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Unité de recherche 1303
alimentation et sciences sociales

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Janvier 2011

Working Paper ALISS 2011-01

INRA UR 1303 ALISS
65, Bd de Brandebourg
94205 Ivry-sur–Seine Cedex
France

http://www.paris.inra.fr/aliss

Climate, Grapevine Phenology, Wine Production and Prices: Pauillac (1800-2009)*

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Abstract: This paper analyzes 19th and 20th century data from a well-known château in Bordeaux. The dataset includes information on weather conditions, starting dates of three phenological stages of grapevine, prices, and yields. We discuss how these variables have evolved over the last two centuries. We also study to what extent the impact of climate on yields and prices has changed over time. Our regression analysis suggests that the effect of temperature on yields has become weaker since the 19th century. The influence on prices has, on the contrary, become stronger.

Key-Words: Climate; Grapevine; Phenology; Yields; Prices; Pauillac.
JEL codes: Q12, Q54.

*We are grateful to Victor Ginsburgh, Bronwyn Hall, and Karl Storchmann for helpful comments.

Climate conditions play an important role in explaining all sorts of agricultural outcomes. Temperatures and precipitations during the growing season, wind directions and intensities, the strength of solar radiation, and other climate variables, influence the phenological growth stages of crops. The precise onsets and durations of growth stages in turn influence the yields, qualities and prices. Ultimately, climate thus affects the revenues and profits of farmers, and consumer prices of agricultural products. To predict future values of these variables requires accurate and reliable models on the relationship between climate and agriculture. Recent concerns over global warming and its possible consequences also motivate a good understanding of this relationship.

The wine and viticulture sectors are particularly sensitive to climate variations. Gregory Jones and Robert Davis (2001) have shown that onsets of grapevine growth stages vary significantly with rainfall, hours of insolation, and the number of very hot days. They have argued that the increased temperatures observed in Bordeaux are largely responsible for the recent trend in earlier starts of phenological events. Climate also exerts a strong influence on wine prices (see, for example, Orley Ashenfelter 2008; Victor Ginsburgh et al. 1994; Jones and Karl Storchmann 2001). These studies find that high prices are associated with wet winters and warm and dry growing seasons. Weather variables are also key elements in explaining production yields. John Gladstones (1992) finds that, once technology factors are controlled for, climate is the main determinant of grapevine yields. Jones and Davis (2001) show that amounts of rainfall during certain phenological growth stages have significant effects.

This paper contributes to the above literature by studying two centuries of data that come from the archives of one of the most prestigious Bordeaux châteaux. These archives contain detailed information on several climate variables (daily min-max temperatures and daily rainfalls), yearly starting dates of three phenological growth stages of grapevine, and yearly production yields. We also have a series of wine prices obtained from several Bordeaux wine brokers. A unique aspect of these data is that they cover such a long period.[1]

Section I gives some background information about the château we are analyzing and defines the variables in our dataset. Section II contains our empirical findings. First, we provide a descriptive analysis of the data. Graphs of time series allow us to discuss how climate, onsets of phenological growth stages, yields, and prices have evolved over the past two centuries. We also explain how the extreme values of our outcome variables can be explained in terms of 19th and 20th century climate events. Second, we present regression results showing that climate effects on prices and yields have changed over time. Section III concludes.

1 Data

The data analyzed in this paper concern essentially one single Bordeaux château. It is located in Pauillac, a district situated some 50 kilometers (30 miles) northwest of the city of Bordeaux. The vineyards are near the Gironde estuary and cover 72 hectares (178 acres). The vines are planted on a sandy-gravelly soil, with no less than 90 percent made up of Cabernet Sauvignon (the grape varieties Cabernet Franc, Merlot and Petit Verdot account for the remaining 10 percent). The yearly average production during the period 1920-1978 was around 120 tonneaux of red wine (Cyril Ray 1980).[2] The château is classified as a first growth wine according to the famous 1855 classification and its clarets are widely regarded as among the finest in Bordeaux.

We were kindly given access to the historical archives of the château. From these archives we constructed time series of several variables. We have yearly starting dates of three grapevine growth stages: flowering (when the pollination and fertilization of the grapevine takes place, resulting in the development of grape

[1] A related paper is by Storchmann (2005). He studies the impact of English weather on Rhine wine quality between 1700 and 2000.

