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Predicting the Quality of an Unborn Grange*

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In a recent paper Ashenfelter, Ashmore and Lalonde found they could explain the variation in the price (and quality) of Bordeaux vintages by a combination of age, temperature and rainfall. The same ideas are applied here to Grange Hermitage, Australia's premier wine. Weather variation is less important than in Bordeaux. However, some remarkably robust results are obtained: a 'quality index' for Grange is derived, predictions about still unreleased vintages are made, the Australian regression coefficients work well in the Bordeaux equation, and issues relating to market efficiency in the pricing of young wines are examined.

I Introduction

In a recent paper Ashenfelter, Ashmore and Lalonde (1993) demonstrate that the price of vintage Bordeaux wines is largely explained by the weather during the growing period. The authors form a price index for Bordeaux wines by averaging the prices of 13 chateaux. They then fit a regression line to the log of this price index for the period 1952 to 1980 using age and three weather-during-vintage variables as predictors. Equating price at auction with the perceived quality of the wine is one method used to rank chateaux; so if weather and age explain price, weather and age explain quality. This means that an investor has an objective guide to the quality of young wines when cellaring. Ashenfelter, Ashmore and Lalonde found that they could explain 83 per cent of the variation in vintage wine prices with four variables; the age of the wine, the average temperature during the growing season (Temp), rain in August and September (RainA-S) and the rain in the winter preceding the vintage (RainO-M). They found age, winter rain and temperature have positive effects on price, whereas rain in the harvest and pre-harvest period has a negative effect.

The authors make the comment that 'great vintages for Bordeaux wines are the years in which August and September are dry, the growing season is warm, and the previous winter has been wet'. The following equation provides regression evidence in support of this

$$\log(\text{price}) = \underset{(3.35)}{0.0238}\ \text{Age} + \underset{(6.47)}{0.616}\ \text{Temp} - \underset{(4.76)}{0.00386}\ \text{RainA-S} + \underset{(2.44)}{0.00117}\ \text{RainO-M} \quad (1)$$

* We are grateful to Lynda Bourke for research assistance, to Stewart Langton of Langton's Fine Wine Auctions for his interest and for providing, collecting and processing the price data, to Mike Farmilo (Chief Winemaker [Red] at Penfolds) and John Gladstones for their helpful comments and to Peter Flint of the Bureau of Meteorology in Adelaide for his assistance. In fact, everyone contacted, whether it was librarians, marketing managers, or wine retailers, was extremely helpful and interested in the project. Writing this paper has been an extremely enjoyable experience. Such is the esteem in which Grange is held. It is a very sad coincidence that the first draft of this paper was written just before the death of Max Schubert, the father of Grange Hermitage. This paper should not be interpreted as a statistical trivialization of his accomplishments. It is intended, in the spirit of scientific enquiry, to establish if the variation in the price of Grange can be explained by climatic factors—which it is the winemaker's purpose to counter-act.

No intercept was given for the equation, although one was fitted, *t*-values are contained in parenthesis, all variables are statistically significant and, as mentioned, the R^2 is 0.83. If age is the only explanator of the log of price, only 21 per cent of the variation is explained. Thus the inescapable conclusion: the bulk of price variation is attributable to weather variation and wine quality is largely explained by the weather in the vintage year.

An interesting question is whether the same phenomenon is observed in Australia. The initial reaction might be that predicting wine vintages in Australia will be more difficult because the climate is so good there is not sufficient weather variation to produce the quality variability observed in European vintages, and second, because the auction system is relatively undeveloped, trading is thin and prices are likely to be more volatile as a result.

Langton's (1991,1993) provide a record of maximum and minimum prices for wines they have auctioned in the 18-month periods 1991–1992 and 1992–1993. Langton's auctions are of the 'silent bid-written tender' kind, so they are not subject to the criticism often made of auctions as a price determination mechanism. Average prices are not reported in their publications; however, they kindly provided the authors with price, quantity and date records of each sale from January 1991 to May 1994. The average price for each vintage, by auction year, was then calculated. It is worth noting that the Langton's auction prices are well below the prices quoted in Bradley's excellent *Australian and New Zealand Wine Vintages* (1993). Bradley's prices are not recommended retail, but more an intrinsic value figure, containing an estimate of the vintage's potential. The auction price should be an informed market outcome; if purchasers are buying below retail prices through Langton's then the argument that price is a measure of quality is not invalidated, providing the discount is equivalent across all vintages.

The weather data in Australia are readily accessible and the Bureau of Meteorology in Adelaide provided monthly records for rainfall, minimum and maximum temperatures for the Barossa, Adelaide (three sites), McLaren Vale (two sites), Clare and Coonawarra. However, a major problem with each site (except Nuriootpa in the Barossa) is that the Climate Station may not be in sufficiently close proximity to the vineyard it represents. For example, the Magill vineyard is in the hills 5.5 kilometres from Adelaide and roughly 4.5 kilometres from the nearest weather station. To complicate matters further that weather station is located in an urban area rather than an exposed hillside. A similar problem applies to the Morphett Vale vineyard, on the outskirts of Adelaide.

