WINE VS. THE WEATHER: CAN ECONOMETRICS PIP THE PALATE?

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Introduction and overview

Wine lovers have long known that the quality of their favorite libation is variable: it depends on, among other things, the geography and geology of the vineyard, the type of grape and how it is grown and harvested, and the weather in the year of its harvest.

This variation in quality is reflected in auction prices, with good vintages commanding significantly higher prices than bad vintages. In fact, when Napoleon III asked wine brokers to classify Bordeaux wines in advance of the Exposition Universelle de Paris in 1855[1], price was the primary mechanism by which wines were classified from first to fifth growths (*crus*).

Prices of Bordeaux wines are set when they are first produced in the *en primeur*, or futures, market, and later at auctions. Figure 1 displays the prices of sixteen well known wines, along with the equally weighted average price for each vintage, for vintages ranging from 1945 to 2018. Our dataset reflects end of year auction prices in 2021 as captured by the Wine Market Journal, and is plotted on a logarithmic scale on account of its exceptionally wide range.

Figure 1 tells three fascinating stories:

1. Prices exhibit enormous variability across châteaux: the median ratio of the price of the most expensive wine of a given vintage to that of the least expensive wine of the same vintage is 11.6.

2. The average price is spiky – it can jump by a factor of six from one year to the next! Particularly sharp spikes are visible in 1959, 1961, 1965, 1982, 1989 / 1990, 2000 and 2009 / 2010.

3. Prior to the 1972 vintage, prices increased with age, and after this date, they first gently increase and then decrease with age.

The first fact likely reflects differences in quality as well as differences in both oenophile tastes and imbalances in supply and demand: it seems improbable that two wines from well-known châteaux in the same geographic region could exhibit a ten-fold difference in quality.

The second has given rise to an industry of wine critics, who taste and rate young wines with a view to predicting their quality when mature. We will have more to say about this.

The third splits into two parts, one logical, the other mysterious. As storing wine is not costless, older vintages *should* be more expensive than younger vintages. This is standard economic theory, and is exactly the pattern we see prior to 1972[2].

[1] A concise history of the 1855 classification can be found at https://en.wikipedia.org/wiki/Bordeaux_Wine_Official_Classification_of_1855

[2] We later present auction data from 2001, 2011, 2017, 2020 and 2021. A review of the data shows that this pattern is found in every single year, though the trough in prices tends to occur about one vintage year later.

But it is much harder to explain the post-1972 pattern of prices – unless there is a steady improvement in quality over time, or if the cost of storage is offloaded to buyers in some way, there is no good reason for young wines to be about as expensive as old wines. This is a puzzle to which we do not have a full resolution, but to which we offer some thoughts supported by anecdotal evidence.

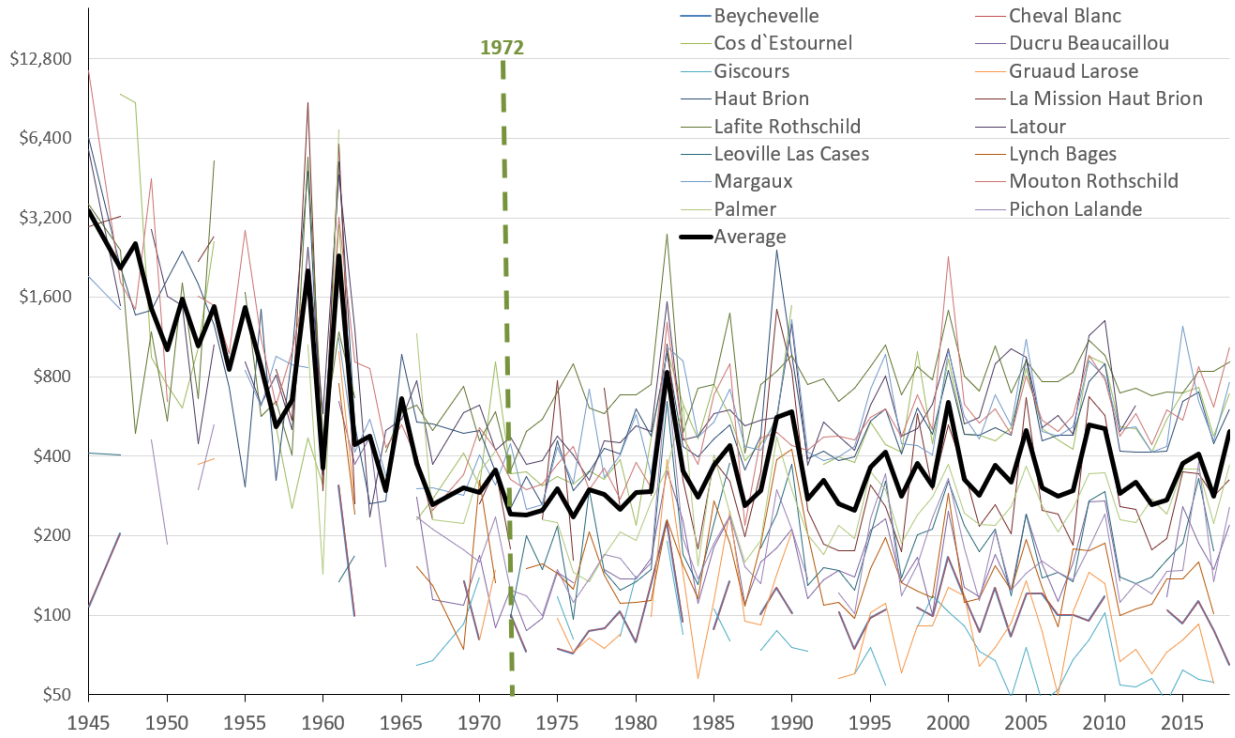

Figure 1: Price vs. Vintage Year: 2021 Auctions.