[2] A tonneau is a frequently used measure of Bordeaux wine production, and consists of approximately 1,200 standard-size bottles.

berries; in Bordeaux this event usually begins in May or June), veraison (when grape berries start to soften and change color, signalling the beginning of their ripening process; July or August), and harvest (grapes are harvested when they are fully mature; September or October).[3] We also constructed time series of several temperature variables (monthly average temperatures, average temperatures of growing season, etc.), and a time series of monthly total rainfalls. Finally we compiled a series of yearly yields, defined as hectoliters of wine per hectare.[4] The data from the château records were supplemented with a series of yearly prices obtained from several wine brokers in Bordeaux. These are so-called en primeur prices paid by brokers to the château owner a couple of months after harvest, typically in spring, when wine is still maturing in casks and not yet bottled. Prices are per tonneau and are converted into 2009 euros using cost-of-living indices (19th century indices from Maurice Lévy-Leboyer and François Bourguignon 1985; 20th century indices from the French Institute of Statistics, INSEE). All time series at our disposal end in 2009 but start at different instants: harvest dates are first observed in 1800, onsets of flowering and veraison in 1830, climate variables in 1896, wine prices in 1839, and yields in 1847.[5]

2 Findings

Figure 1 displays the series of average temperatures between April and September, and cumulated rainfalls between October and September. The months between

[3] We do not know to which grape variety the onsets of the three phenological stages refer.

[4] The climate series come partly from the archives of a château adjacent to the one we are studying and from several Bordeaux weather stations. This is unlikely to pose problems as Sébastien Lecocq and Michael Visser (2006) have shown that local weather data do not add much in explaining wine prices (relatively to using data from stations located further away). The yield data are from the château under study for the period 1924-2009, and from the adjacent château for the period 1847-1923. The correlation between the two yields is 0.86 (calculated over the period where they are observed for both châteaux: 1924-2009).

[5] Each time series has a few missing observations (except the series of yields which is complete).

April and September correspond to the growing season months of grapevine, and it is essentially during this period that temperatures matter. Rain not only matters during the growing season but also during the dormant period, i.e., the period right after harvest (October until March). As Figure 1 indicates, the overall mean growing season temperature during 1896-2009 was 17.4°C. The coldest growing season was in 1925, with average temperature barely above 15°C, while the hottest season was in 2003 (average temperature slightly above 20°C). The overall mean October-September cumulated rainfall was 865.8mm. 1898 was the driest year: between October 1897 and September 1898 only 472mm of rainfall was measured in Bordeaux. In 1977, the wettest year, there was almost three times more rainfall (between October 1976 and September 1977 cumulated rainfall amounted to 1,360.5mm). Figure 1 also shows that cumulated rainfall fluctuates quite evenly about the overall mean. Temperatures decline from the beginning of the observation period until roughly 1925, and there is an upward trend starting around 1985 until the end of the period.

Figure 2 shows the time series of yearly starting dates of our three phenological growth stages. The overall mean occurrence date of flowering, veraison, and harvest is May 28th (148 Julian days), July 23rd (204), and September 24th (267) respectively. For each phenological stage the earliest observed onset occurred in 1893. In that year, flowering started on April 28th, veraison on June 22nd, and grape-harvest on August 22nd. Although there are no precise and reliable data on the climate conditions that prevailed in 1893, it is known to have been a bakingly hot year. The latest observed onsets did not occur in the same year for each growth stage. The latest occurrence of flowering was in 1879. That year was marked by very low temperatures in winter and spring, and consequently the first signs of flowering appeared only on June 16th. The latest occurrence of veraison was in 1845, a cold and humid year which drastically slowed down the growth process of grapevines in Bordeaux. The first signs of ripening only showed up on August 12th. The latest harvest was in 1816. Historians have called it the "year without summer" and grape-picking began only on October 28th. The years around 1816 were marked by violent eruptions of several volcanoes (notably the 1815 eruption of the Tambora in Indonesia). These volcanoes expelled huge quantities of dust and ash in the atmosphere which diminished the strength of solar radiation. Consequently average yearly temperature dropped by 0.4-0.7°C in those years (Emmanuel Le Roy Ladurie, 2006). Figure 2 shows that the three trajectories have quite similar patterns. Since around 1985 there is a downward trend in starting dates of phenological events.

