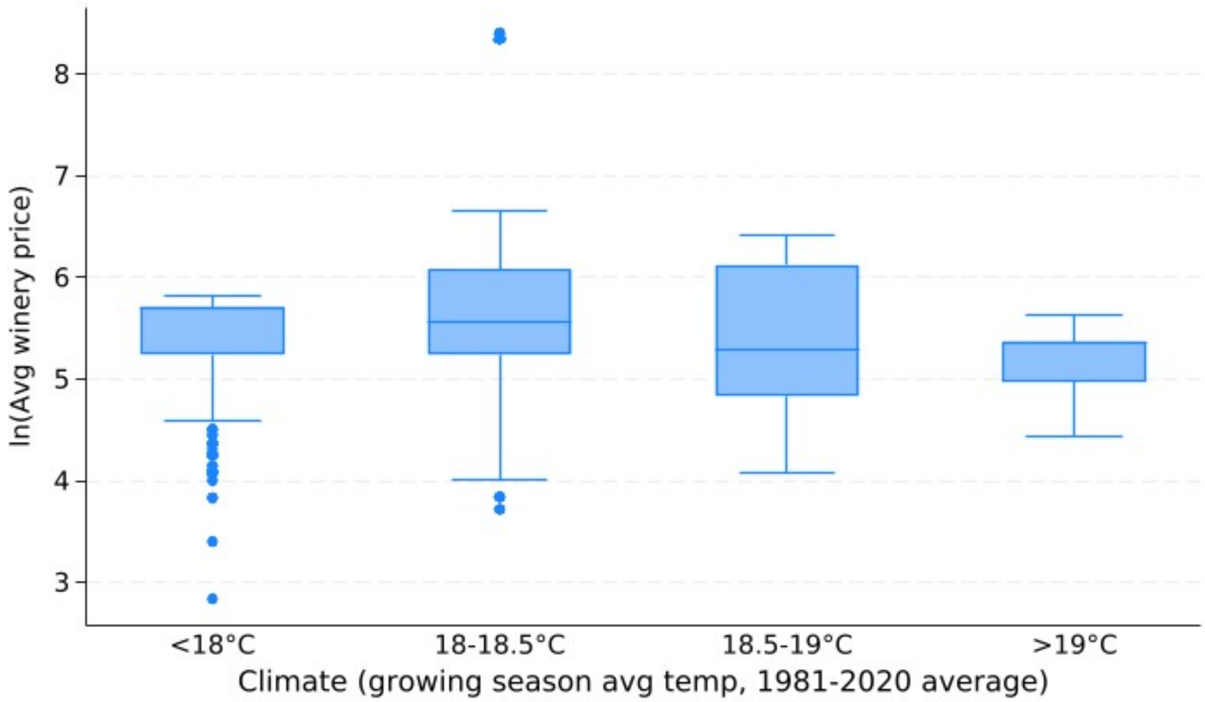


Figure 8 Distribution of winery-by-region fixed effects for Cabernet Sauvignon prices by regional climate

Notes: Winery-by-region fixed effects from the regression of K&L Cabernet Sauvignon prices against growing season average temperature, 1981–2020 average. Includes linear and quadratic vintage year trend, year of publication fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. Each fixed effect is weighted by the number of observations from that combination of winery and region.

Table 5 Estimated effect of degree-days indices on natural logarithm of wine scores from Wine Spectator

	(1) All varieties	(2) Cabernet Sauvignon	(3) Chardonnay	(4) Pinot Noir	(5) Merlot	(6) Zinfandel
DD <-2°C Feb-Oct	-0.0062*	-0.0086	-0.0007	-0.0122	-0.0079***	-0.0021
	(0.0033)	(0.0054)	(0.0079)	(0.0128)	(0.0029)	(0.0015)
	[-0.014]	[-0.017]	[-0.001]	[-0.026]	[-0.014]	[-0.009]
	{-0.040}	{-0.059}	{-0.003}	{-0.053}	{-0.047}	{-0.022}
DD -2°C to 10°C Feb-Oct	-0.0001***	-0.0001***	-0.0000**	-0.0000	-0.0001***	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	[-0.836]	[-1.320]	[-0.599]	[-0.199]	[-1.057]	[0.044]
	{-0.124}	{-0.195}	{-0.075}	{-0.025}	{-0.148}	{0.006}
DD 30°C to 35°C Apr-Jul	0.0001***	0.0002*	0.0001	-0.0001	0.0000	0.0003**
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	[0.234]	[0.431]	[0.127]	[-0.127]	[0.065]	[0.694]
	{0.060}	{0.086}	{0.032}	{-0.036}	{0.014}	{0.140}
DD 30°C to 35°C Aug-Oct	-0.0001*	-0.0002*	0.0000	0.0002	-0.0002	-0.0002**
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
	[-0.196]	[-0.518]	[0.061]	[0.276]	[-0.457]	[-0.532]
	{-0.042}	{-0.084}	{0.013}	{0.074}	{-0.068}	{-0.090}
DD >35°C Apr-Jul	-0.0003***	-0.0006***	-0.0002	0.0000	0.0006**	-0.0001
	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0002)
	[-0.093]	[-0.273]	[-0.042]	[0.002]	[0.272]	[-0.061]

	{-0.064}	{-0.133}	{-0.029}	{0.002}	{0.143}	{-0.038}
DD >35°C Aug-Oct	-0.0003**	-0.0003**	-0.0004**	-0.0001	-0.0006**	-0.0001
	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
	[-0.093]	[-0.139]	[-0.118]	[-0.015]	[-0.263]	[-0.033]
	{-0.066}	{-0.084}	{-0.084}	{-0.013}	{-0.141}	{-0.020}
Precipitation	-0.0380*	-0.1446***	-0.0276**	0.0167	-0.0542*	0.0159
	(0.0198)	(0.0228)	(0.0132)	(0.0131)	(0.0311)	(0.0269)
	[-0.482]	[-1.736]	[-0.342]	[0.210]	[-0.670]	[0.238]
	{-0.187}	{-0.584}	{-0.120}	{0.083}	{-0.230}	{0.084}
Precipitation squared	0.0710*	0.3507***	0.0560	0.0066	0.0603	-0.0737
	(0.0374)	(0.0798)	(0.0390)	(0.0284)	(0.0910)	(0.0574)
	[0.165]	[0.877]	[0.122]	[0.015]	[0.129]	[-0.206]
	{0.140}	{0.590}	{0.096}	{0.014}	{0.092}	{-0.160}
Wine age	0.0015*	-0.0000	0.0081**	0.0065***	0.0010	-0.0008
	(0.0008)	(0.0003)	(0.0033)	(0.0014)	(0.0020)	(0.0019)
	[0.422]	[-0.013]	[1.892]	[1.619]	[0.297]	[-0.221]
	{0.163}	{-0.006}	{0.358}	{0.370}	{0.060}	{-0.076}
Wine age squared	-0.0000	0.0001***	-0.0010	-0.0005***	0.0002	0.0001
	(0.0001)	(0.0000)	(0.0006)	(0.0002)	(0.0002)	(0.0001)
	[-0.013]	[0.137]	[-0.570]	[-0.355]	[0.150]	[0.089]
	{-0.020}	{0.190}	{-0.229}	{-0.214}	{0.089}	{0.155}
Vintage trend	0.0026***	0.0013**	-0.0016	0.0049***	-0.0006	0.0047**
	(0.0007)	(0.0005)	(0.0012)	(0.0014)	(0.0025)	(0.0019)

	[4.432]	[2.243]	[-2.665]	[9.266]	[-0.753]	[7.505]
	{0.292}	{0.220}	{-0.072}	{0.281}	{-0.034}	{0.442}
Vintage trend squared	-0.0000	0.0000	0.0001**	-0.0001**	0.0001	-0.0001*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0001)
	[-1.207]	[0.421]	[2.737]	[-3.628]	[2.028]	[-3.635]
	{-0.119}	{0.059}	{0.132}	{-0.198}	{0.155}	{-0.297}
Constant	4.4687***	4.5042***	4.4664***	4.4341***	4.4572***	4.4518***
	(0.0081)	(0.0056)	(0.0062)	(0.0077)	(0.0118)	(0.0059)
	[.]	[.]	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}	{.}	{.}
R^2	0.498	0.548	0.561	0.503	0.566	0.496
Winery fixed effects	✓	✓	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓	✓	✓
Observations	44570	12609	10020	12253	3350	5311

Notes: Each column shows the results from a separate regression model for the varietal wine identified in the column header, using winery-vintage observations from all premium growing regions in California from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in parentheses are heteroskedastic robust and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * p<0.05, ** p<0.01, *** p<0.001.

Table 6 Estimated effect of degree-days indices on natural logarithm of cases made from Wine Spectator

	(1) All varieties	(2) Cabernet Sauvignon	(3) Chardonnay	(4) Pinot Noir	(5) Merlot	(6) Zinfandel
DD <-2°C Feb-Oct	0.2745***	0.4051***	0.0078	0.2045	0.8959***	0.1918***
	(0.0347)	(0.0835)	(0.2059)	(0.1701)	(0.0652)	(0.0629)
	[0.708]	[0.967]	[0.015]	[0.490]	[2.664]	[0.860]
	{2.079}	{3.456}	{0.035}	{0.996}	{8.703}	{2.187}
DD -2°C to 10°C Feb-Oct	-0.0006*	-0.0004	-0.0008*	0.0003	-0.0022***	-0.0012**
	(0.0003)	(0.0003)	(0.0005)	(0.0009)	(0.0006)	(0.0005)
	[-8.162]	[-5.824]	[-11.701]	[5.267]	[-32.228]	[-19.468]
	{-1.208}	{-0.860}	{-1.473}	{0.654}	{-4.498}	{-2.573}
DD 30°C to 35°C Apr-Jul	0.0018	0.0008	0.0017	0.0066*	-0.0020	0.0036**
	(0.0013)	(0.0017)	(0.0033)	(0.0039)	(0.0033)	(0.0016)
	[3.072]	[1.756]	[2.355]	[7.321]	[-3.881]	[7.445]
	{0.789}	{0.350}	{0.598}	{2.109}	{-0.817}	{1.497}
DD 30°C to 35°C Aug-Oct	-0.0029**	-0.0049*	0.0003	-0.0071*	-0.0103*	-0.0077*
	(0.0014)	(0.0028)	(0.0034)	(0.0039)	(0.0052)	(0.0041)
	[-5.255]	[-10.552]	[0.466]	[-9.813]	[-21.629]	[-16.782]
	{-1.130}	{-1.710}	{0.102}	{-2.634}	{-3.239}	{-2.846}
DD >35°C Apr-Jul	0.0027	-0.0014	0.0047	0.0163***	0.0075	0.0016
	(0.0024)	(0.0030)	(0.0048)	(0.0044)	(0.0053)	(0.0023)
	[0.918]	[-0.665]	[1.143]	[2.759]	[3.412]	[0.805]
	{0.634}	{-0.323}	{0.795}	{2.603}	{1.796}	{0.502}