Source: First Growth Technologies / Wine Market Journal

The Influence of Weather on Quality

In early work, Bruno Prats, the well-known wine entrepreneur and former owner of Château Cos d'Estournel, compared vintages using hand-gathered data on growing season temperature and harvest-time rainfall with a view to predicting the eventual quality of his vineyard's wines even before the year's harvest was over. His underlying logic was simple: a warm growing season allows grapes to ripen fully, and low harvest-time rainfall prevents the dilution of the flavors in the grape's juice.

Figure 2 illustrates the relationship between harvest rainfall[3] and average growing season temperatures[4], and each point is labelled with both its vintage and the average auction price of those of the sixteen wines of that vintage that were actually traded in 2021. Vintages that sold at above-average auction prices are identified using green triangles, and the dotted blue trendline illuminates the broad relationship between average

[3] The harvest season runs from the beginning of August to the end of September.

[4] The growing season extends from the beginning of March to the end of September, and overlaps the harvest season.

growing season temperature and harvest rainfall: a 1^{O}C increase in average growing season temperature is associated with a 40 mm decrease in harvest rainfall over this period[5].

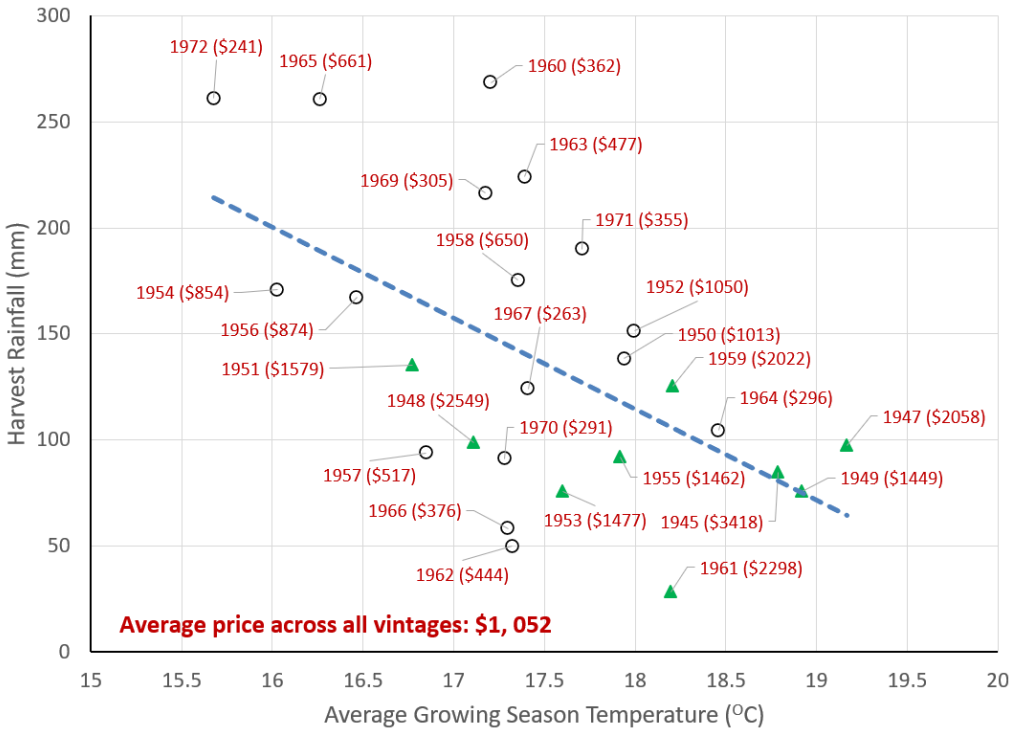

Figure 2: Average Price vs. Weather in Year of Production 1945-1972: 2021 Auctions.
Source: First Growth Technologies / Wine Market Journal and Sebastien Lecocq

On looking at the auction prices in Figure 1, it is clear that prices are higher on average when temperatures are high and rainfall is low, i.e. towards the Southwest corner of the graph. The famous 1961 vintage is visible at the bottom right, as are vintages from the late 1940s, which likely reflect a premium for their age in addition to having been made in hot, dry, years. In contrast, low-priced vintages tend to congregate in the Northwest corner of the graph, reflecting the cool, wet, weather in their year of production.

Even though Prats was on the right track, it was Orley Ashenfelter, a labor economist from Princeton University, who formalized his work and brought econometric techniques to bear on the pricing of wine. He observed that weather in Bordeaux was unusually variable, and could therefore be used as an input to a

[5] Weather data was obtained from Jean-Michel Chevet, Sebastien Lecocq, and Michael Visser, who have created a long data series for the weather in Bordaux. See Chevet, Lecocq and Visser, "Climate, Grapevine Phenology, Wine Production, and Prices: Pauillac (1800-2009)", *American Economic Review*, 2011. Starting with the year 2000, data for the Merignac weather station can be obtained from https://prevision-meteo.ch/climat/mensuel/bordeaux-merignac/.

linear regression model[6] that expresses the natural logarithm of the average price[7] as a weighted combination of five variables[8]:

1. Age of the wine in the year it is auctioned,
2. Rainfall in the preceding winter (rainfall from October–March),
3. Harvest rainfall (i.e., rainfall in August and September),
4. Average growing season (April–September) temperature, and
5. Average September temperature.