Penfold's Grange Hermitage is a blend of Shiraz grapes, drawn predominantly from the Barossa valley but with contributions from Clare, McLaren Vale, the Magill vineyard near Adelaide and, more recently, Coonawarra. Len Evans (1984, p.620) presents a table compiled by David Farmer which lists the origins and composition of each vintage of Grange from 1951 to 1980. Grange started life as a shiraz wine based equally on grapes from Magill and Morphett Vale. The blend altered over the years with a reduction in the Magill component and an increasing contribution from the Kalimna vineyard in the Barossa. By the late 1970s 50–60 per cent was sourced from Kalimna, 20–30 per cent from Magill and 10–20 per cent component from Clare. In three of the 30 years documented there were small (5–10 per cent) contributions of cabernet savingnon. Since 1980 the blend has remained a company secret.[1] Obviously, with access to such information for the full sample period it becomes theoretically possible to construct weather indexes weighted by grape origin, providing the appropriate weather station data is available.

II The Problem

Grange was traded continuously in the 1991–1994[2] auctions at Langton's right back to the 1951 vintage. A few of the early vintages were not traded in a particular year and represent missing observations. However, many of the early vintages are scarce and beyond their optimal life and their price reflects scarcity or collector value rather than quality (e.g. $5500 was paid for a '51 Grange in 1993). Hence in any attempt to explain the price of Grange by weather related factors, such observations should be discarded from the sample. The Grange prices (Table 5 in the Data Appendix) are for the period 1959 to 1987; the price for earlier 1950s Grange escalates

[1] We are grateful to a referee for drawing our attention to the Evans's table.

[2] The '94 sales reflect only four months trading and were excluded from the data used in the statistical calculations partly because they represent an incomplete year; in fact, their inclusion makes very little difference to the results obtained.

rapidly and the volume traded declines. A plot of the price of each vintage by year of auction reveals the challenge. Can weather related factors explain why the market rates the 62, 66, 71 and 76 vintages so highly, whilst downgrading the 68–70 and 72–74 vintages?

In any one year the price of Grange varies by vintage according to the market's perception of its quality. However, the issue is more complicated as older wines become more scarce and the available stocks decrease,[3] but even then, year to year variations reflect perceived quality changes. If there was no year to year variation, Grange could be treated as a simple investment good and the rate of return could be assessed by plotting price against time or, better still, by fitting a regression equation.

The equation is specified as log(price) = $\beta_0 + \beta_1$ time + u, where u is a random disturbance. The graphs are similar when based on the 1992 and 1993 auction data. The fitted regression equation (1961–1985) is

$$\log(\text{price}_{91}) = \underset{(37.99)}{3.65} + \underset{(3.65)}{0.039}\ \text{Age} \qquad R^2 = 0.73 \qquad (2)$$

The result is much 'better' than that of Ashenfelter *et al*; (the R^2 is 0.73 compared to 0.21) which is an indication that Grange varies far less in price (quality) than the great wines of Bordeaux. However, the Bordeaux data relate to vintages from 1952 to 1980 and it might be argued that if data from the 50s had been deleted and data from the 80s incorporated, the price variability should be less because there has been considerable improvement in the underlying technology of winemaking in Bordeaux, as elsewhere.

The fitted equations based on the 1992 (1960–1986) and 1993 (1960–1987) auction data are

$$\log(\text{price}_{92}) = \underset{(37.02)}{3.91} + \underset{(6.84)}{0.036}\ \text{Age} \qquad R^2 = 0.65 \qquad (3)$$

$$\log(\text{price}_{93}) = \underset{(34.03)}{4.04} + \underset{(5.79)}{0.033}\ \text{Age} \qquad R^2 = 0.56 \qquad (4)$$

The 1991 auction results imply a real rate of return of 3.9 per cent per annum. Allowing a rate of inflation of 8.2 per cent per annum between 1966 and 1991 (i.e. purchasing wine on release and holding it until the 1991 auctions), this suggests a nominal rate of return on capital of around 12-13 per cent. If the entire data set were used, including the very high prices for early 1950s, the return on capital would be much higher. The rate of return appears reasonable, the interesting question is whether a better rate of return could be achieved by correctly predicting quality at time of release (i.e. when 5 years old), e.g. if the 1971 wine had been correctly predicted at the time of release, the rate of return on capital would be more like 7–8 per cent (real) or 15–16 per cent nominal per annum. Assuming it is more difficult to judge whether a Grange is outstanding when young, the price of young Grange should vary less than mature Grange.