DD >35°C Aug-Oct	-0.0052*	-0.0107***	-0.0131**	0.0024	-0.0121*	0.0029
	(0.0030)	(0.0033)	(0.0052)	(0.0039)	(0.0062)	(0.0024)
	[-1.836]	[-4.387]	[-4.058]	[0.569]	[-5.174]	[1.437]
	{-1.311}	{-2.633}	{-2.896}	{0.481}	{-2.763}	{0.868}
Precipitation	0.1324	1.3713***	-0.4083	-0.3609	0.1278	-0.7441
	(0.2189)	(0.4584)	(0.3910)	(0.5106)	(0.6622)	(0.5846)
	[1.832]	[37.928]	[-4.209]	[-3.797]	[1.731]	[-7.782]
	{0.709}	{12.766}	{-1.477}	{-1.496}	{0.595}	{-2.749}
Precipitation squared	-0.9112*	-3.7642**	-0.1763	0.3942	-0.3994	0.2459
	(0.5292)	(1.8620)	(0.8590)	(1.0661)	(1.7304)	(1.3041)
	[-1.338]	[-2.038]	[-0.343]	[1.086]	[-0.683]	[0.808]
	{-1.140}	{-1.371}	{-0.270}	{1.025}	{-0.489}	{0.628}
Wine age	-0.2677***	-0.2517***	-0.7081***	-0.1307***	-0.4074***	-0.0517*
	(0.0206)	(0.0275)	(0.1019)	(0.0443)	(0.0756)	(0.0278)
	[-67.829]	[-83.406]	[-118.532]	[-30.598]	[-100.515]	[-13.723]
	{-26.207}	{-36.723}	{-22.445}	{-6.986}	{-20.428}	{-4.726}
Wine age squared	0.0143***	0.0124***	0.0593***	-0.0014	0.0287***	-0.0003
	(0.0016)	(0.0021)	(0.0218)	(0.0041)	(0.0076)	(0.0014)
	[14.587]	[21.944]	[35.652]	[-0.924]	[28.040]	[-0.219]
	{21.995}	{30.568}	{14.309}	{-0.558}	{16.687}	{-0.383}
Vintage trend	-0.0232	-0.0110	-0.0078	-0.0701	0.1408	-0.1947***
	(0.0217)	(0.0151)	(0.1163)	(0.0580)	(0.0910)	(0.0292)
	[-38.778]	[-18.399]	[-12.792]	[-127.555]	[204.312]	[-282.077]

	{-2.556}	{-1.803}	{-0.344}	{-3.862}	{9.230}	{-16.598}
Vintage trend squared	0.0008	-0.0000	0.0008	0.0021	-0.0045	0.0056***
	(0.0007)	(0.0003)	(0.0037)	(0.0019)	(0.0030)	(0.0010)
	[27.734]	[-0.539]	[28.244]	[86.810]	[-107.766]	[175.479]
	{2.724}	{-0.076}	{1.365}	{4.744}	{-8.262}	{14.339}
Constant	7.7615***	7.8991***	8.5619***	6.6629***	8.5768***	7.3809***
	(0.1076)	(0.1273)	(0.2772)	(0.3549)	(0.4322)	(0.2381)
	[.]	[.]	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}	{.}	{.}
R^2	0.630	0.688	0.663	0.574	0.728	0.640
Winery fixed effects	✓	✓	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓	✓	✓
Observations	43600	12339	9744	12036	3250	5201

Notes: Each column shows the results from a separate regression model for the varietal wine identified in the column header, using winery-vintage observations from all premium growing regions in California from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in parentheses are heteroskedastic robust and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * p<0.05, ** p<0.01, *** p<0.001.

Table 7 Observed and projected (EC Earth3 SSP2-4.5) average temperature and degree day variables in Napa Valley AVA

Variable		2001–2010	2011–2020	2041–2050	2091–2100
Average temp °C	Apr-Oct	18.1	18.6	20.1	21.8
DD < –2°C	Apr-Oct	0.007	0.02	0.04	0.04
DD –2°C to 10°C	Apr-Oct	147	127	113	63
DD 30°C to 35°C	Apr-Jul	21	25	38	49
DD 30°C to 35°C	Aug-Oct	21	23	41	48
DD > 35°C	Apr-Jul	5	4	14	22
DD > 35°C	Aug-Oct	4	5	16	28

Notes: Observed and projected temperatures and degree-day variables in Napa Valley AVA, simple average across vintages. Projected temperatures came from global climate model EC-Earth3 for emissions scenario SSP2-4.5.

Table 8 Estimated percentage change in Cabernet Sauvignon prices relative to 2001–2010 caused by observed and projected changes in degree days in Napa Valley AVA

Variable		2001–2010	2011–2020	2041–2050	2091–2100
				percentage change	
DD < –2°C	Apr–Oct		-0.1	-0.3	-0.3
DD –2°C to 10°C	Apr–Oct		1.2	2.0	5.0
DD 30°C to 35°C	Apr–Jul		-0.5	-2.2	-3.6
DD 30°C to 35°C	Aug–Oct		-1.2	-11.8	-15.9
DD > 35°C	Apr–Jul		0.8	-7.6	-14.3
DD > 35°C	Aug–Oct		-0.5	-6.0	-12.0
Total change in price %			-0.3	-25.9	-41.1

Notes: Estimated effect of changing temperatures (measured in degree-days) on Cabernet Sauvignon prices by midcentury and end of century, assuming no additional adaptation. Projected temperatures came from global climate model EC-Earth3 for emissions scenario SSP2-4.5.

Table 9 Observed temperature in Napa Valley AVA and Fresno County, 1981–2020

Variable		Napa Valley AVA	Fresno County
Average temp °C	Apr–Oct	18.4	21.9
DD < –2°C	Apr–Oct	0.04	0.02
DD –2°C to 10°C	Apr–Oct	134	96
DD 30°C to 35°C	Apr–Jul	23	58
DD 30°C to 35°C	Aug–Oct	22	52
DD > 35°C	Apr–Jul	5	23
DD > 35°C	Aug–Oct	4	16

Notes: Observed temperatures in Napa Valley AVA and Fresno County, 1981–2020, simple average across vintages.

7. Appendix

7.1. Results using growing season average temperature

We estimated the following model on K&L prices which replicates Equation (2) but replaces degree day variables with a conventional measure of temperature: a quadratic function of growing season average temperature (April to October).

$$ln(Price_{wrvt}) = \alpha_{wr} + \beta_1 tavg_{rv} + \beta_2 tavg_{rv}^2 + \rho_1 ppt_{rv} + \rho_2 ppt_{rv}^2 + \delta_1 \, wine \; age_{wrvt} + \delta_2 wine \; age_{wrvt}^2 + \theta_1 v + \theta_2 v^2 + \psi_t + \epsilon_{wrvt} \tag{3}$$

We do not detect a statistically significant relationship between growing season average temperature and K&L wine prices. Even if the relationship were significant, the direction of the results is unintuitive—hotter vintages are associated with higher prices.

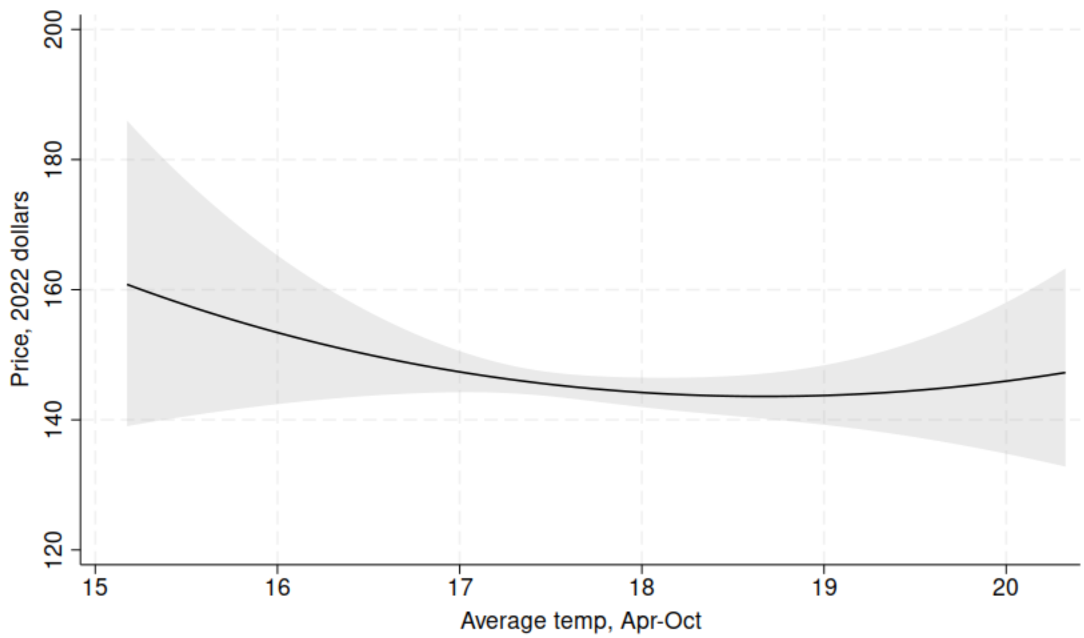


Figure 9 Estimated effect of growing season average temperature (April–October) on natural logarithm of wine prices from K&L

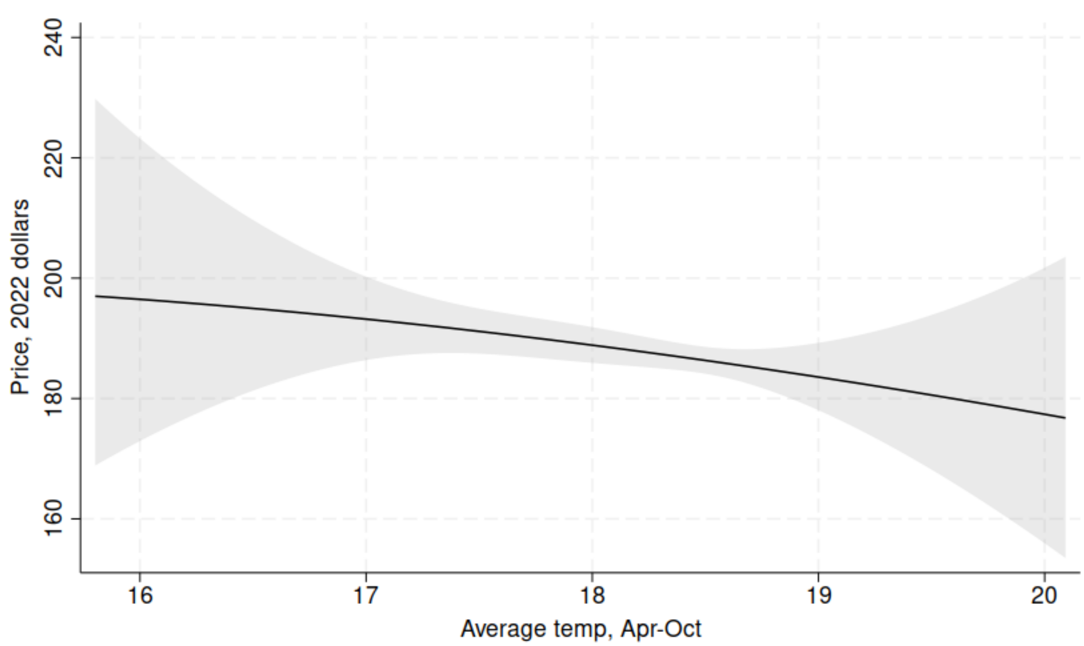


Figure 10 Estimated effect of growing season average temperature (April–October) on natural logarithm of wine prices from K&L, Cabernet Sauvignon