Table 1 displays the correlation of the correlation between the natural logarithm of average price with each of these variables. Age is the primary determinant of price and is positively correlated with it, while rainfall and temperature display weaker correlations. Importantly, most of the correlations run in the right direction: the log of price is negatively correlated with harvest rainfall, and positively correlated with growing season and September temperatures.

The one oddity is the negative correlation with winter rainfall – we expect the correlation to be positive, as winter rains feed vines and prepare them for growth in the coming year. This may, however, be a reflection of the fact that mature vines have roots that may go down forty feet or more, so the most recent winter's rain may have little influence on its grapes, and also as a certain degree of water stress is thought to contribute to more complex grapes.

Item	Correlation with ln(Average Auction Price)
Age of the wine in the year it is auctioned	0.838
Rainfall in the preceding winter	–0.211
Harvest rainfall	–0.441
Average growing season temperature	0.452
Average September temperature	0.341

Table 1. Correlation between ln(Average Auction Price) and Weather Variables: 1945-1972

In practice, a simple regression model that uses only age, average growing season temperature and harvest rainfall does about as well as the more complex model, and explains 69% of the variance of wine prices[9]. We find that the following equation models the average price of this basket of wines for vintages between 1945

[6] Linear regression models fit a straight line (or more generally a flat surface) through a noisy collection of points, and identify an optimal surface that fits the collection of points as well as possible.

[7] Ashenfelter used the natural logarithm of price to linearize the relationship by straightening out the extreme curvature on the left-hand side of the graph, and also to simplify the interpretation of the coefficient of Age in his regressions.

[8] Ashenfelter, Orley, "How Auctions Work for Wine and Art", *Journal of Economic Perspectives*, Summer 1989 and "Predicting the Quality and Prices of Bordeaux Wine", *The Economic Journal*, June 2008.

[9] Formally, the Adjusted R^2 of the regression is 69%. Ashenfelter's regressions, using a different dataset, had an Adjusted R^2 of 83%.

and 1972 quite well, and remain cognizant of the fact it might change over time as oenophile tastes and auction markets evolve:

$$P_{Average} = e^{0.944 + 0.07786 \times Age - 0.0015 \times Harvest\ Rain + 0.06 \times Growing\ Season\ Temperature}$$

As might be expected, the world of wine responded with unvarnished fury to the suggestion that a simple weather-based model could do better than a well-trained palate when passing judgement on young wines[10], but Orley Ashenfelter was adamant, and used it to guide his own purchases, as well as to offer advice in *Liquid Assets*, a newsletter he edited and published.

He then made a bold prediction that was at odds with the views of the critics: he predicted that 1989 vintage would be a great one. Time proved him right, and resistance to the econometric approach slowly faded. Thirty years later, econometric analyses of quality arouse no great passions, and it seems almost quaint to remark that they were once novel, and that the pushback against them was fierce.

Moving the study forward

After 1972, something changed. The established pattern of weather in Bordeaux was replaced by a new pattern in which harvest season rainfall depends only weakly on growing season temperatures, and the strong dependence of price on age simply disappeared. The equation for the average traded price for wines in our 1973-2018 subset becomes:

$$P_{Average} = e^{4.131 + 0.00076 \times Age - 0.00019 \times Harvest\ Rain + 0.106 \times Growing\ Season\ Temperature}$$

Figure 3 illustrates the change. The dotted blue trendline is now almost flat – there appears to be essentially no relationship between harvest rainfall and average growing season temperature. Furthermore, the average price over the entire period is only a third of what it was in the earlier period, but even more importantly, young wines are now no more expensive than old wines! Finally, even though the green triangles that identify higher-than-average-priced vintages still cluster toward the bottom right, the explanatory power of our regression, as measured by its Adjusted R^2, drops to 18%. The post-1972 period presents us with an economic mystery in addition to its weather-related mystery – if young wines are no more expensive than old wines, who pays the cost of storage?

It is tempting to chalk these facts up to global warming, but this is unsupported by evidence – the change in the structure of prices started in 1972, well before global warming was accorded the importance it is today. Average growing period temperature increased by only 0.5^{O}C from the first period to the second, and the average September temperature increased by only 0.1^{O}C. And while it is still true that wines made in hot, dry,

[10] See, for example, https://www.nytimes.com/1990/03/04/us/wine-equation-puts-some-noses-out-of-joint.html.

years tend to command higher prices than wines made in cool wet years, the relationship is weak as the low Adjusted R^2 of the regression makes clear.