III Results

The model is a simple one; the log of the price of Grange at auction is to be explained by a variety of weather variables and the age of the wine. A major issue, given Grange is a blended wine, is the definition of the weather variables. Initially the weather data was based on two recording stations in Adelaide, under the assumption that most of the grapes for Grange came from the Magill vineyards. This was quite unsuccessful and Mike Farmilo, the Chief Winemaker (Red) at Penfolds suggested that the Nurioopta Viticultural Climate Station would be a good representative site. The decision was taken prior to a referee's comment on the source of the grapes used to make Grange. As mentioned in the previous section, some information is available for the period up to 1980, but Penfolds will neither confirm nor deny its accuracy. We were unsuccessful despite determined attempts to create a weather index because of the difficulty in matching vineyards and weather stations—Magill and Morphett Vale presented insurmountable problems.[4] Examining the

[3] Information on the yearly production of Grange was not available, nor any assessment of the remaining stocks by vintage in any auction year. Langton's auction data included the quantity traded by vintage and while this was negatively correlated with price, it did not contribute significantly to the regression equations subsequently fitted.

[4] In attempting to create a weather index using Farmer's information on grape source we restricted ourselves to 1961 to 1979 because the Adelaide recording station changed from West Terrace to Kent Town in 1980. All the regressor variables were recreated. The climate stations for the vineyards were Adelaide-Kent Town, Clare Post Office, Barossa-Nurioopta Viticultural and McLaren Vale Post Office-Adelaide Airport respectively. The urban Kent Town minimum temperatures are 3°C higher than the rural Barossa or Clare sites which suggests Kent Town might not be a good proxy for the Magill vineyard. In addition, there are problems with

results below, Farmilo's suggestion turned out to be an inspired one.

The three years of auction data used show an upward drift in prices from 1991 to 1993, reflecting underlying macroeconomic influences. The equations were estimated separately for each year and then combined with individual intercepts to allow for the expected annual upward shift in price. The dependent variable was log of price, the explanatory variables were the wine's age, as well as a number of rainfall and temperature measures in the vintage year. The implication, of course, is that the partial derivative of the change in price to the change in (say) temperature depends on the regression equation slope coefficient and the price variable. Thus the effect of temperature on price will increase in magnitude with the cost (and age) of the wine, which would seem to be appropriate.

The problem is more difficult than the Bordeaux example, because the Grange prices relate to an individual wine rather than the average of thirteen wines; nevertheless, the results are encouraging as goodness of fit (R^2)[5] measures of 0.87 were observed. Surprisingly, the winter rain effect, reported for Bordeaux, was not observed in the results. It appears the best Grange vintages, as measured by price, require a warm growing period, a dry summer and the absence of extreme differences in day and night temperatures. Drip irrigation is now widely used in the Barossa, but it does not explain the results given the sample period used. Sources at Penfolds emphatically denied the use of irrigation. Blending from different areas may explain why winter rainfall appears irrelevant.

The weather period for each vintage is taken as April in the previous year to March of the vintage year. The sample period is from 1960 to 1985, 1986 and 1987 for the 1991, 1992 and 1993 auctions respectively. If the results showed that the weather variables had different effects on the 91, 92 and 93 auction data, it would be cause for concern. The first step then was to estimate the equations separately for each auction and test if the results were the same. This is an essential step in establishing the credibility of the explanatory variables and the functional form.

The combined equations can be estimated more efficiently as a system using the cross equation restrictions that corresponding coefficients must be equal. The approach, termed 'seemingly unrelated regressions' or SUR is well known to econometricians (see, Green, ch. 17, 1990, for example). The restrictions are tested, again the approach is well known, and if the restrictions are accepted the model passes the first hurdle and it is appropriate to treat the three equations as one and average the price at the three sets of auctions.

Remembering that the 'great vintages for Bordeaux wines are the years in which August and September are dry, the growing season is warm, and the previous winter has been wet' in the Australian context we are looking for a dry summer, a wet winter and a warm spring and summer. Other weather related factors which might have a bearing on wine quality are not hard to find. The literature on viticulture is full of folklore on the importance of weather, climate and micro-climate in grape production. The early literature on the subject is associated with the University of California at Davis, in the works of Amerine (1960) and Winkler (1962), for example. Gladstones (1990, 1992) refines their ideas and presents a much more sophisticated development of their work. Halliday and Johnson (1990) provide an easily accessible reference to many of the ideas in Gladstones, Amerine and Winkler. Gladstones makes a make a number of suggestions which were followed up; the first, sunlight, did not prove to be critical, whereas the second, temperature variability did. The issue of temperature variability, or rather its absence, is one first identified by Gladstones (1990, p. 11). 'Most damage to vines and fruit is done by extremes of temperature in either direction.' Gladstones (1990) also suggests humidity as a factor, specifically humidity in the

the weather data for the Morphett Vale vineyard. There are rainfall recording centres in McLaren Vale, but no temperature stations; hence we used McLaren Vale Post Office for rainfall and Adelaide Airport for temperature. The altitude of McLaren Vale Post Office is 65 metres, that of the Airport is five metres and the McLaren Vale Post Office is close to the Morphett Vale vineyard. The preferred equation was re-estimated using the Farmer weights to create the weather variables. Perhaps unsurprisingly, the results were disappointing; only summer rain was significant and the R^2 dropped to 0.66. When the Nurioopta weather data was used in the 1961–1979 sample period the R^2 was 0.85, all the variables were significant and the coefficients were essentially unchanged. As mentioned before, the preferred equation is extremely robust.