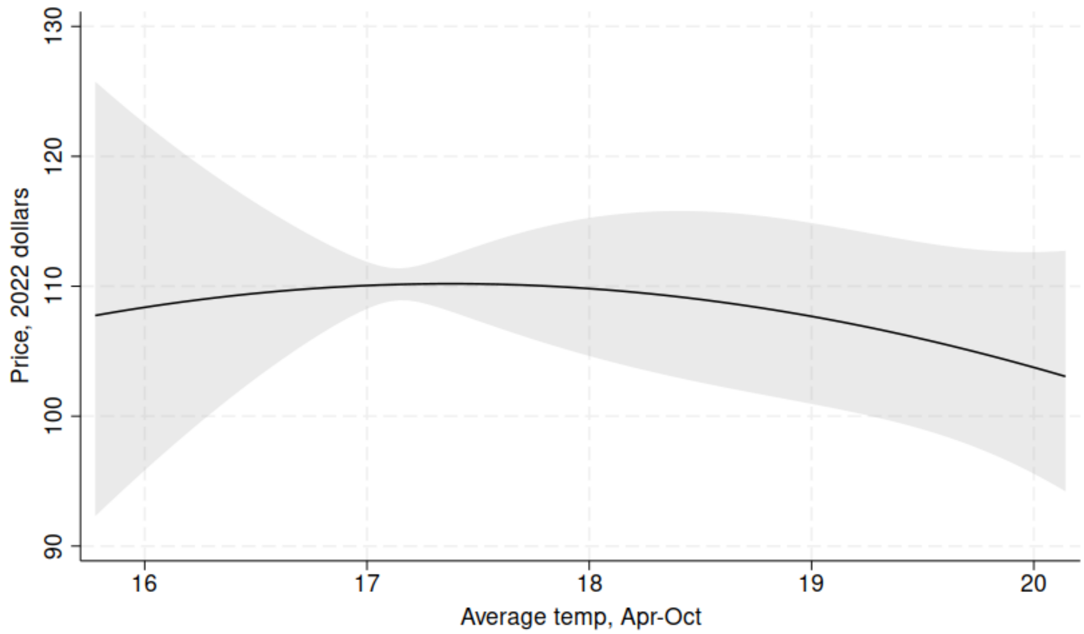


Figure 11 Estimated effect of growing season average temperature (April–October) on natural logarithm of wine prices from K&L, Chardonnay

Table 10 Estimated effect of growing season average temperature (April–October) on natural logarithm of wine prices from K&L

	(1) All varieties	(2) Cabernet Sauvignon	(3) Chardonnay
Growing season avg temp, Apr-Oct	-0.3430	0.0784	0.3016
	(0.3221)	(0.5946)	(0.5124)
Growing season avg temp, Apr-Oct squared	0.0092	-0.0029	-0.0087
	(0.0089)	(0.0165)	(0.0139)
Precipitation	-1.0406***	-1.6947***	-0.2640
	(0.3201)	(0.1638)	(0.4093)
Precipitation squared	1.5506**	3.0423***	-0.6241
	(0.5738)	(0.3757)	(0.6304)
Wine age	-0.0458***	-0.0221***	-0.1724***
	(0.0083)	(0.0060)	(0.0251)
Wine age squared	0.0008***	0.0005***	0.0020***
	(0.0001)	(0.0001)	(0.0003)
Vintage trend	0.0000	0.0000	0.0000
	(.)	(.)	(.)
Vintage trend squared	-0.0003**	-0.0001	-0.0019***
	(0.0001)	(0.0001)	(0.0003)
Constant	8.9087***	5.1343	5.1522
	(2.8118)	(5.4071)	(4.8383)
R^2	0.808	0.817	0.604
Winery fixed effects	✓	✓	✓
Issue year fixed effects	✓	✓	✓
Observations	47662	30649	6123

Notes: Each column shows the results from a separate regression model for the varietal wine identified in the column header, using winery-vintage observations from all premium growing regions in California from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the

natural logarithm of wine prices. Standard errors for the reported estimates in parentheses are heteroskedastic robust and clustered by region. Significance: * p<0.05, ** p<0.01, *** p<0.001.

7.2. Wine Spectator website

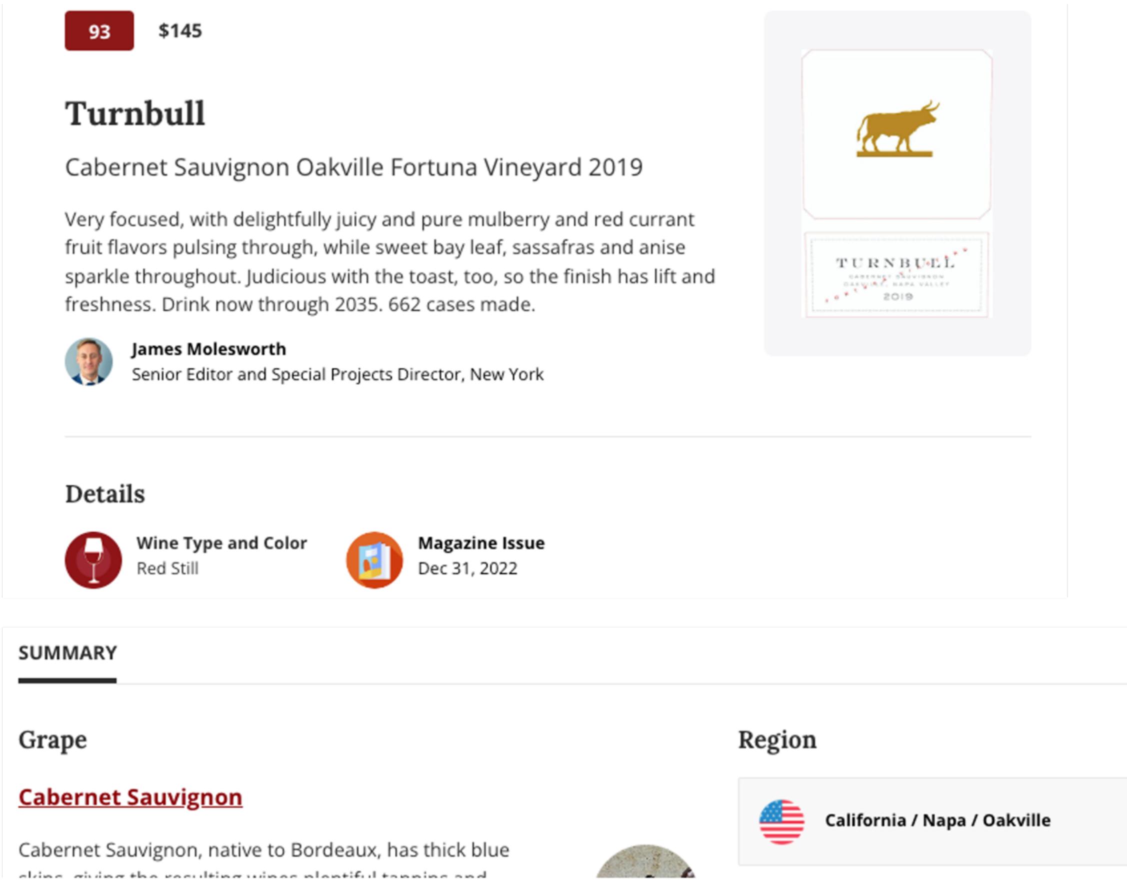
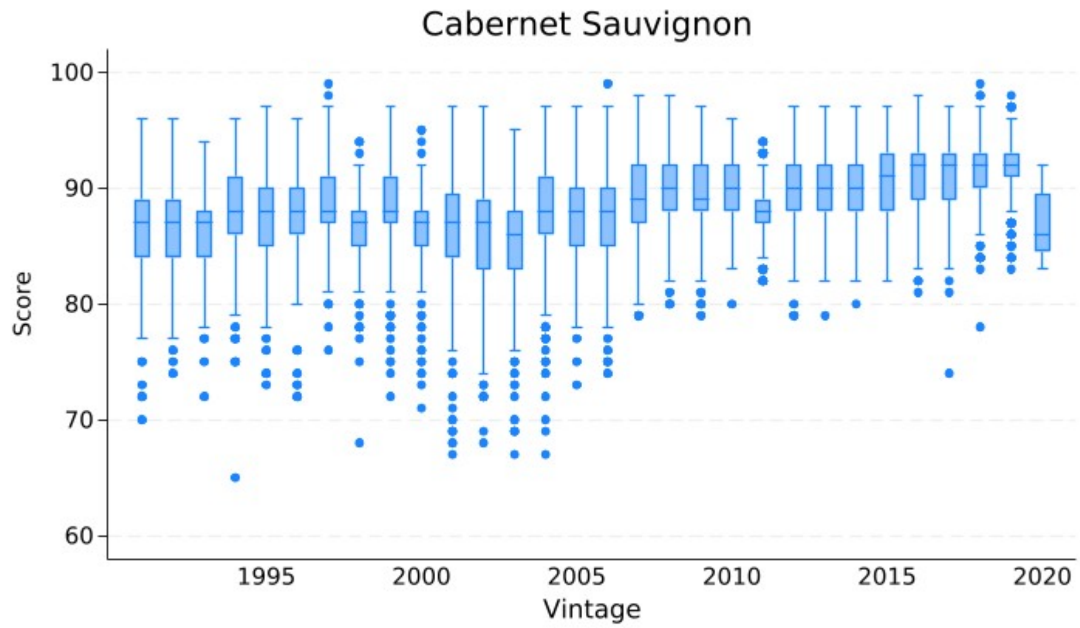
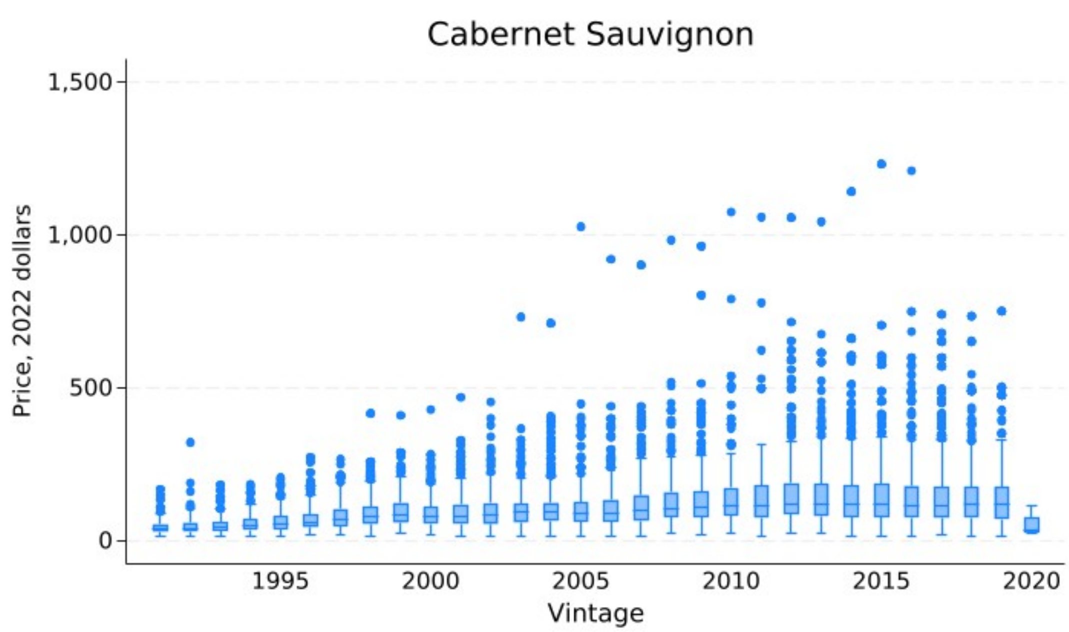