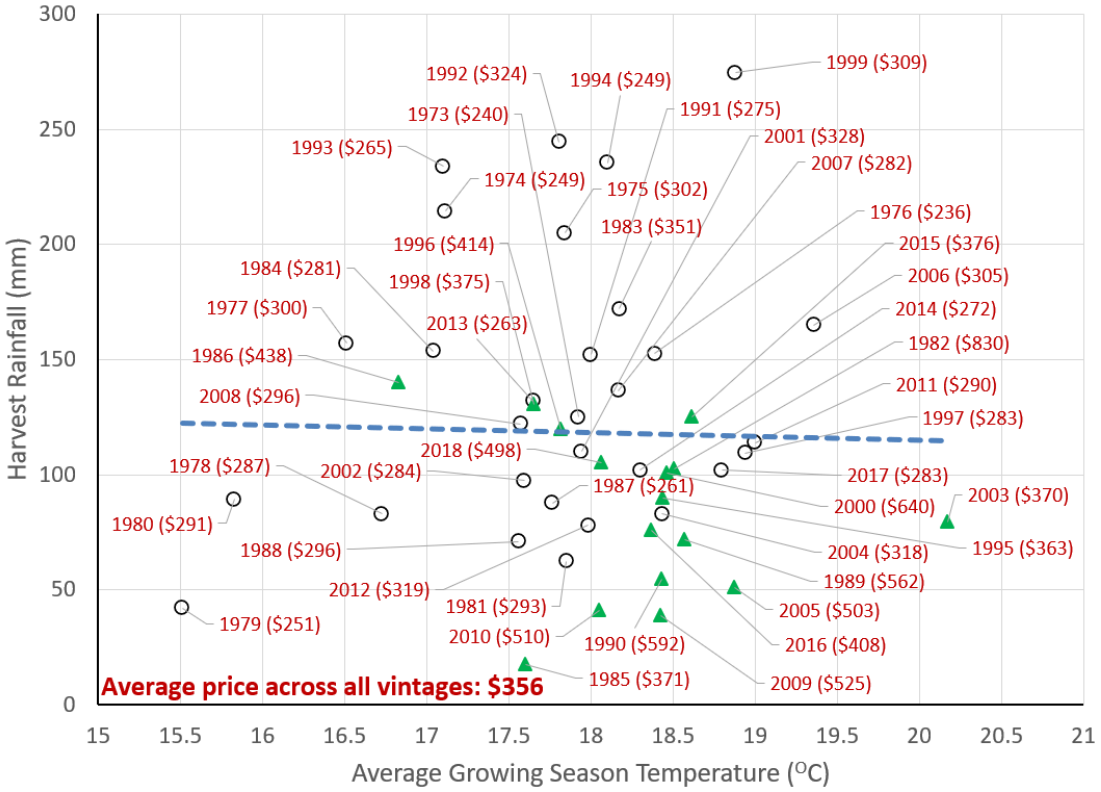

Figure 3: Average Price vs. Weather in Year of Production 1973-2018: 2021 Auctions.
Source: First Growth Technologies / Wine Market Journal and Sebastien Lecocq

Figures 4 and 5 give us a longer-term perspective on the weather in Bordeaux. Our data is obtained from Chevet, Lecocq and Visser (2010) and is updated using data from the Merignac weather station published on the web at https://prevision-meteo.ch/climat/mensuel/bordeaux-merignac/. Both the temperature and the rainfall in Bordeaux exhibit substantial fluctuations over the course of time.

Starting in the mid–1950's, growing season temperature has risen by about 0.25°C each decade, while September temperatures have grown at about 0.15°C each decade. Rainfall has displayed even larger proportional fluctuations than temperature: After a very wet 2001, winter rainfall fell by two-thirds over the next four years, but has since recovered. Harvest season rainfall fell sharply along with winter rainfall, but has also recovered, and seems to have stabilized at around 100 mm per year.