[5] Note the R^2 results are based on the price91 and price92 equations fitted for the periods 1961–1985 and 1961–1986 respectively, rather than for the period 1960-1987 with the dummies included. The other results are the same, but the dummies lift the R^2 in the equations to 0.99 and 0.98, which is misleading.

last six weeks of the growing period. Humidity did not prove to be significant. Both references mention the point that there is an ideal average growing period temperature for red wines of around 20–21°C, which suggests that the relationship is quadratic. One further influence, introduced as a dummy variable, was the Schubert factor. Max Schubert made Grange until 1975, so a dummy variable was tried with the break at 1975. It was not significant; his successors were neither worse, nor better, than the master.

The regressors for the equations reported below are

age = 1991/92/93—year of vintage
rain = total rain in January and February
temp = (sum of average temperature in October–March)/6 where average temperature–(maximum + minimum temperature)/2.
$temp^2$ = temperature squared
diff = (sum of difference between maximum and minimum temperatures in October-March)

In Table 1 the estimated equation is of the form

$$\log(\text{price}) = \beta_0 + \beta_1\text{age} + \beta_2\text{rain(Jan–Feb)} + \beta_3\text{temp(Oct–Mar)} + \beta_4\text{temp}^2 + \beta_5\text{diff} \quad (5)$$

and the same specification is applied to each year of auction data. The model is treated as if there are 28 vintage observations (1960—1987) for each auction year, but no 1960, 1986 or 1987 Grange was auctioned in 1991 and no 87 Grange was auctioned in 1992. In the SUR context these missing observations are handled by the introduction of three dummy variables.

The initial least squares estimates (OLS) of the three price equations are improved by exploiting the correlation structure in the disturbances, ie. by the use of the 'seemingly unrelated regressions' (SUR) technique. In addition, it appears reasonable to assume that the coefficients of the regressor variables will be the same, once a shift is allowed for auction year. Hence the coefficients on age, temperature and rain are constrained to be the same across the three equations. Wald tests on each of these restrictions were accepted, prior to constrained estimation. In fact, the constraints make very little difference and simply adding the three equations together produces essentially the same results—this is equivalent to creating a new dependent variable which is the sum of the three log price variables in the separate equations.

Diagnostic testing was performed on the residuals of the three OLS equations for the 91–93 auctions. The results were broadly satisfactory in relation to normality, serial correlation and functional form, but there was evidence of heteroskedasticity. White's (1980) heteroskedasticity correction for the coefficient variances was calculated and the appropriate *t*-statistics are given as the second set of terms in parenthesis in Table 1.

Note in Table 1, the 1993 results are not as tight as those for 1991 or 1992; nevertheless, the coefficients remain in the neighbourhood of the equivalent estimates for 1991 and 1992. The relationship appears to be very robust, adding or dropping an observation or even the addition of the 1994 auction data makes very little difference. Given the similarity of the coefficient estimates, irrespective of the estimation method used, the preferred equation became the aggregated form below and a full set of diagnostics are given; the dependent variable is a composite price, i.e. it is just $[\log(\text{price}_{91}) + \log(\text{price}_{92}) + \log(\text{price}_{93})]/3$. The constrained SUR results in Table 1 are based on an age variable which differs by year (price91, price92 and price93) and sample end point in the second and third equations. Nevertheless the unconstrained intercepts were indistinguishable. Hence, the decision to create a composite dependent variable. The resulting intercept reflects an average of the price levels for the three years. The age variable in the composite equation is for the '92 auctions. Note also that once this composite price term is adopted as the dependent variable it becomes necessary to reduce the sample for estimation to 1961 to 1985. Auction price data is available for 86 and 87 and there is now retail price data for 88 and 89. This data provides an out-of-sample forecast period for model validation.

The estimated results of the composite equation were

$$\begin{aligned}\log(\text{price}) = {} & -57.58 + 0.043\ \text{Age} - 0.0034\ \text{rain} \\ & \quad (2.57)\quad (9.48) \qquad\quad (3.29) \\ & \quad (2.78)\quad (9.40) \qquad\quad (4.08) \\ & + 6.59\ \text{temp} - 0.173\ \text{temp}^2 - 0.203\ \text{diff} \\ & \quad (2.75) \qquad (2.69) \qquad (2.07) \\ & \quad (2.94) \qquad (2.86) \qquad (2.36) \\ & R^2 = .86 \quad \bar{R}^2 = .82 \quad DW = 1.64 \end{aligned} \quad (6)$$

The following diagnostic test results were produced using Shazam,

Jarque-Bera test for Normality $[\chi^2(2)]$ = .57,

Breusch-Pagan-Godfrey test for Heteroskedasticity $[\chi^2(4)]$ = 11.99, Harvey test for Heteroskedasticity [$\chi^2(4)$] = 10.24,

Arch Test for Conditional Heteroskedasticity [$\chi^2(1)$] = 3.30.