Figure 12 Example of a wine's rating on the Wine Spectator website

7.3. Scores and Prices by Vintage and Grape Variety

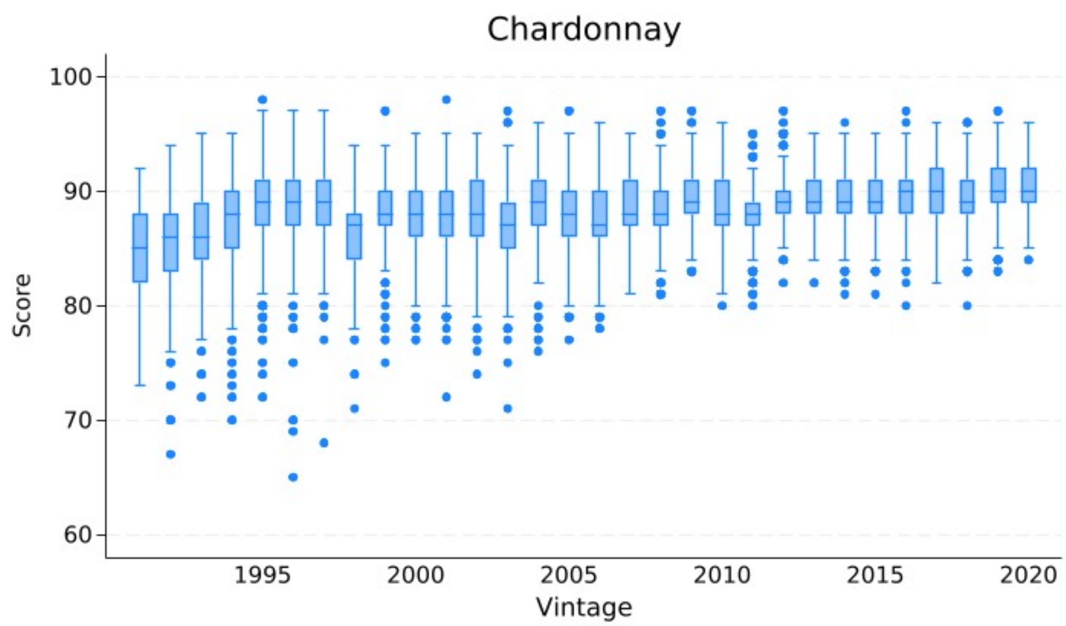


(a) Score

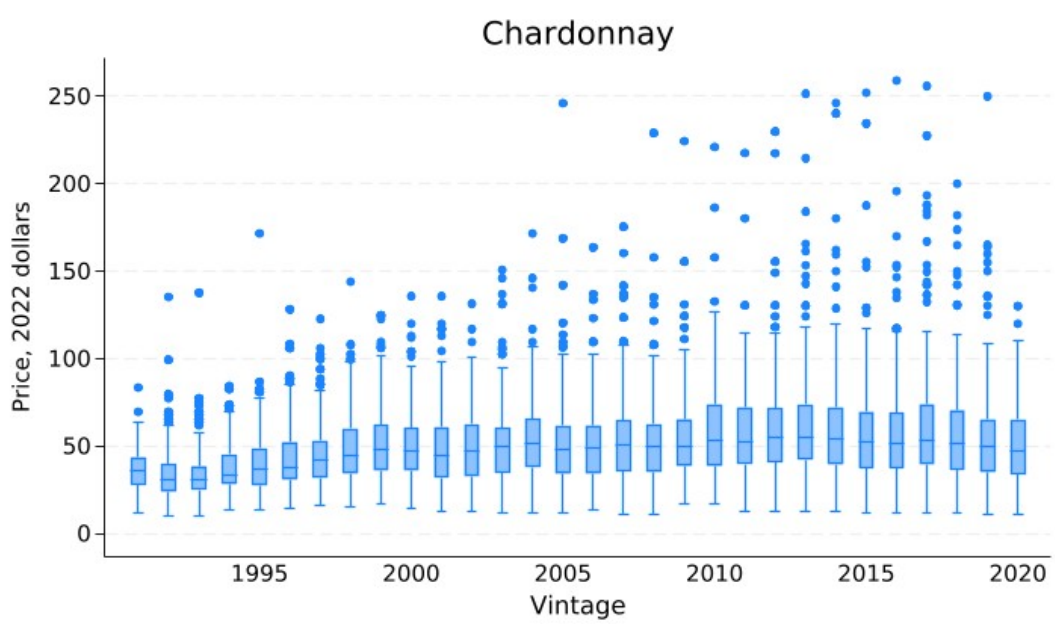


(b) Price (2022 dollars/bottle)

Figure 13 Wine scores and prices by vintage, Cabernet Sauvignon

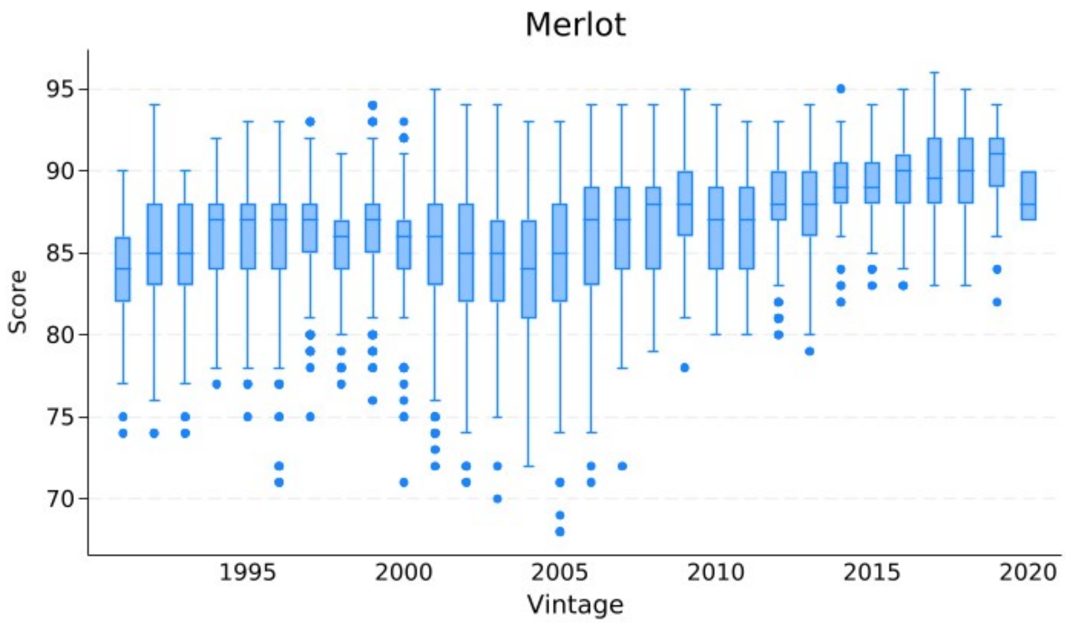


(a) Score

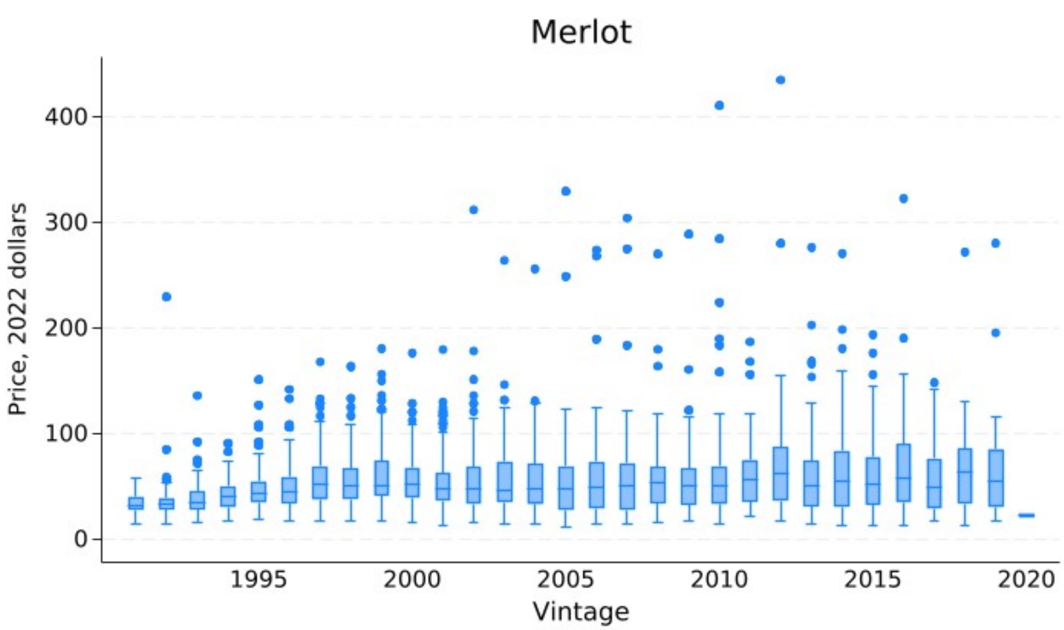


(b) Price (2022 dollars/bottle)