Figure 3 displays the series of yearly yields and prices. The average yield over the observation period 1847-2009 was 23.58 hectoliters per hectare. The lowest yield was observed in 1854 (2.82hl/ha) and the highest in 1973 (62.34hl/ha). Between 1853 and 1856 many vineyards in Pauillac were infected by powdery mildew (also called oidium). This disease, caused by low levels of sunlight and high humidity, dramatically reduced productivity levels in those years. 1973 was marked by heavy rainfall during the weeks preceding the onset of veraison (July 23rd).[6] Rain between the end of flowering and start of veraison favors berry growth, which in turn augments yields. For expository reasons Figure 3 displays the logarithm of prices (in levels the graph is not informative since it is practically flat for 19th century prices). The average price over the period 1839-2009 was 33,623 euros per tonneau. The lowest price paid by brokers was for the 1920 vintage (2,124 euros per tonneau) and the highest for the 2009 vintage (540,000). Although weather conditions may partly explain these extreme prices, specific economic factors probably mattered more. In 1917, World War I seemed never to end, and in this period of uncertainty a number of well-known châteaux (including three first growths but not the château studied in this paper) contracted with a broker and fixed their prices for the four consecutive years at 2,650 old francs per tonneau. This constrained the prices of other comparable estates through

[6]Rainfall in July 1973 amounted to 128mm, more than twice the average precipitation in that month (49mm).

competition effects and consequently, in 1920, the château under study could sell its wines at only 2,400 old francs (2,124 euros). The sky-high price paid for the 2009 vintage can in large part be attributed to increased wine demand from Asia (China in particular). Figure 3 shows that yields have been relatively stable and below the overall mean until about 1960. They increased substantially in the following thirty years, and have fluctuated at somewhat lower levels since around 1990. The series of prices has an inverse U-shaped profile between 1839 and 1910, and prices have steadily increased since the 1960s.

Now that we have described the data, we wish to address the following question: to what extent has the effect of climate on wine outcomes changed over time? Specifically, how has climate impact on prices and yields changed since the beginning of the 19th century? To answer this question, we regress the logarithm of prices and yields on climate variables (average growing season temperature, cumulated rainfall during winter months and growing season) for the whole observation period and for three subperiods: 19th century, 1901-1960, and 1961-2009. A practical problem here is that climate conditions are not observed before 1896, and are sometimes missing between 1901 and 1960. To solve this, we infer climate from starting dates of our three growth stages. We first regress each climate variable on starting dates of flowering, veraison and harvest using observations from 1896-2009. Using the estimated model, we predict climate before 1896 and when it is unobserved between 1901 and 1960.[7] To account for the sample variance in the predicted climate variables, we present bootstrap estimates and bootstrap standard errors for the regressions based on the whole period, 19th century, and 1901-1960 (for the period 1961-2009 there are no missing observations and we report the usual robust standard errors). Results are in Table 1.

Focussing on the three subperiods and the coefficients associated with average

[7] The basic idea to infer climate from phenological stages can be found in Isabelle Chuine et al. (2004). Using a process-based phenology model they predict spring-summer temperatures from harvest dates since 1370 in Burgundy.

April-September temperature, we see that the effect of climate on yields has become smaller and smaller over time: the estimates (standard errors) are 0.31 (0.26) for the period 1847-1900, 0.14 (0.08) for 1901-1960, and 0.08 (0.04) for 1961-2009, and the last two coefficients are significant at the 10 percent level. A natural explanation is that over time wine-growers have increased their control on production levels through all sorts of techniques. In the 19th and beginning of 20th century the vineyards in Pauillac were infected by many climate-related diseases (powdery mildew, different types of grapevine moth), and the natural fertilizers used at the time were not that effective. However, since the 20th century new and more efficient sorts of natural fertilizers were employed and better care was taken of the vineyards. Synthetic pesticides were employed on a massive scale since the 1960s (resulting in increasing yields; see Figure 3), and the cloning of vines which started early in the 1970s rendered vineyards more "weather-resistant". Finally, starting around 1990, yields were deliberately reduced (see Figure 3) by the wine growers through fruit thinning in July ("green harvesting") in order to obtain higher quality. This may explain why in more recent periods the impact of temperature is smaller. In the price regressions the opposite is taking place. The impact of growing-season temperatures has increased over time: 0.004 (0.27) for 1839-1900, 0.26 (0.13) for 1901-1960, and 0.45 (0.11) for 1961-2009, and the second and third estimates are significant at the 5 percent and 1 percent level respectively. An explanation for the increasing role of temperatures could be the following. In the 19th century and first half of the 20th, there was less hype surrounding wine (wine magazines did not exist yet, experts played a less active role than today, wine was less consumed). In these periods prices fluctuated therefore less with variations in temperatures (i.e., quality). In later periods, in particularly between 1980 and 2009, wine consumption was considerably higher, wines were much more discussed (wine experts, wine magazines, wine trials), possibly explaining the stronger link between temperatures and prices in later periods.