The age of the wine was the dominant influence on price, winter rainfall does not appear to be important, too much rain in January and February is detrimental to price and the warmer the October to March temperature the higher the ultimate price of the vintage. In other words, the results are very similar to those for Bordeaux, with the exception of the winter rain effect. The fact that there might be an ideal growing period temperature led to the inclusion of a quadratic temperature variable—the idea being that if temperature improves the grape, but at a decreasing rate. Ultimately, very hot temperatures are detrimental. This hypothesis was confirmed. The other coefficients also have the right signs; for example, temperature variability has a negative effect on quality (see Gladstones, 1990, p. 11, and Halliday and Johnson 1990, p. 30).

The graphs give a better view of how well the model performs. The peaks in the composite price are '62, '66, '71 and '76, the troughs are '64, '69 and '81. The model tracks quite well, all observations lie within the 95 per cent confidence interval (high-low). Next, by removing the effect of age, a 'quality' index is created. The age variable in the regression equation has the coefficient .043, if we remove the effect of age from price we have the

TABLE 1

Regression Estimates[5]

(t-values in parenthesis)

	OLS			SUR			constrained SUR		
dep var	price91	price92	price93	price91	price92	price93	price91	price92	price93
constant	−49.68 (2.15) (2.51)	−75.42 (3.02) (3.69)	−48.31 (1.63) (1.77)	−44.75 (1.89)	−57.67 (2.32)	−48.31 (1.58)	−51.16 (2.40)	−51.00 (2.39)	−52.92 (2.39)
age	0.046 (9.94) (11.50)	0.041 (9.36) (8.07)	0.038 (6.75) (6.37)	0.043 (9.65)	0.039 (8.57)	0.037 (6.54)		0.041 (10.56)	
rain (J–F)	−0.0031 (2.95) (4.04)	−0.0037 (3.22) (4.78)	−0.0041 (2.75) (3.34)	−0.0033 (2.90)	−0.0034 (2.84)	−0.0041 (2.67)		−0.0031 (3.04)	
temp (O–M)	5.72 (2.31) (2.67)	8.55 (3.20) (3.85)	5.76 (1.81) (1.96)	5.26 (2.07)	6.67 (2.50)	5.76 (1.75)		5.93 (2.59)	
temp^2	−0.150 (2.26) (2.60)	−0.226 (3.16) (3.75)	−0.152 (1.77) (1.92)	−0.138 (2.03)	−0.177 (2.47)	−0.152 (1.72)		−0.157 (2.55)	
diff	−0.179 (1.77) (2.15)	−0.205 (1.98) (2.80)	−0.307 (2.27) (2.32)	−0.196 (1.86)	−0.186 (1.68)	−0.307 (2.20)		−0.149 (1.59)	
*d*60	−5.05 (61.3)			−5.18 (45.8)			−5.11 (51.7)		
*d*86	−3.86 (70.7)			−4.11 (38.1)			−4.20 (42.7)		
*d*87	−3.36 (36.6)	−3.57 (17.6)		−3.64 (25.6)	−3.91 (35.6)		−3.67 (30.1)	−3.93 (43.3)	
R^2	.87	.84	.74						

FIGURE 1

Actual versus Predicted: Composite Price

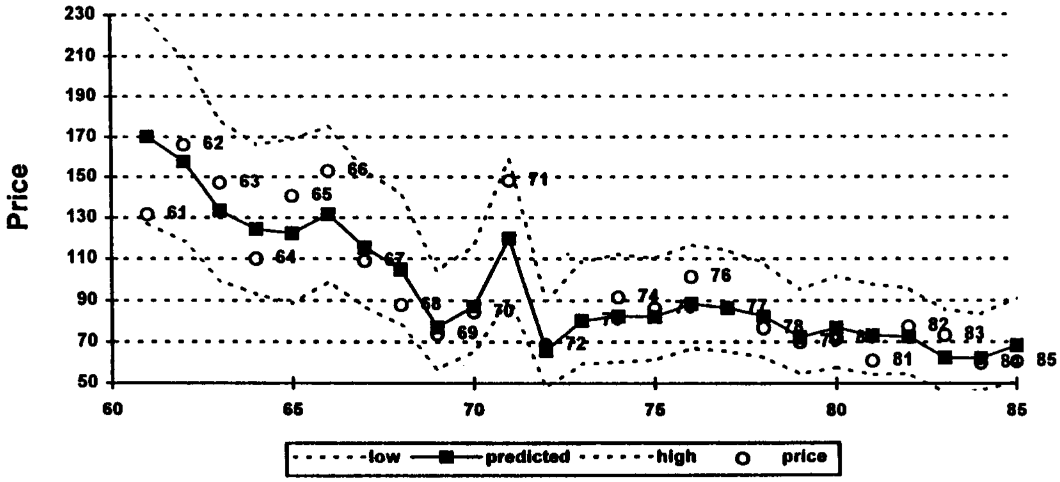
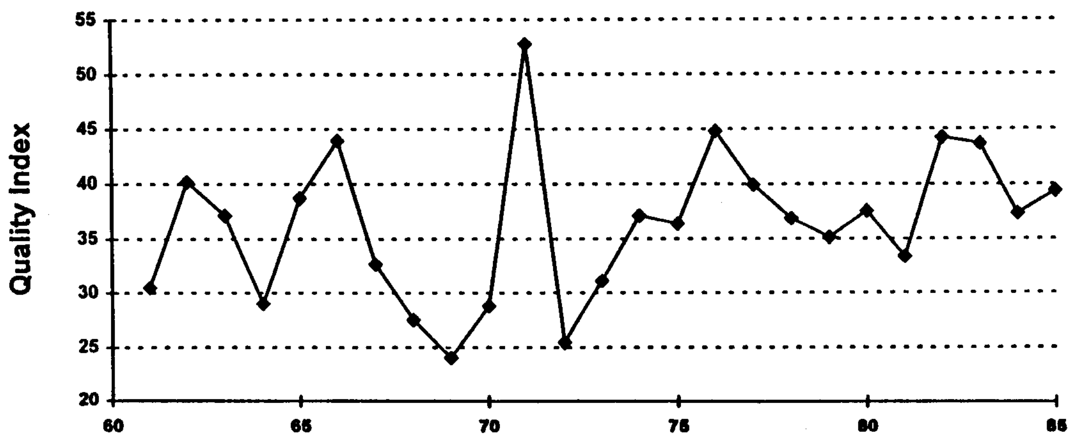