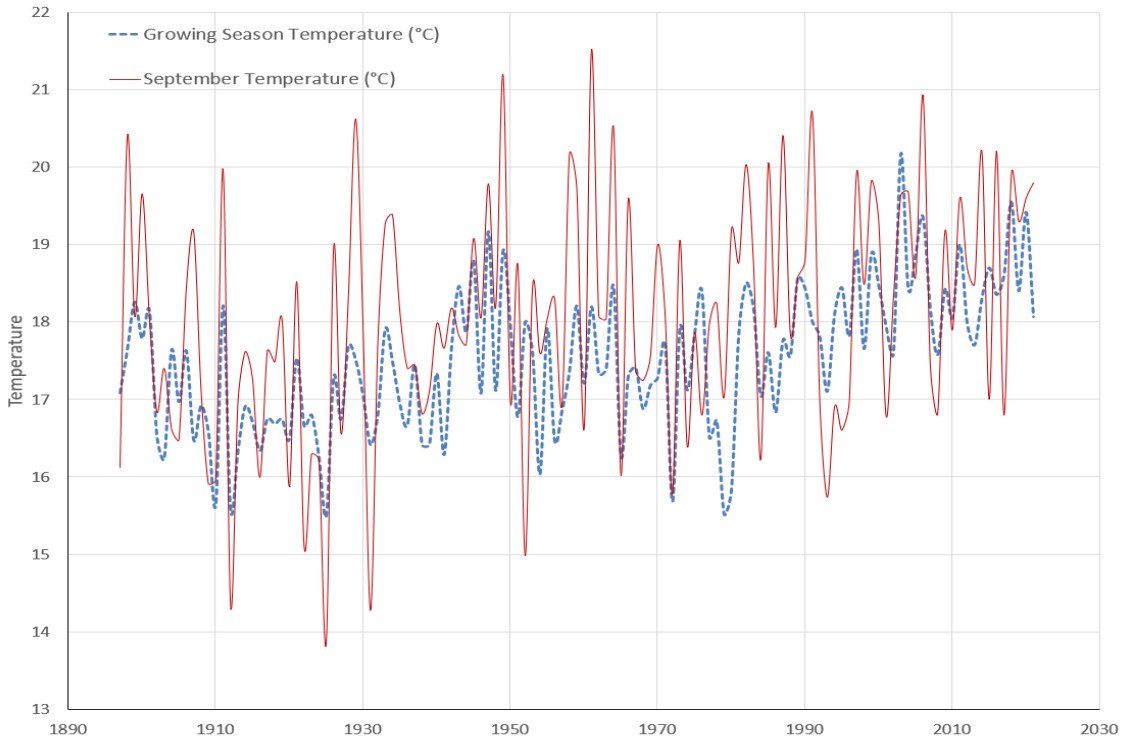

Figure 4: Average Growing Season and September Temperature in Bordeaux 1896-2021
Source: Sebastien Lecocq and https://prevision-meteo.ch/

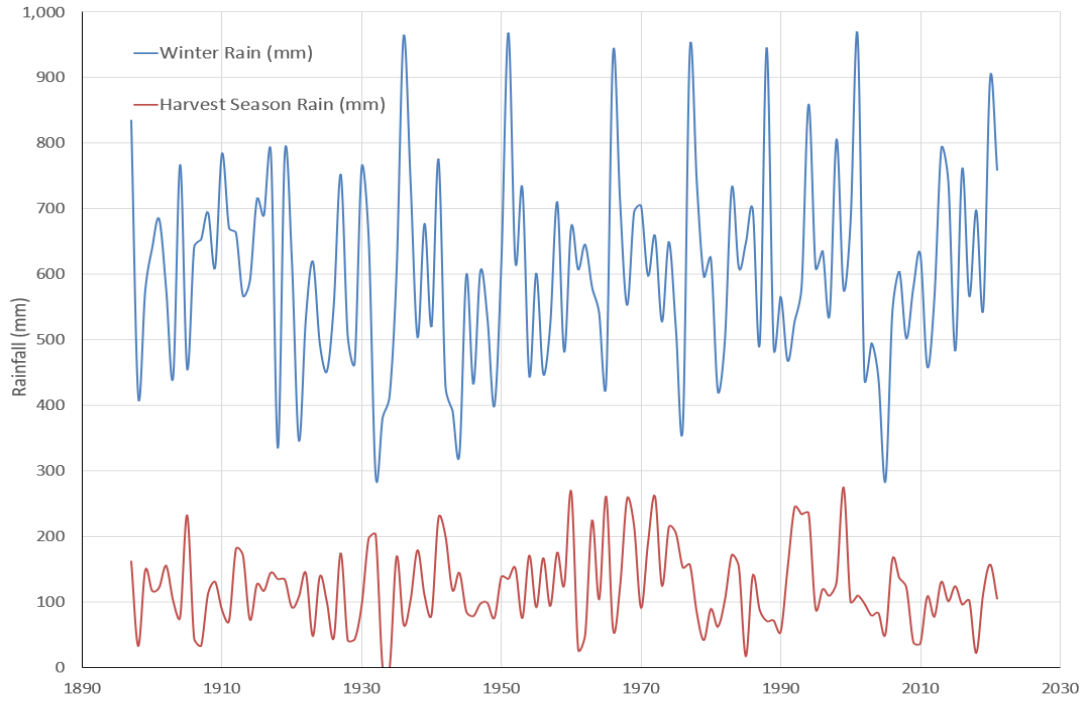

Figure 5: Winter and Harvest Rainfall in Bordeaux 1896-2021
Source: Sebastien Lecocq and https://prevision-meteo.ch/

Winemaking practice evolved in response to these changes, as well as to an enormous mid-1973 scandal that rocked some of the Bordeaux wine trade's most storied participants, who were found to have mislabeled inexpensive wines as expensive ones, combined wines to increase the supply of expensive wines, excessively sweetened wines using additives, used artificial colorings, and evaded taxes[11]. Prices of Bordeaux wines plummeted, forcing major changes at the surviving members of the wine community, as well as at vintners, who responded by introducing innovative new growing and production techniques at their vineyards.

Technological change played a role as well: starting in the 1970's, it became possible to forecast local weather using sophisticated computer models, allowing winemakers to harvest their grapes late in the season, but before large harvest rains. Additionally, the warming trend that is evident in our data has steadily moved the date of flowering and physiological ripeness earlier.

Producers now keep close track of the secondary market for their wines and try to price new releases to better reflect the prices of more mature vintages. Investors, too, often view wine in much the same way that they view a stock option: the longer its time to maturity, the higher its value. Finally, younger wine drinkers often like the flavors of younger wines more than those of older wines, and wines *do* get valued on things beyond just quality: birth year and anniversary year vintages have long had value for purely that reason.

Jancis Robinson, the wine critic, publishes an annual time series of flowering dates and grape harvest dates for Burgundy on her website at https://www.jancisrobinson.com/articles/burgundy-picking-and-flowering-dates-1975-2020, and the Ministry of Ecological Transition and Territorial Cohesion in France publishes time series of first harvest dates for Alsace, Champagne, Châteauneuf-du-Pape, Saint-Émilion and Tavel on its website at https://www.ecologie.gouv.fr/impacts-du-changement-climatique-agriculture-et-foret.