3 Concluding Comments

This paper has analyzed 19th and 20th century data concerning a well-known château in Bordeaux. The dataset includes information on weather conditions, starting dates of three phenological stages of grapevine, prices, and yields. We have discussed how these variables have evolved over the last two centuries. We have also studied to what extent the impact of climate on yields and prices has changed over time. Our regression analysis suggests that the effect of temperature on yields has become weaker since the 19th century. The influence on prices has, on the contrary, become stronger.

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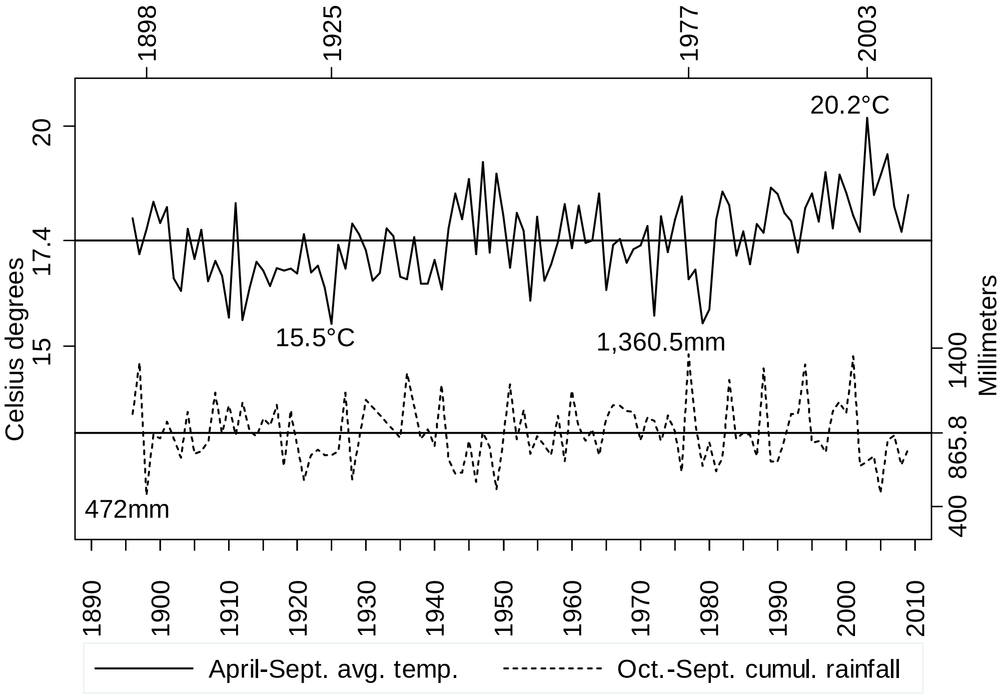
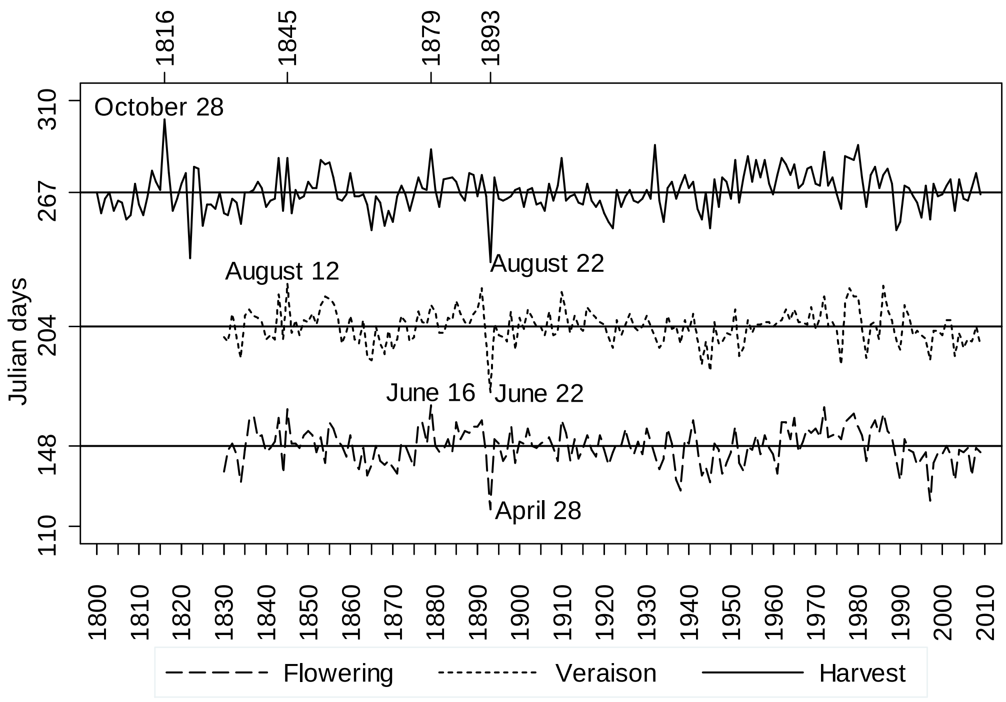
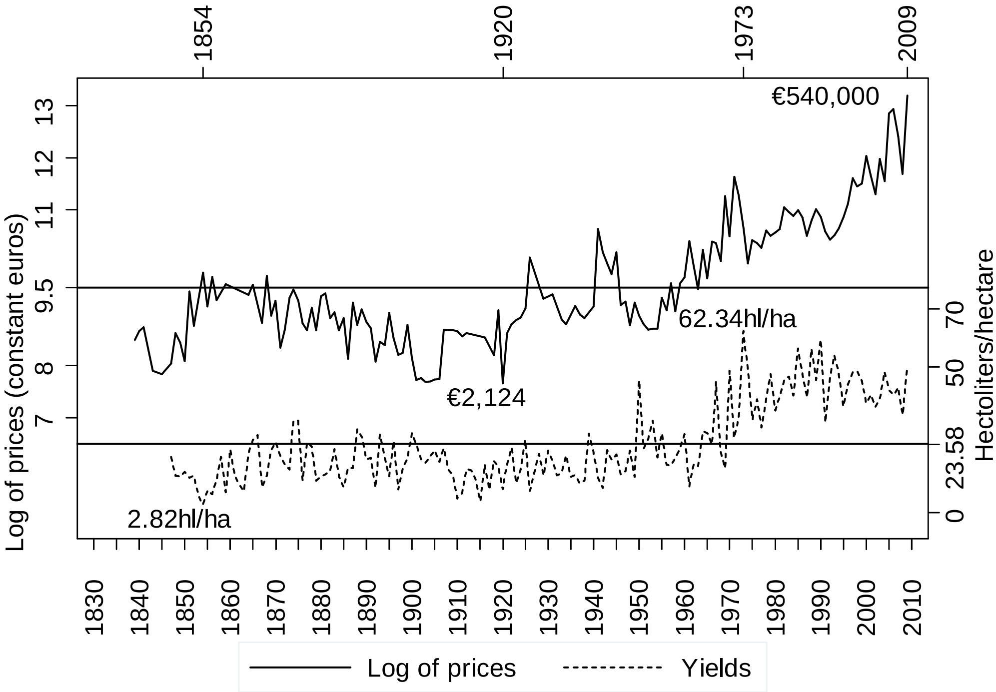