Figure 14 Wine scores and prices by vintage, Chardonnay

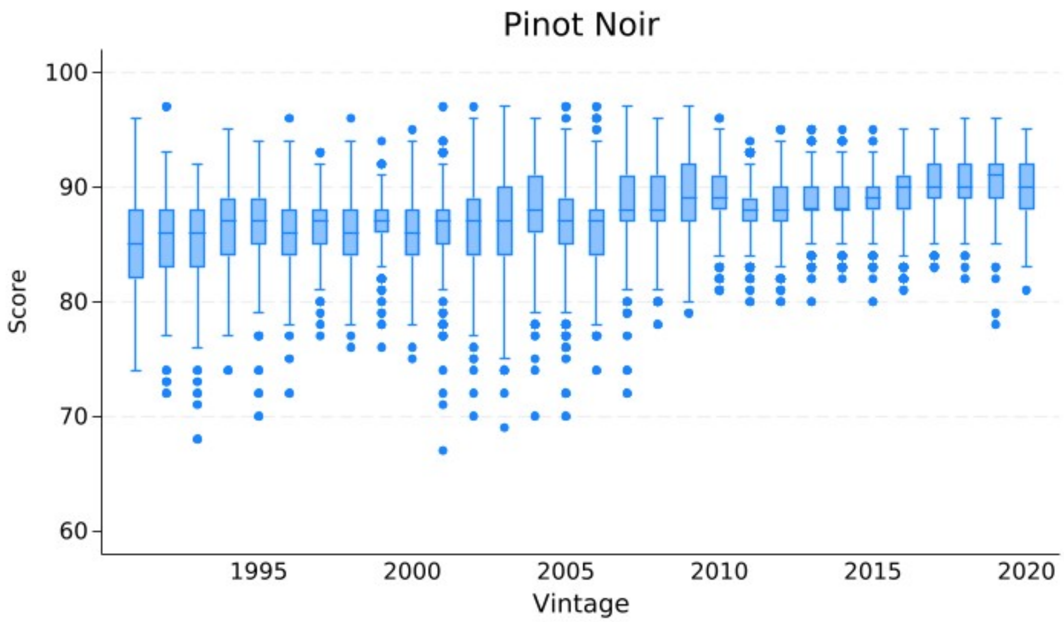


(a) Score

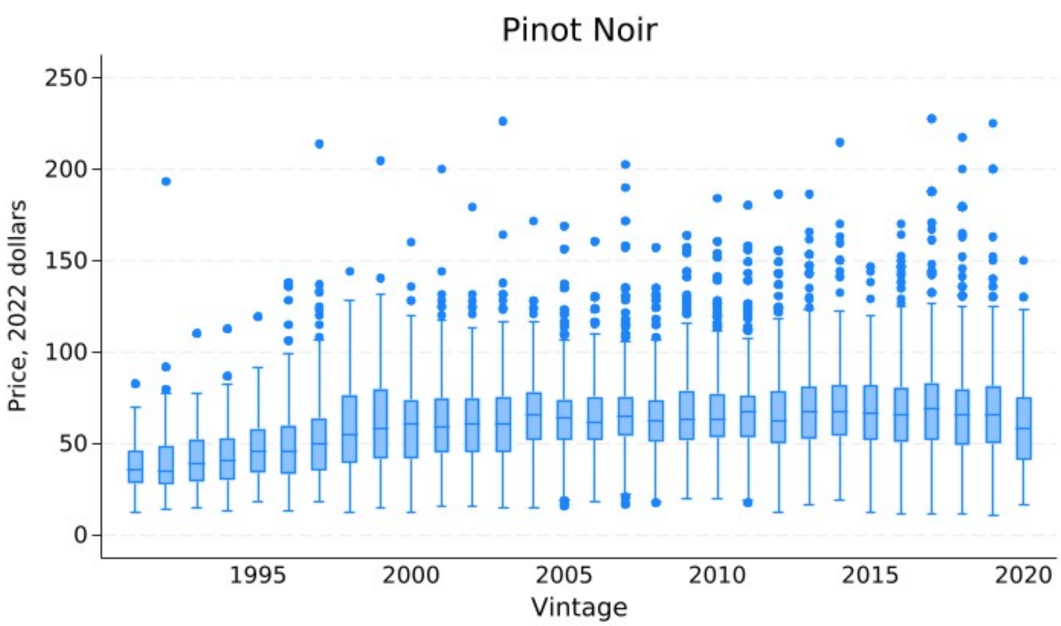


(b) Price (2022 dollars/bottle)

Figure 15 Wine scores and prices by vintage, Merlot

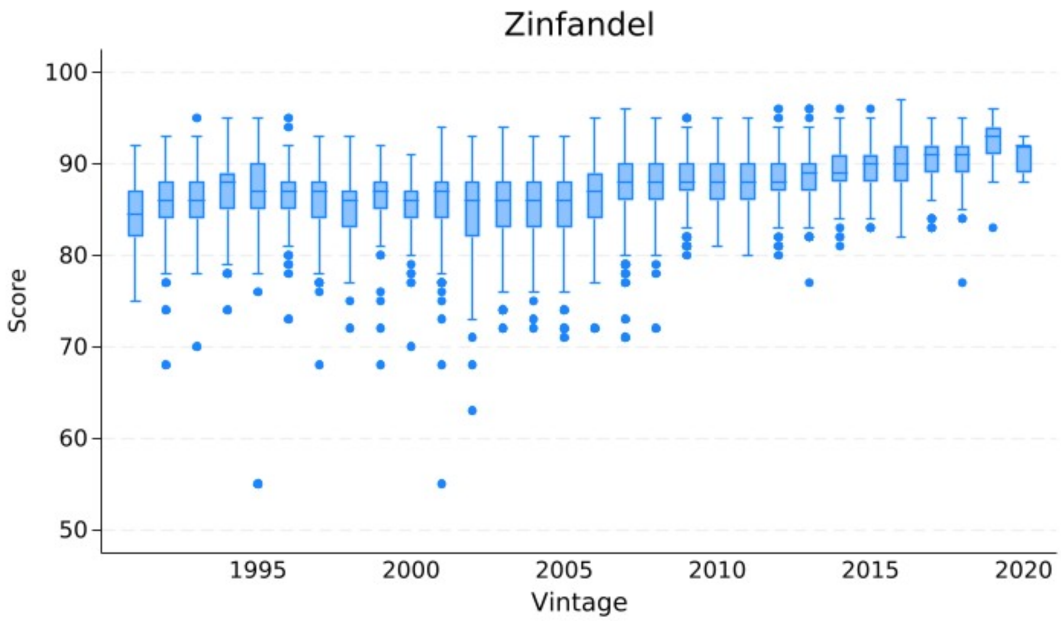


(a) Score

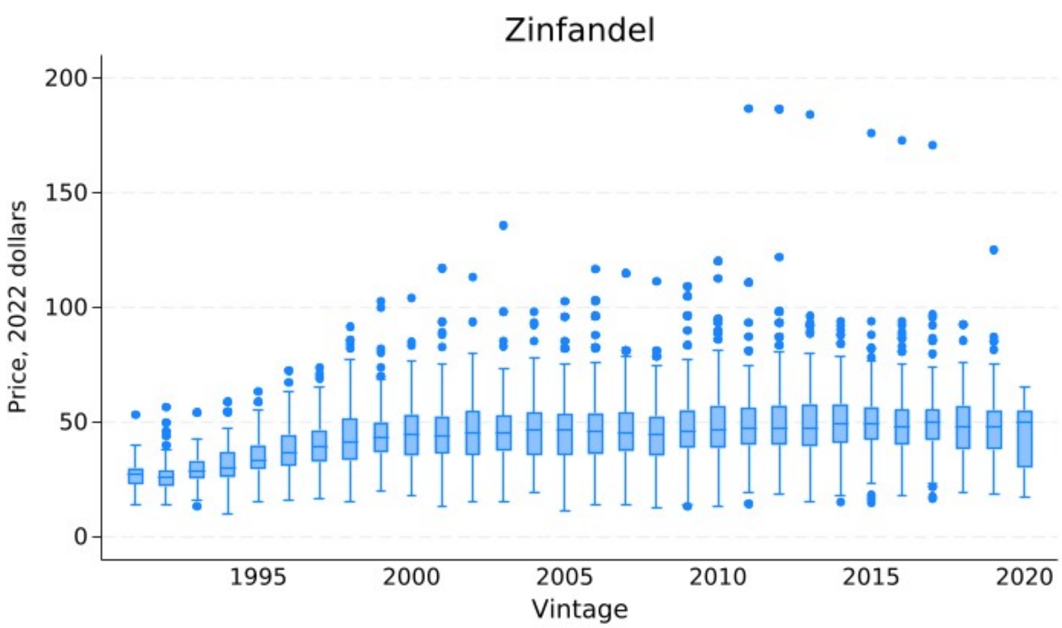


(b) Price (2022 dollars/bottle)

Figure 16 Wine scores and prices by vintage, Pinot Noir



(a) Score



(b) Price (2022 dollars/bottle)

Figure 17 Wine scores and prices by vintage, Zinfandel

7.4. Summary Statistics by Region and Grape Variety

Table 2a. Summary Statistics: All Varieties

Region	Average Temp. Apr–Oct	WS No. of Obs.	WS Average Price	WS Average Score	WS Cases Made	WS Average "Age"	K&L No. of Obs.	K&L Average Price	K&L Average "Age"
	°C	*Count*	*$/bottle*	*points*	*Average*	*Years*	*Count*	*$/bottle*	*Years*
North Coast AVAs	17.9	36,718	76.9	88.4	3,977	3.0	44,039	250.3	11.8
Napa Valley AVAs	18.4	19,238	93.6	88.5	4,433	3.3	28,363	328.3	13.7
Oakville	18.5	921	155.8	90.3	1,969	3.6	1,659	184.8	10.4
Rutherford	18.6	817	130.9	89.4	2,481	3.5	561	204.2	12.8
Howell Mountain	18.2	688	105.9	89.1	1,069	3.5	2,051	199.6	15.6
Stags Leap District	18.3	480	123.1	89.3	2,314	4.0	2,042	289.5	12.4
St Helena	19.2	378	146.4	90.5	822	3.4	175	127.6	8.4
Mt Veeder	18.4	323	99.8	89.3	1,261	3.4	45	111.6	11.0
Other NV sub-AVAs	18.8	1,141	70.7	88.2	3,752	2.7	497	113.3	7.2
Napa Valley	18.4	11,464	90.4	88.2	5,517	3.4	20,589	375.0	14.4
Sonoma Coast AVAs	17.3	15,558	59.5	88.4	3,006	2.7	15,422	109.9	8.4
Russian River Valley	17.0	6,259	59.7	88.6	2,323	2.5	4,207	90.2	7.7
Sonoma Valley	17.3	1,473	55.9	87.6	2,269	3.0	724	87.5	12.2
Dry Creek Valley	18.2	1,688	42.6	86.9	2,350	2.8	450	63.2	10.6
Alexander Valley	18.2	1,568	50.3	87.1	7,506	3.1	707	77.0	16.4
Other SC sub-AVAs	18.2	1,175	74.2	89.2	3,882	2.8	1,659	133.2	7.9
Sonoma Coast	17.0	3,395	68.3	89.4	2,531	2.5	7,675	123.6	7.6
Other NC AVAs	17.7	1,922	49.6	87.1	7,269	2.6	254	65.5	8.1
Anderson Valley	17.5	1,020	62.0	88.3	1,125	2.5	144	72.4	7.9
Central Coast AVAs	17.5	7,852	52.2	87.3	6,414	2.5	3,803	171.2	12.7
Sta. Rita Hills	17.3	1,462	63.1	88.9	1,041	2.4	66	78.1	6.2
Sta. Lucia Highlands	16.8	1,319	63.5	88.8	1,732	2.3	491	91.4	6.8
Paso Robles	19.0	1,020	39.4	85.8	10,341	2.7	136	48.3	9.3
Other CC AVAs	17.5	4,051	47.8	86.7	8,889	2.5	3,110	191.1	13.9
All Coastal Regions	17.9	44,570	72.5	88.2	4,406	2.9	47,842	244.0	11.9

Notes: Summary statistics for premium growing regions in California using PRISM data for average temperature, and winery-vintage observations for Wine Spectator data for vintages between 1991 and 2020 and for K&L data for vintages between 1981 and 2020. Averages are simple averages across the relevant sample—so effectively weighted by shares of observations in sub-regions.