Figure 6 shows the evolution of first harvest dates, along with a LOESS smoother [12] and its 95% confidence interval, for a vineyard in Saint-Émilion[13]. The gentle increase from 1892 to 1974, as well as the more rapid decline in the five following decades, are clearly visible in the smooth LOESS line.

First harvest dates are seen to gently increase from 1892 to 1988 and are centered around September 26, after which they experience a sudden decline, and now appear to be centered around September 15, a week and a half earlier. The Ministry's website also publishes data on the dates of flowering and fruit ripening (veraison) dates[14].

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[11] See, for example, https://www.nytimes.com/1973/09/13/archives/french-wine-scandal-reaches-far-beyond-the-vineyards-high-prices-an.html and https://www.nytimes.com/1973/11/11/archives/the-case-of-the-bad-bordeaux-by-waverley-root-scandale-could-there.html

[12] Cleveland, W.S., 1979: Robust locally-weighted regression and smoothing scatterplots. *Journal of the American Statistical Association*, v, 74, pp. 829-836.

[13] The data for this plot was provided by Professor Cornelis van Leeuwen, EGFV, Univ. Bordeaux, Bordeaux Sciences Agro, INRAE, ISVV, 33882 Villenave d'Ornon, France. See also Labbé, Pfister, Brönnimann, Rousseau, Franke and Bois "The longest homogeneous series of grape harvest dates, Beaune 1354–2018, and its significance for the understanding of past and present climate", *Climate of the Past*, v. 15, pp.1485–1501, 2019 for a 600-year history of grape harvest dates in Burgundy.

[14] Veraison is the final phase of ripening, when the grapes begin to change color and accumulate sugars. This stage is evaluated by touch, and not just by color.

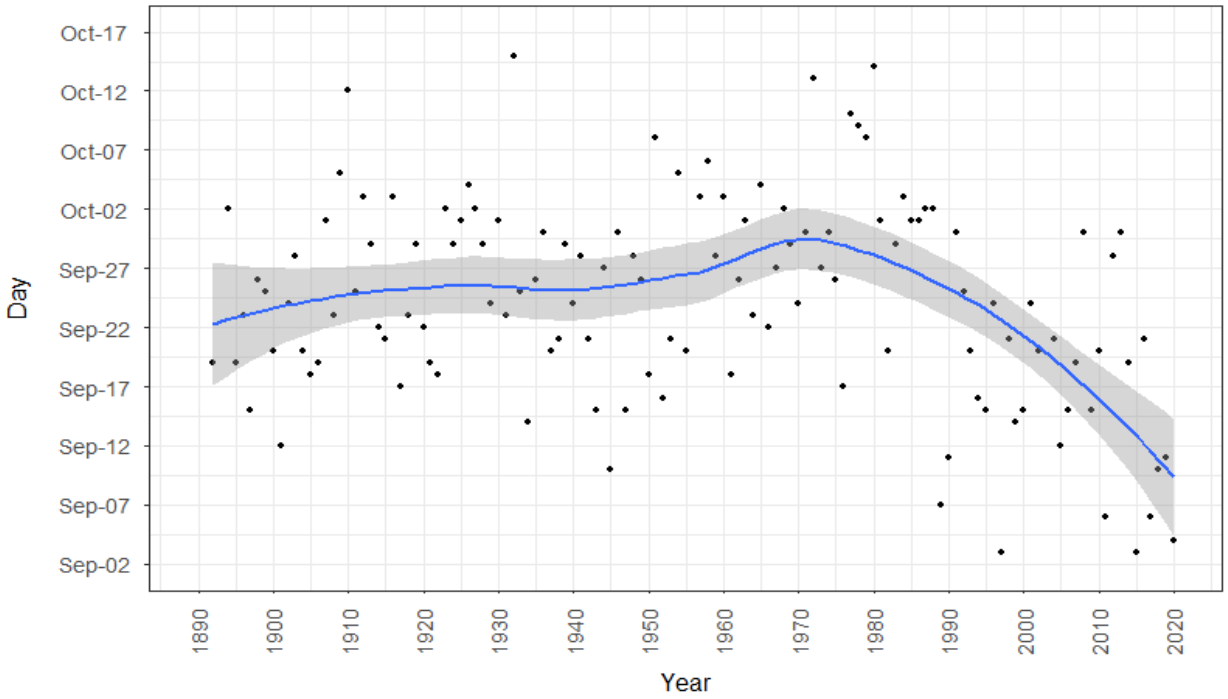

Figure 6. First harvest data in Saint-Emilion with LOESS smoothing, 1892 – 2022

Source: Professor Cornelis van Leeuwen, EGFV, Univ. Bordeaux, Bordeaux Sciences Agro, INRAE, ISVV, 33882 Villenave d'Ornon, France

While we believe that these factors play a role in the post-1972 pattern of wine prices, we readily admit that the evidence we offer in support of them is anecdotal, and based largely on our professional experience. That said, we feel confident in saying that they offer the patient investigator a rich vein of possibilities to explore.