FIGURE 2

Quality Index based on Age Adjusted Price 1961–1985



market's markup for quality; i.e. quality = exp(log price − .043*age). In Figure 2, we simply remove the effect of age from the price series, the scaling is irrelevant.

The 'quality index' in Figure 2 is derived from the actual prices paid at auction and points to the '66, '71, '76, '82 and '83 being great vintages. Interestingly, in *The Rewards of Patience* (1990), Penfolds list their great vintages as '66, '70, '71, '75, '77, '80, '82 and '83. The differences being the ranking of the '70, the '75–'77 and the '80 vintages. Which vintages does the model rate higher than the market; i.e. which vintages could the market have got wrong? Figure 1 suggests the '66, '71 and '76, which appear to be excellent vintages, are nevertheless over-priced by the market, whereas the '61, '64 and '68 are relatively speaking under-priced. It should be noted that some of these differences may not be statistically significant and these remarks should be treated as thought provoking, rather than as definitive statements.

As a final exercise we use the model to study the quality of previous vintages and to forecast the quality of vintages not yet released. Figure 3 (and Table 2) present the 'predicted quality index' as distinct from the 'observed quality index' in Figure 2. If the weather is a more reliable indicator of quality, on average, than the price alone, then the index in Figure 3 may provide more useful information to the wine drinker than does the index in Figure 2. (For the wine investor Figure 3 provides a useful guide too, but, of course, the investor faces the additional risks associated with any slippage between wine quality and price.) The index of quality in Figure 3 is based on the predicted regression line, with the age effect removed, and then converted to an index with 1971–100. (The year 1971 was selected for the base of the index since it is both the highest predicted—and actual—price of the mature vintages.) As a result the predicted quality index in Table 2 is a function of the weather data only.

There are two interesting features of Figure 3. First, the weather for producing the Grange was not especially favourable during the decades of the 1960 and 1970s, 1971 being a notable exception. Since the late 1970s there have been no really difficult vintages except 1987. Note that no data from the vintages produced after 1985 were used to estimate the model, but that the initial auction results on the 1987 vintage support this conclusion. The period of the late 1980s and the early 1990s has been very favourable for producing the Grange, with 1985, 1989, 1990, and 1992 being capable of reaching the kind of peak attained in 1971. The vintages of 1993 and 1994 reflect a dip in quality from these heights, but this dip hardly represents a major disaster. Since 14 per cent of the variation in the observed sample was unexplained, the model remains noisy and a 95 per cent confidence interval around the index in Figure 3 is quite wide (being on the order of 15 index points). This suggests that *these predictions should be treated with some caution and that not too much should be made of small differences in the index values*. For example, the difference between the predicted quality levels for 1989 and 1990 is not statistically significant. Despite this caution, we should note that the predictions coincide remarkably well with the observations of wine commentators on the quality of the 1989 and 1990 vintages.