Temperature and rainfall.



Start of phenological stages.



Yearly price and yield.

Table 1–Prices, yields and weather

	All	≤ 1900	1901-1960	>1960
Prices (in logarithm)				
Oct.-March cumul. rainfall	−0.0002	0.0012	−0.0003	−0.0006
	(0.0008)	(0.0048)	(0.0007)	(0.0007)
April-Sept. cumul. rainfall	0.0030**	−0.0029	0.0019	0.0001
	(0.0012)	(0.0065)	(0.0021)	(0.0007)
April-Sept. avg. temp.	0.6610***	0.0039	0.2619**	0.4549***
	(0.1432)	(0.2676)	(0.1254)	(0.1130)
Constant	−2.9460	9.1613*	3.8850	3.1593
	(2.7476)	(5.7103)	(2.5547)	(2.0533)
R-squared	0.1948	0.0555	0.0941	0.2823
Observations	149	51	49	49
Yields (in logarithm)				
Oct.-March cumul. rainfall	−0.0004	−0.0010	−0.0004	−0.0004
	(0.0004)	(0.0049)	(0.0004)	(0.0004)
April-Sept. cumul. rainfall	0.0015**	0.0007	0.0012	0.0005
	(0.0006)	(0.0065)	(0.0009)	(0.0007)
April-Sept. avg. temp.	0.2925***	0.3116	0.1401*	0.0809*
	(0.0629)	(0.2628)	(0.0822)	(0.0445)
Constant	−2.4266*	−2.4666	0.1336	2.2094**
	(1.2076)	(5.7254)	(1.4987)	(0.8957)
R-squared	0.1556	0.1907	0.0663	0.0629
Observations	160	53	58	49

Notes: Standard errors in parentheses; bootstrap estimates and bootstrap standard errors in the first three columns, robust standard errors in the last column; ***, ** and * significant at the 1, 5 and 10 percent levels.

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