An independent perspective on these facts can be found in Robert Parker's wine ratings, which can be viewed at https://www.robertparker.com/resources/vintage-chart. There are essentially no bad vintages in recent years, suggesting that Bordeaux's winemakers have found innovative ways in which to cope with factors outside their control. This, in turn, leads to yet another question: what techniques did winemakers adopt, and why, and what drove them to adopt these solutions and not others?

Wine in the Time of COVID

Finally, we explore the impact of COVID-19 on the prices of our sixteen Bordeaux wines. There is a body of work that indicates that alcohol consumption increased in 2020 and 2021, as did alcohol-related mortality[15],

[15] See, for example, White, Castle, Powell, Hingson, and Koob, "Alcohol-Related Deaths During the COVID-19 Pandemic", *Journal of the American Medical Association*, May 2022, and Barron, Parry, Bradshaw, Dorrington, Groenewald, Laubscher, and Matzopoulos, "Alcohol, violence and injury-induced mortality: Evidence from a modern-day prohibition", *The Review of Economics and Statistics*, July 2022.

but we know of no corresponding literature on the pricing of Bordeaux wines before, during, and after this period. To explore the impact of COVID-19, we obtain auction prices for our set of 16 wines from 5 years: 2001, 2011, 2017, 2020 and 2021, adjust past prices for the impact of inflation to make all prices roughly comparable[16], and then plot inflation adjusted prices by vintage in each of these years.

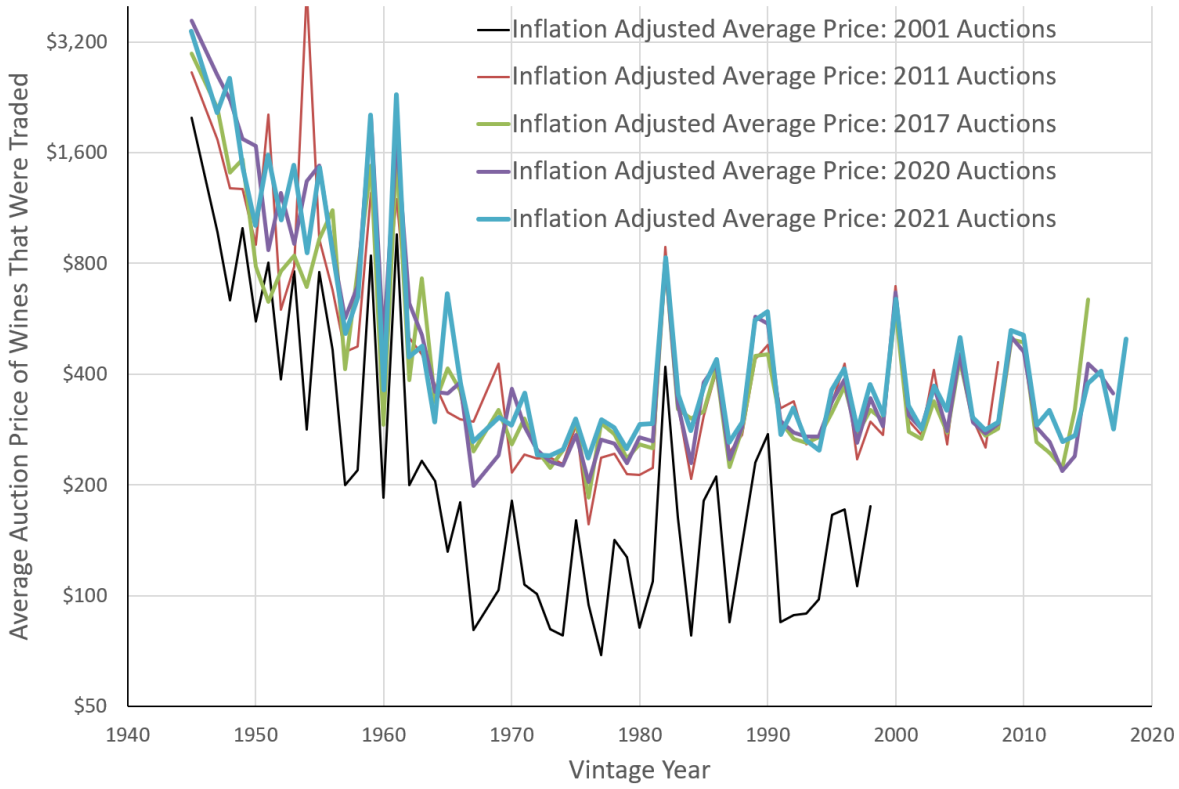

Figure 7: Inflation adjusted average price vs. vintage for 16 Bordeaux wines in 5 auctions
Source: First Growth Technologies / Wine Market Journal

Figure 7 makes clear that prices took a leg up from 2001 to 2011, even after adjusting for inflation, and then rose again in 2017, 2020 and 2021, but by a lesser amount. And it does contain an outlier: in the 2011 auctions, only two wines from the 1954 vintage were traded (Château Latour and Château Lafite Rothschild), and the Latour traded at $5,376, a price it did not achieve in any other auction. This outlier is clearly visible in Figure 6, and could be the result of a data error, or of a demand spike for the 1954 Château Latour that dissipated in later years, and we have no way in which to adjudicate between competing explanations.

A similar phenomenon occurred in the 2010 auctions in Hong Kong, when the price of the 2009 Château Lafite Rothschild was four times as high as that for its 2008 vintage, skewing our average price for the 2009's sharply higher. As it turns out, this outlier has an explanation.