IV Comparison with Bordeaux

Equation (3) constitutes a hedonic price equation that, in principle, can be used for much more than the determination of the quality of Grange vintages. For example, this equation provides direct guidance on where it may be sensible to plant shiraz grapes in order to produce high quality wines. Most of the suitable land in France is, in fact, already planted in grape vines and the matching of vine type to location has evolved over many centuries. In much of the rest of the world, on the other hand, the decision whether to plant grapes for wine production is still evolving.[6]

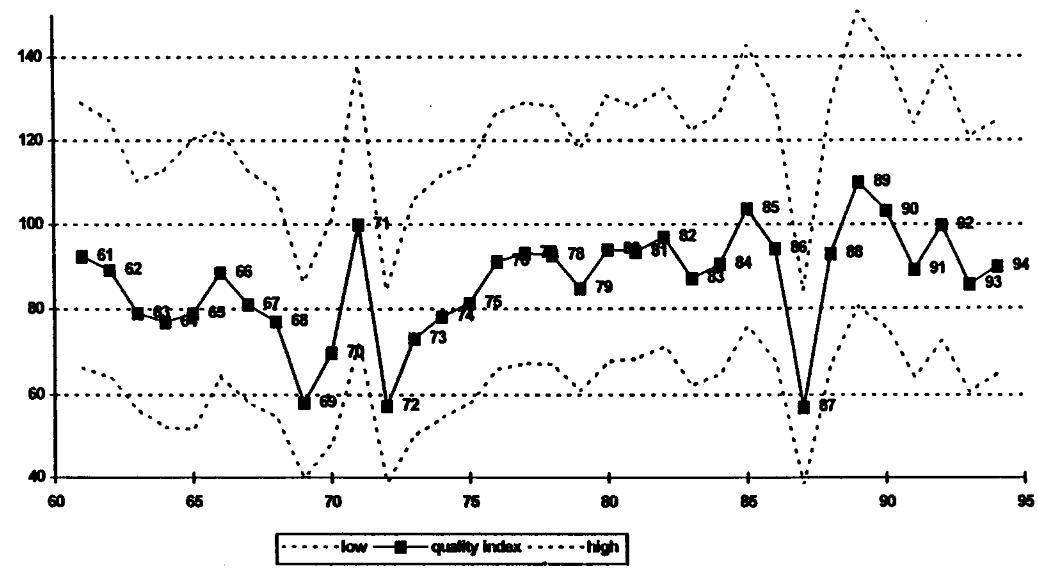
Since Grange generally fetches prices as high as the top Bordeaux wines at auction it is an example of one of the few 'new world' wines that can successfully compete with the finest wines of France. As a result, it is of considerable interest to compare the weather and the regression equations in the Barossa Valley with the comparable figures from Bordeaux.

Note first that the rainfall coefficients in the regression equations are -0.0038 for Bordeaux and -0.0034 for the Barossa Valley (from equations (1) and (6) respectively). These are obviously not significantly different. The temperature variable in the preferred specification for the Grange enters as a quadratic and implies that the finest wines are produced when the temperature over the growing season is around 19.0 Centigrade (6.59/2(.173)). This is only slightly higher than the mean growing season temperature in the Barossa Valley of 18.7°C. (from Table 1). Apparently the average growing season in the Barossa Valley is close to the 'ideal.' Note that in Bordeaux the temperature has never exceeded 18.7°C. As a result, it is not possible to isolate in Bordeaux the quadratic effect in the temperature that is so noticeable in the Barossa Valley. If we linearize the Grange equation and evaluate it at the Bordeaux average temperature, we find an implied coefficient for the Bordeaux equation of 0.812, which is not statistically significantly different from the actual Bordeaux coefficient of 0.616 from equation (1).

[6] Grange is made from the shiraz grape (called the syrah in France), while Bordeaux wines are made primarily from various blends of cabernet sauvignon, cabernet franc, and merlot grapes. As Gladstones (1990) observes, the optimum growing conditions for the shiraz and cabernet varieties are very similar. It seems likely that the comparisons we make with the Grange would be equally useful for plantings of shiraz and cabernet.

FIGURE 3

Quality Index (and 95% Confidence Intervals) based on Predicted Price 1961–1985



The real rate of return on Bordeaux wines is estimated at 0.024, while the return on the Grange is somewhat higher at 0.043. Not too much should be made of this difference in view of the sampling errors involved, but it is tempting to speculate that the return on the Grange may include a component due to the uncertainty over the ability of the Grange to improve over time. If this is the case, then it is likely that the real return to holding the Grange will decline to a return comparable to that for holding Bordeaux wine as the uncertainty over the ageability of the Grange is resolved.

It is apparent that in many ways the Australian weather patterns provide an excellent laboratory for estimating the effects of the weather on the quality of fine wines. For example, the Grange equation does a pretty good job of predicting the quality of the Bordeaux vintages! Applying the Grange coefficients for temperature, rainfall, and age to the Bordeaux data produces predicted prices that have a correlation of 0.80 with the actual Bordeaux prices.[7] This corresponds to an R-squared of 0.64, which may be compared with the actual R-squared of 0.83 for the Bordeaux equation. Alternatively, applying the Bordeaux coefficients to the Australian data provides a correlation of actual and predicted prices of only 0.32 because the linearity in the Bordeaux equation does not capture the negative effect of high temperatures in the Barossa Valley.