Table 2b. Summary Statistics: Cabernet Sauvignon

Region	Average Temp. Apr–Oct	WS No. of Obs.	WS Average Price	WS Average Score	WS Cases Made	WS Average "Age"	K&L No. of Obs.	K&L Average Price	K&L Average "Age"
	°C	*Count*	*$/bottle*	*points*	*Average*	*Years*	*Count*	*$/bottle*	*Years*
North Coast AVAs	18.4	12,087	118.0	89.0	4,618	3.8	28,311	329.6	14.1
Napa Valley AVAs	18.5	10,459	126.7	89.4	3,879	3.8	26,362	346.1	14.0
Oakville	18.5	828	166.4	90.6	1,987	3.6	1,655	185.1	10.4
Rutherford	18.6	666	144.8	89.6	2,713	3.7	550	204.6	13.0
Howell Mountain	18.2	431	133.6	89.8	1,029	3.8	1,895	210.8	15.6
Stags Leap District	18.3	396	134.2	89.7	2,491	4.2	2,042	289.5	12.4
St Helena	19.2	309	165.1	91.0	881	3.5	175	127.6	8.4
Mt Veeder	18.4	206	123.4	89.7	1,486	3.7	45	111.6	11.0
Other NV sub-AVAs	18.8	910	128.0	89.7	1,217	3.6	470	132.9	9.4
Napa Valley	18.4	6,713	117.3	89.0	5,065	3.9	19,530	390.4	14.5
Sonoma Coast AVAs	17.8	1,478	65.3	86.9	7,830	3.6	1,949	106.6	14.9
Russian River Valley	17.0	48	46.9	86.3	1,645	3.4	23	53.8	12.9
Sonoma Valley	17.3	257	69.7	87.0	3,267	3.7	128	77.0	26.5
Dry Creek Valley	18.2	192	56.7	86.2	2,822	3.5	175	84.9	11.3
Alexander Valley	18.2	751	60.3	86.6	10,419	3.6	651	80.1	17.3
Other SC sub-AVAs	18.2	230	87.5	88.6	9,945	3.6	80	80.3	20.8
Sonoma Coast	17.0	0	.	.	.	.	892	138.1	11.8
Other NC AVAs	18.1	150	31.5	85.1	24,518	3.0	0		
Anderson Valley	17.5	7	45.4	88.1	501	3.1	0		
Central Coast AVAs	17.7	724	55.0	85.6	16,366	3.3	2,525	218.2	14.5
Sta. Rita Hills	17.3	0					0		
Sta. Lucia Highlands	16.8	10	33.6	84.0	4,278	3.0	0		
Paso Robles	19.0	297	41.5	85.4	28,125	3.1	0		
Other CC AVAs	17.6	417	65.2	85.8	8,280	3.4	2,525	218.2	14.5
All Coastal Regions	18.3	12,811	114.4	88.8	5,282	3.7	30,836	320.5	14.1

Notes: Summary statistics for premium growing regions in California using PRISM data for average temperature, and winery-vintage observations for Wine Spectator data for vintages between 1991 and 2020 and for K&L data for vintages between 1981 and 2020. Averages are simple averages across the relevant sample—so effectively weighted by shares of Cabernet Sauvignon observations in sub-regions.

Table 2c. Summary Statistics: Chardonnay

Region	Average Temp. Apr–Oct	WS No. of Obs.	WS Average Price	WS Average Score	WS Cases Made	WS Average "Age"	K&L No. of Obs.	K&L Average Price.	K&L Average "Age"
	°C	*Count*	*$/bottle*	*points*	*Average*	*Years*	*Count*	*$/bottle*	*Years*
North Coast AVAs	17.5	8,033	54.1	88.6	5,955	2.3	5,993	123.1	6.3
Napa Valley AVAs	17.8	3,532	50.8	88.2	6,798	2.3	1,011	111.8	5.5
Rutherford	18.6	63	72.8	89.3	1,104	2.1	7	271.7	2.4
Howell Mountain	18.2	32	52.3	86.7	1,110	2.0	0	.	.
Stags Leap District	18.3	21	55.1	87.5	1,327	2.2	0	.	.
Mt Veeder	18.4	37	59.6	89.4	1,071	2.6	0	.	.
Other NV sub-AVAs	18.5	1,592	51.4	88.6	5,897	2.3	669	108.6	5.1
Napa Valley	18.4	1,787	49.2	87.8	8,087	2.2	335	115.0	6.2
Sonoma Coast AVAs	17.3	4,217	58.1	89.1	4,124	2.4	4,978	125.5	6.4
Russian River Valley	17.0	2,095	54.5	88.9	3,510	2.4	1,023	106.4	6.3
Sonoma Valley	17.3	333	57.7	88.6	3,052	2.5	381	108.4	8.4
Dry Creek Valley	18.2	81	30.3	86.0	4,079	2.3	0	.	.
Alexander Valley	18.2	265	42.2	88.4	8,310	2.4	0	.	.
Knights Valley	18.7	87	110.1	91.1	1,289	2.3	1,207	138.9	7.3
Other SC sub-AVAs	18.4	307	67.7	90.0	5,331	2.5	146	80.2	8.5
Sonoma Coast	17.0	1,049	64.4	89.8	4,520	2.5	2,221	132.9	5.6
Other NC AVAs	18.0	284	35.3	86.7	22,652	2.2	4	66.2	4.2
Anderson Valley	17.5	102	41.5	87.4	1,318	2.4	3	73.2	4.3
Central Coast AVAs	17.4	2,280	42.1	87.6	10,189	2.3	146	56.1	7.8
Santa Cruz Mnts	17.5	196	48.7	88.4	1,426	2.5	124	60.1	7.6
Sta. Rita Hills	17.3	330	51.7	88.8	1,340	2.4	2	67.5	6.0
Sta. Lucia Highlands	16.8	264	49.6	88.8	3,595	2.2	10	24.4	8.5
Paso Robles	19.0	51	25.8	82.6	4,327	1.9	0	.	.
Other CC AVAs	17.5	1,439	38.2	87.2	14,829	2.3	10	35.0	10.4
All Coastal Regions	17.5	10,313	51.4	88.4	6,891	2.3	6,139	121.5	6.3

Notes: Summary statistics for premium growing regions in California using PRISM data for average temperature, and winery-vintage observations for Wine Spectator data for vintages between 1991 and 2020 and for K&L data for vintages between 1981 and 2020. Averages are simple averages across the relevant sample—so effectively weighted by shares of Chardonnay observations in sub-regions.

7.5. Results by Region and Grape Variety

Table 3a. Estimated effect of degree days indices on natural logarithm of wine prices from K&L by region, Cabernet Sauvignon

	(1) All regions	(2) Napa AVAs	(3) Sonoma AVAs	(4) Central Coast AVAs
DD <-2°C Feb-Oct	-0.0928*	-0.1007***	-0.0656	-0.1090
	(0.0490)	(0.0203)	(0.0449)	(0.0933)
	[-0.171]	[-0.184]	[-0.212]	[-0.097]
	{-1.053}	{-1.098}	{-1.263}	{-0.738}
DD -2°C to 10°C Feb-Oct	-0.0006***	-0.0006***	0.0001	-0.0009***
	(0.0001)	(0.0001)	(0.0003)	(0.0002)
	[-8.902]	[-8.831]	[1.254]	[-12.623]
	{-2.037}	{-2.003}	{0.243}	{-3.371}
DD 30°C to 35°C Apr-Jul	-0.0007	-0.0013**	-0.0003	0.0154***
	(0.0007)	(0.0005)	(0.0023)	(0.0022)
	[-1.311]	[-2.696]	[-0.549]	[17.109]
	{-0.388}	{-0.779}	{-0.157}	{7.127}
DD 30°C to 35°C Aug-Oct	-0.0062***	-0.0059***	-0.0141***	-0.0090***
	(0.0009)	(0.0007)	(0.0025)	(0.0024)
	[-12.089]	[-11.936]	[-24.353]	[-12.233]
	{-2.819}	{-2.681}	{-6.053}	{-4.258}
DD >35°C Apr-Jul	-0.0089***	-0.0084***	-0.0110**	-0.0318***
	(0.0018)	(0.0011)	(0.0052)	(0.0049)
	[-3.543]	[-3.570]	[-3.053]	[-6.271]
	{-2.354}	{-2.261}	{-2.258}	{-7.643}
DD >35°C Aug-Oct	-0.0056***	-0.0050***	0.0097*	-0.0019
	(0.0020)	(0.0013)	(0.0053)	(0.0049)
	[-1.795]	[-1.669]	[2.649]	[-0.474]
	{-1.268}	{-1.150}	{2.015}	{-0.427}
Precipitation	-2.0282***	-2.1282***	0.2547	-3.6476***

	(0.2285)	(0.1295)	(0.5097)	(0.4509)
	[-11.118]	[-11.087]	[4.351]	[-13.016]
	{-5.489}	{-5.480}	{1.882}	{-6.935}
Precipitation squared	4.4249***	4.7157***	-1.5620	9.2921***
	(0.7428)	(0.4195)	(1.3410)	(1.4797)
	[171.318]	[221.913]	[-2.173]	[25039.115]
	{166.165}	{216.517}	{-1.961}	{23696.590}
Wine age	-0.0246***	-0.0299***	-0.0360***	0.0502***
	(0.0069)	(0.0024)	(0.0111)	(0.0079)
	[-34.303]	[-41.261]	[-52.970]	[74.723]
	{-16.962}	{-20.199}	{-19.524}	{45.056}
Wine age squared	0.0005***	0.0006***	0.0001	-0.0003*
	(0.0001)	(0.0000)	(0.0002)	(0.0001)
	[14.508]	[16.439]	[4.061]	[-7.380]
	{14.123}	{15.913}	{2.913}	{-8.541}
Vintage trend	0.0022	0.0006	-0.0523***	0.0563***
	(0.0063)	(0.0031)	(0.0116)	(0.0089)
	[5.246]	[1.467]	[-120.538]	[140.665]
	{1.506}	{0.413}	{-28.121}	{50.729}
Vintage trend squared	-0.0002	-0.0001***	0.0005**	-0.0006***
	(0.0001)	(0.0001)	(0.0002)	(0.0002)
	[-11.408]	[-9.950]	[31.253]	[-43.683]
	{-5.136}	{-4.398}	{11.807}	{-24.146}
Constant	5.9413***	6.0834***	6.1519***	4.1058***
	(0.1886)	(0.0840)	(0.3651)	(0.2513)
	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}
R^2	0.820	0.832	0.563	0.246
Winery fixed effects	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓
Observations	30649	26178	1925	2525

Notes: Each column shows the results from a separate regression model for all regions or sub-regions as identified in the column header, using winery-vintage observations for Cabernet Sauvignon from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in round parentheses are heteroskedastic robust and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 3b. Estimated effect of degree-days indices on natural logarithm of wine prices from K&L by region, Chardonnay

	(1) All regions	(2) Napa AVAs	(3) Sonoma AVAs	(4) Central Coast AVAs
DD <-2°C Feb-Oct	-0.1152	-0.4217***	0.1292	-7.6656
	(0.1828)	(0.1373)	(0.1000)	(5.4572)
	[-0.331]	[-0.987]	[0.429]	[-0.382]
	{-0.680}	{-1.969}	{0.931}	{-0.789}
DD -2°C to 10°C Feb-Oct	-0.0011**	-0.0005**	-0.0017***	-0.0013
	(0.0005)	(0.0002)	(0.0002)	(0.0013)
	[-17.224]	[-7.289]	[-25.820]	[-18.738]
	{-3.714}	{-1.544}	{-5.552}	{-4.755}
DD 30°C to 35°C Apr-Jul	0.0008	-0.0059**	-0.0027*	-0.0410**
	(0.0029)	(0.0025)	(0.0016)	(0.0167)
	[1.313]	[-8.572]	[-4.555]	[-43.765]
	{0.361}	{-2.245}	{-1.242}	{-14.608}
DD 30°C to 35°C Aug-Oct	-0.0040*	-0.0004	-0.0039***	-0.0156
	(0.0022)	(0.0021)	(0.0014)	(0.0148)
	[-6.664]	[-0.639]	[-6.963]	[-20.640]
	{-1.963}	{-0.208}	{-1.982}	{-6.768}
DD >35°C Apr-Jul	-0.0035	0.0206***	-0.0011	0.0790**
	(0.0063)	(0.0076)	(0.0035)	(0.0354)
	[-0.798]	[4.398]	[-0.273]	[12.191]
	{-0.628}	{2.965}	{-0.207}	{15.149}
DD >35°C Aug-Oct	-0.0070***	-0.0075**	-0.0069***	-0.0018
	(0.0014)	(0.0038)	(0.0025)	(0.0232)
	[-2.066]	[-1.865]	[-2.198]	[-0.520]
	{-2.068}	{-2.062}	{-2.130}	{-0.517}
Precipitation	-0.5690*	0.4732	-0.7931***	-2.8298
	(0.3046)	(0.5838)	(0.2608)	(2.1355)
	[-6.175]	[6.434]	[-8.184]	[-10.370]
	{-3.007}	{2.676}	{-4.083}	{-5.694}