[16] We adjust past prices using the ratio of year-end 2021 CPI to the corresponding year-end CPI level in the earlier period. We measure CPI using the Consumer Price Index for All Urban Consumers: All Items in U.S. City Average (series CPIAUCNS from the Federal Reserve Bank of St. Louis' FRED database).

Château Lafite Rothschild has a history of garnering higher prices in Hong Kong than like-quality brands. This phenomenon dates back to the elimination of all taxes on wine in Hong Kong in 2008 by the then Financial Secretary, Mr. John Tsang. Decanter magazine, which is widely read in Hong Kong, concurrently ran an article that asserted that Château Lafite Rothschild had a greater history of appreciation than any other wine, and it instantly became the wine of choice for wealthy Hong Kongers to buy for purposes of investment, prestige gifting, and prestige consumption. At one point, some vintages of Lafite Rothschild were valued more highly than Petrus – which is exceptionally rare and more highly regarded. A "first case", or the option on it, might therefore be especially highly valued for reasons other than the quality of its contents[17].

Prices in 2020 and 2021 were almost identical, and were slightly higher than prices in 2017, particularly for older vintages other than 1954, suggesting that there was some COVID-19 related bump in prices, particularly for older vintages. Table 2 explores this phenomenon in more detail and consists of three sections.

The first runs from 1945 to 1972, the natural breakpoint that we identified in the 2021 auction data[18]. The second runs from 1973 to various endpoints, each of which corresponds to the last vintage that was traded in a given auction year. The third covers the entire period starting in 1945 and ending at each of these endpoints.

Vintage Years	*2001 Auctions*	*2011 Auctions*	*2017 Auctions*	*2020 Auctions*	*2021 Auctions*
1945-1972	$482.14	$945.81[19]	$842.92	$1,064.77	$1,051.63
1973-1998	$142.32	$311.50	$316.01	$326.48	$345.42
1973-2009		$327.63	$326.20	$338.20	$355.15
1973-2015			$331.24	$335.08	$352.82
1973-2017				$336.88	$352.50
1973-2018					$355.66
1945-1998	$312.23	$628.65	$579.47	$695.62	$698.52
1945-2009		$586.87	$539.45	$638.06	$642.59
1945-2015			$524.05	$610.03	$616.14
1945-2017				$603.43	$608.52
1945-2018					$606.99

Table 2. Average auction prices in various years for 16 Bordeaux wines

Source: First Growth Technologies / Wine Market Journal, Authors' own calculations

[17] See https://liv-ex.typepad.com/livex_fine_wine_market_bl/2010/10/the-sothebys-lafite-ex-cellar-auction-in-hong-kong-has-seen-frenzied-buying-so-far-with-numerous-vintages-fetching-super-pre.html for an at-the-time perspective on the pricing of a range of vintages of Château Lafite Rothschild in Hong Kong in 2010.

[18] Even though the pricing trough is achieved about a year later for earlier auction years, we use 1972 as our breakpoint for consistency. Our results show essentially no change if the breakpoint is changed to 1973.

[19] Excluding the 1954 vintage, the average price for the 1945-1972 vintages is $806.65

The large increase in average price over both sub-periods from 2001 to 2011 is clearly visible in Table 2, as is the drop from 2011 to 2017 in the first period. The jump in average price from 2017 (prior to the COVID–19 pandemic) to 2020/2021 (squarely in the middle of the pandemic) is concentrated among wines made in the first period (1945-1972): there is only a modest change in price for wines made between 1973 and 2018.

Once again, we offer no causal explanation for this phenomenon, which could be an artifact of our dataset or a reflection of a change in tastes, but are inclined to lean towards the second, as adjusting for inflation and averaging over a large number of vintages takes out much of the noise in individual prices.

Conclusion

This article barely scratches the surface of the many applications of econometric techniques to oenology, and raises as many questions as it answers, particularly in regard to the 1973–2018 period. The reader who wishes to dig deeper into this fascinating subject should consider subscribing to two free open-access journals: the Journal of Wine Economics (https://wine-economics.org/) and Oeno One (https://oeno-one.eu/), and to purchasing the two-volume World Scientific Reference on Handbook of the Economics of Wine (https://www.worldscientific.com/worldscibooks/10.1142/9834).

The first volume of the Handbook focuses on the central questions of wine economics, including the influence of the weather and terroir on the quality and price of wines. The second volume covers regulation, auction formats, the reliability of competitions, and the organization of markets and firms.

But at days end, regardless of how one conducts one's analyses, it is important to keep in mind that wine is a drink, one that can be savored or abused, and that price is but one aspect of its value – the company in which it is consumed might well prove to be a far more important determinant of value in the eye of its consumer!

Acknowledgements

We thank First Growth Technologies for supplying the auction data used to conduct the analyses presented in this article, and Professor Cornelis van Leeuwen of EGFV, Univ. Bordeaux, Bordeaux Sciences Agro, INRAE, ISVV, 33882 Villenave d'Ornon, France for supplying the time series of first harvest dates for a vineyard in Saint-Emilion that was used to create Figure 6. Finally, we thank Michel Anastassiades for his careful reading of this article and for bringing to our attention the enormous impact of the 1973 scandal on just about every aspect of the Bordeaux wine trade.