Precipitation squared	0.1241	-1.7056	0.2452	8.9392
	(0.7542)	(2.3703)	(0.6782)	(7.2830)
	[0.340]	[-1.099]	[0.790]	[12967.552]
	{0.356}	{-0.894}	{0.822}	{13092.339}
Wine age	-0.0604***	-0.0489***	-0.0571***	0.0862*
	(0.0083)	(0.0098)	(0.0072)	(0.0473)
	[-37.021]	[-26.105]	[-36.098]	[70.265]
	{-19.800}	{-13.392}	{-19.747}	{35.140}
Wine age squared	0.0019***	0.0013***	0.0017***	-0.0040**
	(0.0003)	(0.0004)	(0.0003)	(0.0019)
	[10.959]	[6.069]	[10.286]	[-31.018]
	{14.568}	{8.431}	{13.613}	{-53.629}
Vintage trend	0.1031***	0.0518*	0.1064***	-0.2530*
	(0.0286)	(0.0279)	(0.0160)	(0.1346)
	[350.883]	[177.850]	[359.102]	[-709.615]
	{36.709}	{14.922}	{39.901}	{-87.285}
Vintage trend squared	-0.0018***	-0.0010**	-0.0019***	0.0041*
	(0.0004)	(0.0004)	(0.0002)	(0.0021)
	[-192.975]	[-110.599]	[-194.153]	[424.615]
	{-35.611}	{-16.034}	{-38.332}	{83.027}
Constant	3.9399***	4.4087***	4.1384***	8.3192***
	(0.5228)	(0.5207)	(0.3191)	(2.3852)
	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}
R^2	0.614	0.793	0.415	0.529
Winery fixed effects	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓
Observations	6123	1005	3952	145

Notes: Each column shows the results from a separate regression model for all regions or sub-regions as identified in the column header, using winery-vintage observations for Chardonnay from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in round parentheses are

heteroskedastic robust and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * p<0.05, ** p<0.01, *** p<0.001.

Table 3c. Estimated effect of degree-days indices on natural logarithm of wine prices from K&L by region, Pinot Noir

	(1) All regions	(2) Napa AVAs	(3) Sonoma AVAs	(4) Central Coast AVAs
DD <-2°C Feb-Oct	0.0009	-0.9783***	-0.4926***	0.0040
	(0.0308)	(0.2815)	(0.1575)	(0.0279)
	[0.003]	[-1.898]	[-0.987]	[0.037]
	{0.011}	{-5.923}	{-1.570}	{0.141}
DD -2°C to 10°C Feb-Oct	-0.0006**	-0.0024*	-0.0005***	-0.0006**
	(0.0003)	(0.0013)	(0.0002)	(0.0002)
	[-10.798]	[-36.334]	[-9.269]	[-9.551]
	{-2.022}	{-5.161}	{-1.645}	{-2.073}
DD 30°C to 35°C Apr-Jul	0.0015	0.0325**	-0.0054**	0.0013
	(0.0031)	(0.0139)	(0.0024)	(0.0024)
	[1.755]	[40.944]	[-5.868]	[1.326]
	{0.620}	{11.721}	{-2.028}	{0.583}
DD 30°C to 35°C Aug-Oct	0.0012	-0.0075	0.0089***	-0.0082***
	(0.0033)	(0.0098)	(0.0020)	(0.0018)
	[1.661]	[-10.473]	[11.352]	[-11.309]
	{0.542}	{-2.779}	{3.662}	{-4.880}
DD >35°C Apr-Jul	-0.0104*	-0.1662***	0.0036	-0.0079
	(0.0055)	(0.0487)	(0.0061)	(0.0060)
	[-1.442]	[-29.122]	[0.417]	[-1.112]
	{-1.736}	{-15.666}	{0.516}	{-1.316}
DD >35°C Aug-Oct	0.0059	0.0203	-0.0083	0.0295***
	(0.0050)	(0.0271)	(0.0051)	(0.0060)
	[1.234]	[3.301]	[-1.480]	[6.465]
	{1.169}	{3.166}	{-1.493}	{5.470}
Precipitation	0.5186	-6.0295**	1.3615***	-0.1543
	(0.3064)	(2.7371)	(0.2878)	(0.5129)
	[10.413]	[-11.232]	[46.177]	[-0.810]
	{5.244}	{-4.434}	{21.594}	{-0.434}

Precipitation squared	-0.9402*	22.2422*	-2.9510***	-2.2817
	(0.4881)	(11.0284)	(0.7587)	(2.7122)
	[-1.895]	[7.147e+09]	[-2.979]	[-0.410]
	{-1.994}	{4.888e+09}	{-2.803}	{-0.495}
Wine age	-0.0546***	-0.0501*	-0.0535***	-0.0679***
	(0.0033)	(0.0284)	(0.0063)	(0.0104)
	[-42.199]	[-73.095]	[-38.881]	[-60.283]
	{-20.488}	{-15.907}	{-18.507}	{-32.754}
Wine age squared	0.0007***	-0.0006	0.0007***	0.0006**
	(0.0001)	(0.0010)	(0.0002)	(0.0002)
	[5.724]	[-20.959]	[5.178]	[7.517]
	{6.971}	{-6.003}	{6.539}	{9.875}
Vintage trend	-0.0491***	-0.2485***	-0.0470***	-0.0665***
	(0.0117)	(0.0678)	(0.0155)	(0.0183)
	[-144.043]	[-508.367]	[-140.189]	[-187.070]
	{-18.482}	{-71.634}	{-16.310}	{-32.102}
Vintage trend squared	0.0001	0.0036***	0.0000	0.0002
	(0.0003)	(0.0012)	(0.0002)	(0.0003)
	[11.455]	[225.588]	[2.821]	[18.146]
	{2.574}	{60.857}	{0.585}	{4.749}
Constant	6.2910***	8.9804***	6.3517***	6.8219***
	(0.1408)	(1.0587)	(0.2853)	(0.4267)
	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}
R^2	0.569	0.877	0.506	0.662
Winery fixed effects	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓
Observations	8688	74	4556	938

Notes: Each column shows the results from a separate regression model for all regions or sub-regions as identified in the column header, using winery-vintage observations for Pinot Noir from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in round parentheses are

heteroskedastic robust and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 3d. Estimated effect of degree-days indices on natural logarithm of wine prices from K&L by region, Merlot

	(1) All regions	(2) Napa AVAs	(3) Sonoma AVAs	(4) Central Coast AVAs
DD <-2°C Feb-Oct	0.0007	-0.0121	-0.7396	-8945.1059
	(0.0854)	(0.0698)	(1.1642)	(8842.1582)
	[0.002]	[-0.036]	[-0.846]	[-0.537]
	{0.012}	{-0.233}	{-1.255}	{-0.701}
DD -2°C to 10°C Feb-Oct	-0.0019***	-0.0018***	-0.0006	5.4185
	(0.0003)	(0.0005)	(0.0011)	(5.3634)
	[-26.938]	[-24.298]	[-10.171]	[3522400.525]
	{-5.671}	{-5.605}	{-1.287}	{860826.055}
DD 30°C to 35°C Apr-Jul	0.0122***	0.0128***	0.0154	85.3325
	(0.0029)	(0.0035)	(0.0102)	(84.4648)
	[23.497]	[27.763]	[16.420]	[1.021e+40]
	{6.254}	{6.853}	{5.986}	{3.291e+39}
DD 30°C to 35°C Aug-Oct	0.0079	0.0057	0.0160	56.0232
	(0.0047)	(0.0041)	(0.0113)	(55.4605)
	[14.944]	[11.675]	[20.926]	[2.503e+27]
	{3.320}	{2.380}	{6.609}	{4.185e+26}
DD >35°C Apr-Jul	-0.0090	-0.0126*	0.0065	-395.0353
	(0.0052)	(0.0074)	(0.0265)	(391.1895)
	[-3.256]	[-5.343]	[0.978]	[-61.164]
	{-2.089}	{-3.150}	{0.912}	{-48.180}
DD >35°C Aug-Oct	-0.0249**	-0.0173**	-0.0762**	-5.4124
	(0.0094)	(0.0083)	(0.0330)	(5.3252)
	[-6.802]	[-5.229]	[-12.045]	[-294.618]
	{-4.906}	{-3.517}	{-10.580}	{-227.113}
Precipitation	-0.3090	0.8440	-2.0642**	-361.7118
	(0.8403)	(0.9782)	(0.9702)	(360.4574)
	[-3.573]	[16.971]	[-13.601]	[-15.465]
	{-1.542}	{6.917}	{-6.576}	{-4.547}

Precipitation squared	1.0578	-3.0969	8.0564***	0.0000
	(2.9361)	(3.1487)	(2.7993)	(.)
	[4.163]	[-1.886]	[9549.649]	[0.000]
	{3.590}	{-1.544}	{8540.386}	{0.000}
Wine age	-0.0623**	-0.0789***	0.0091	-0.0456
	(0.0223)	(0.0229)	(0.0333)	(0.1171)
	[-91.809]	[-121.904]	[11.417]	[-27.858]
	{-45.045}	{-61.540}	{3.279}	{-7.794}
Wine age squared	0.0008***	0.0010***	-0.0015	0.0043
	(0.0002)	(0.0003)	(0.0010)	(0.0081)
	[26.132]	[34.324]	[-28.554]	[20.172]
	{22.868}	{30.002}	{-13.619}	{11.120}
Vintage trend	0.0074	-0.0034	-0.2005***	0.0000
	(0.0200)	(0.0240)	(0.0674)	(.)
	[17.144]	[-7.721]	[-455.630]	[0.000]
	{5.525}	{-2.794}	{-65.317}	{0.000}
Vintage trend squared	-0.0006***	-0.0006**	0.0034***	0.0000
	(0.0001)	(0.0003)	(0.0012)	(.)
	[-39.242]	[-36.543]	[227.292]	[0.000]
	{-20.443}	{-21.211}	{65.196}	{0.000}
Constant	5.1910***	5.6474***	6.9972***	-1899.3502
	(0.8537)	(0.8780)	(1.1015)	(1883.5283)
	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}
R^2	0.603	0.606	0.397	0.879
Winery fixed effects	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓
Observations	805	628	155	20

Notes: Each column shows the results from a separate regression model for all regions or sub-regions as identified in the column header, using winery-vintage observations for Merlot from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in round parentheses are heteroskedastic robust

and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * p<0.05, ** p<0.01, *** p<0.001.

Table 3e. Estimated effect of degree-days indices on natural logarithm of wine prices from K&L by region, Zinfandel

	(1) All regions	(2) Napa AVAs	(3) Sonoma AVAs	(4) Central Coast AVAs
DD <-2°C Feb-Oct	-0.2072***	-0.2058	-0.1816	-0.1729***
	(0.0209)	(0.2149)	(0.1104)	(0.0655)
	[-1.074]	[-0.538]	[-0.370]	[-4.270]
	{-2.709}	{-1.731}	{-1.735}	{-4.902}
DD -2°C to 10°C Feb-Oct	0.0002	0.0000	0.0001	-0.0002
	(0.0004)	(0.0005)	(0.0004)	(0.0008)
	[3.148]	[0.607]	[1.303]	[-3.910]
	{0.682}	{0.147}	{0.278}	{-0.695}
DD 30°C to 35°C Apr-Jul	-0.0026	0.0006	-0.0056	0.0004
	(0.0034)	(0.0046)	(0.0037)	(0.0038)
	[-5.035]	[1.278]	[-10.341]	[1.295]
	{-1.253}	{0.321}	{-2.602}	{0.239}
DD 30°C to 35°C Aug-Oct	-0.0017	-0.0096	-0.0020	-0.0002
	(0.0022)	(0.0065)	(0.0031)	(0.0032)
	[-3.370]	[-18.501]	[-3.617]	[-0.581]
	{-0.826}	{-4.260}	{-0.899}	{-0.104}
DD >35°C Apr-Jul	0.0032	0.0112	-0.0011	0.0012
	(0.0027)	(0.0108)	(0.0059)	(0.0031)
	[1.458]	[4.429]	[-0.373]	[1.718]
	{1.175}	{2.816}	{-0.289}	{0.912}
DD >35°C Aug-Oct	-0.0011	0.0286**	0.0050	-0.0062*
	(0.0033)	(0.0134)	(0.0046)	(0.0034)
	[-0.479]	[6.850]	[1.723]	[-8.693]
	{-0.353}	{5.035}	{1.509}	{-3.495}
Precipitation	-0.0910	-1.3605	0.6842	-1.8183*
	(0.7623)	(0.9262)	(0.5566)	(1.0313)
	[-1.269]	[-10.815]	[15.016]	[-6.747]
	{-0.598}	{-4.783}	{7.256}	{-3.700}

Precipitation squared	-0.8322	2.3399	-2.4452*	3.6411
	(1.9642)	(2.5958)	(1.4641)	(4.0143)
	[-1.566]	[24.547]	[-2.718]	[37.998]
	{-1.498}	{22.254}	{-2.667}	{39.685}
Wine age	-0.0433***	-0.0719**	-0.0287**	-0.0262
	(0.0090)	(0.0288)	(0.0131)	(0.0256)
	[-42.189]	[-82.540]	[-27.766]	[-25.656]
	{-24.707}	{-41.906}	{-18.287}	{-12.090}
Wine age squared	0.0012***	0.0015***	0.0013***	0.0004
	(0.0002)	(0.0005)	(0.0003)	(0.0007)
	[18.823]	[32.477]	[19.715]	[5.260]
	{24.543}	{32.843}	{28.579}	{6.598}
Vintage trend	0.0102	-0.0060	0.0572***	-0.0605
	(0.0269)	(0.0429)	(0.0202)	(0.0564)
	[29.151]	[-15.773]	[170.209]	[-166.123]
	{5.952}	{-3.597}	{38.032}	{-27.481}
Vintage trend squared	-0.0005	-0.0004	-0.0013***	0.0008
	(0.0004)	(0.0006)	(0.0003)	(0.0009)
	[-45.575]	[-32.780]	[-120.975]	[67.222]
	{-14.772}	{-12.036}	{-40.773}	{19.069}
Constant	4.3725***	5.2365***	3.5418***	5.3083***
	(0.4547)	(1.1863)	(0.5143)	(1.0321)
	[.]	[.]	[.]	[.]
	{.}	{.}	{.}	{.}
R^2	0.400	0.483	0.386	0.483
Winery fixed effects	✓	✓	✓	✓
Issue year fixed effects	✓	✓	✓	✓
Observations	1350	276	616	172

Notes: Each column shows the results from a separate regression model for all regions or sub-regions as identified in the column header, using winery-vintage observations for Zinfandel from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. Standard errors for the reported estimates in round parentheses are heteroskedastic robust

and clustered by region. Elasticities in square brackets show the sensitivity of price to the explanatory variable. Marginal effects in curly brackets show the percent change in price caused by a one within-winery standard deviation increase in the explanatory variable. Significance: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

7.6. Testing for differences in coefficients estimates across wine varieties

Table 11 shows the estimated effect of degree days indices on the natural logarithm of wine prices from K&L (same as *Table 3*). It also shows results from testing for differences in the coefficients when the model is estimated for each wine variety individually compared with those from the full sample, including all five wines.

Coefficients on the key degree day variables estimated using Cabernet Sauvignon and Chardonnay wine prices were not significantly different from those from the model using the full sample across all five varieties. The estimates for Cabernet Sauvignon were similar in terms of magnitude and significance to those for the full sample, in part because Cabernet Sauvignon wines comprise more than 60 percent of the total K&L sample. For Chardonnay, the coefficient estimates were all of the same sign as those from the full sample model, but some estimates differed in terms of magnitude or statistically significance.

For Pinot Noir, some coefficient estimates differed in terms of magnitude and direction—for example, DD 30ºC to 35ºC Apr-Jul and DD 30ºC to 35ºC Aug-Oct and DD >35ºC Aug to Oct—but these estimates were statistically insignificant and not significantly different from those for the full sample model.

Some coefficient estimates for Merlot and Zinfandel were statistically significantly different from those estimated on the full sample. The results suggest Zinfandel was significantly more sensitive to exposure to cool temperatures. For Merlot, the estimated effects of DD 30ºC to 35ºC Apr-Jul and DD 30ºC to 35ºC Aug-Oct were positive and significantly different from the estimated effects for the full sample. The estimates of other coefficients for Merlot

and Zinfandel were broadly similar to those from the full sample although generally less statistically significant, perhaps reflecting the smaller sample size for models using only those wine varieties.

Testing at all DD coefficients jointly, we found that the degree day coefficients for Pinot Noir, Merlot, and Zinfandel were significantly different from the coefficients estimated using all varieties at the 1% level.

Table 11 Testing if coefficient estimates from variety-specific models were significantly different from all varieties model

	(1) All varieties	(2) Cabernet Sauvignon	(3) Chardonnay	(4) Pinot Noir	(5) Merlot	(6) Zinfandel
DD <-2°C Feb-Oct	-0.0380	-0.0928	-0.1152	0.0009	0.0007	-0.2072***
		[0.055]	[0.077]	[-0.039]	[-0.039]	[0.169]
		{0.128}	{0.646}	{0.287}	{0.536}	{0.001}
DD -2°C to 10°C Feb-Oct	-0.0007***	-0.0006***	-0.0011*	-0.0006*	-0.0019***	0.0002
		[-0.000]	[0.000]	[-0.000]	[0.001]	[-0.001]
		{0.661}	{0.284}	{0.702}	{0.000}	{0.040}
DD 30°C to 35°C Apr-Jul	-0.0001	-0.0007	0.0008	0.0015	0.0122**	-0.0026
		[0.001]	[-0.001]	[-0.002]	[-0.012]	[0.002]
		{0.322}	{0.725}	{0.553}	{0.000}	{0.429}
DD 30°C to 35°C Aug-Oct	-0.0036***	-0.0062***	-0.0040	0.0012	0.0079	-0.0017
		[0.003]	[0.000]	[-0.005]	[-0.012]	[-0.002]
		{0.066}	{0.863}	{0.090}	{0.002}	{0.315}
DD >35°C Apr-Jul	-0.0068***	-0.0089***	-0.0035	-0.0104	-0.0090	0.0032
		[0.002]	[-0.003]	[0.004]	[0.002]	[-0.010]
		{0.268}	{0.565}	{0.462}	{0.624}	{0.000}
DD >35°C Aug-Oct	-0.0056**	-0.0056**	-0.0070***	0.0059	-0.0249*	-0.0011
		[-0.000]	[0.001]	[-0.012]	[0.019]	[-0.005]
		{0.997}	{0.560}	{0.018}	{0.047}	{0.205}

Precipitation	-1.2986***	-2.0282***	-0.5690	0.5186	-0.3090	-0.0910
		[0.730]	[-0.730]	[-1.817]	[-0.990]	[-1.208]
		{0.010}	{0.188}	{0.000}	{0.360}	{0.077}
Precipitation squared	2.5670**	4.4249***	0.1241	-0.9402	1.0578	-0.8322
		[-1.858]	[2.443]	[3.507]	[1.509]	[3.399]
		{0.006}	{0.048}	{0.000}	{0.653}	{0.063}
Wine age	-0.0409***	-0.0246**	-0.0604***	-0.0546***	-0.0623*	-0.0433***
		[-0.016]	[0.019]	[0.014]	[0.021]	[0.002]
		{0.015}	{0.118}	{0.113}	{0.415}	{0.853}
Wine age squared	0.0009***	0.0005***	0.0019***	0.0007***	0.0008***	0.0012***
		[0.000]	[-0.001]	[0.000]	[0.000]	[-0.000]
		{0.012}	{0.008}	{0.216}	{0.823}	{0.164}
Vintage trend	0.0102	0.0022	0.1031**	-0.0491***	0.0074	0.0102
		[0.008]	[-0.093]	[0.059]	[0.003]	[0.000]
		{0.055}	{0.001}	{0.000}	{0.874}	{0.999}
Vintage trend squared	-0.0004**	-0.0002	-0.0018***	0.0001	-0.0006***	-0.0005
		[-0.000]	[0.001]	[-0.001]	[0.000]	[0.000]
		{0.039}	{0.001}	{0.027}	{0.221}	{0.846}
Constant	5.9206***	5.9413***	3.9399***	6.2910***	5.1910***	4.3725***
		[0.066]	[1.980]	[-1.374]	[0.411]	[0.834]
		{0.508}	{0.000}	{0.000}	{0.587}	{0.070}

Joint test DD vars		{0.023}	{0.059}	{0.000}	{0.000}	{0.000}
R^2	0.810	0.820	0.614	0.569	0.603	0.400
Observations	47662	30649	6123	8688	805	1350

Notes: Each column shows the results from a separate regression model for the varietal wine identified in the column header, using winery-vintage observations from all premium growing regions in California from 1981 to 2020. Includes winery-by-region fixed effects, linear and quadratic vintage year trend, auction year fixed effect, quadratic function of wine age, and quadratic function of growing-season precipitation. The reported estimates are the effect of a one unit increase in the explanatory variable (identified in the row label) on the natural logarithm of wine prices. The value in square brackets is the difference between the coefficient estimate for all varieties in column 1 and the coefficient estimate for the varietal wine identified in the column header. The value in curly brackets is the p-value testing whether the difference between the coefficient estimates in square brackets is significantly different from zero, taking into account uncertainty in the estimated effects. The row labelled "Joint test DD vars" is the p-value from the joint test of the restriction that all degree day coefficients are equal to the corresponding coefficients in the model of all varieties, taking into account uncertainty in the estimated effects. Significance: * p<0.05, ** p<0.01, *** p<0.001.