Finally, in Table 3 we provide summary data on the characteristics of the average grape growing seasons in the Barossa Valley and Bordeaux. It is readily apparent that the weather in the Barossa Valley is very favourable for wine production. First, the rainfall at harvest is typically lower in the Barossa Valley than in Bordeaux. If the mean rainfall in the Barossa Valley were as high as the mean rainfall in Bordeaux the predicted price of an average Grange would be 40 per cent less than it is. Second, the mean temperature in the Barossa Valley is far closer to the ideal than is the case in Bordeaux. For example, if the Barossa Valley had an average temperature that was the same as Bordeaux the predicted price of an average Grange would be less than one-half the predicted price at the observed average.[8] Third, the variability in all

[7] This result is not due to the fact that the prices of the wines are correlated with their age. Subtracting out a linear age effect from the actual and predicted Bordeaux prices gives a correlation of 0.66.

[8] The French vintners have taken many steps to ame-

TABLE 2
Predicted Quality Index and Calculated Return on Capital

year	quality	return	*relprwho**
58			
59	90.1		
60	93.0		1.296
61	92.6	0.183	1.370
62	89.5	0.189	1.778
63	79.0		
64	76.9		
65	79.0		
66	88.7		
67	81.2		
68	77.0		
69	59.0		
70	69.7	0.136	9.519
71	100.0	0.183	9.519
72	57.5	0.141	9.519
73	72.9	0.164	9.519
74	78.1	0.181	10.444
75	81.4	0.186	11.111
76	91.3	0.205	16.037
77	93.1	0.199	17.667
78	92.7	0.184	21.185
79	84.8	0.177	24.222
80	94.0	0.169	30.815
81	93.5	0.153	33.000
82	97.0	0.232	38.519
83	87.2	0.206	39.444
84	90.5	0.168	42.778
85	103.7	0.184	50.370
86	94.1		55.000
87	57.1		62.222
88	93.0		68.593
89	109.9		
90	103.1		
91	89.3		
92	99.7		
93	85.6		
94	90.9		

* *relprwho*: relative wholesale price

of the key weather variables is smaller in the Barossa Valley than in Bordeaux. Thus, the variability in the quality of the Bordeaux vintages should be considerably greater than the variability in the quality of the Grange vintages. This is precisely what the variability in prices shows. The standard deviation (across vintages) of the logarithm of an index of Bordeaux prices is 0.63 and the comparable standard deviation of Grange prices is only 0.38.[9]

liorate the weather patterns they face. These steps include selecting vineyard sites that are especially favourable (southern exposures, good drainage, favourable micro-climates), the use of stones which heat up during the day and discharge warmth at night, and the use of mechanical procedures (such as cryo-extraction, and heating of the grape must in a vacuum to concentrate it by evaporation).

V Economic Efficiency of the Grange Market

The regression results indicate that the price of a mature Grange reflects the weather in the growing season that produced the wine. Moreover, the characteristics of the weather that affect the mature Grange auction prices are those that are widely thought to influence the quality of wine grapes. It seems likely, therefore, that the auction prices for mature Grange reflect some reasonable efficiency in the processing of the information about the quality of the wine.

Since the weather that produced the vintage is known at the time that a new Grange is sold, it is also interesting to examine the prices set for the new wines. In an efficient market the prices for the young wines would be set so as to reflect the quality of the wines at maturity to the extent that such quality variability is known. The weather that produced the wine of the vintage is certainly information known at the time the wine is priced, so in an efficient market the initial price should be a sufficient statistic for the future (auction) price of the wine.

More generally, in an efficient market the rate of return on the wine of vintage v should differ only by a random error from the rate of return on any other vintage. That is, in an efficient market:

$$\text{return} = (\mathit{ln}\,\text{price} - \mathit{ln}\,\text{release price})/\text{age} = a + e,$$

where 'a' is the normal return, 'e' is an error uncorrelated with all information known at the time the wine is released into the market, and 'age' is the time from release to the date at which the auction price is measured. Estimates of this equation, and variants of it, are contained in the first three columns of Table 4.

The return we calculate (and use as dependent variable in Table 4) uses the log auction price minus the log wholesale price at release, divided

[9] Taking deviations of log prices after regression adjustment for the age of the wine (which should measure the variability in prices due only to influences other than the rate of return) gives standard deviations of 0.57 for the Bordeaux wines and 0.22 for the Grange.

TABLE 3
Weather Characteristics

	Barossa			Bordeaux		
	Average Temp. (C)	Harvest Rain (mm)	Winter Rain (mm)	Average Temp. (C)	Harvest Rain (mm)	Winter Rain (mm)
Mean	18.7	38	339	16.7	145	599
Standard Deviation	0.63	33	95	0.82	75	130
Minimum	17.4	0.5	137	15	38	376
Maximum	19.9	138	541	18.7	342	845

by the holding period, as the estimated rate of return. These returns are available for a few scattered years in the 1960s and for all the years since 1970, and are reported in Table 2. It is important to observe that these are returns available to an investor who buys at the wholesale price, not the retail price, and that these returns are not adjusted (downward) for storage costs.[10]

As Table 4 indicates, the average holding period return on the Grange has been around 18 per cent per year. The results in columns 2 and 3 indicate, however, that the returns have been correlated with the weather during the growing season that produced the vintage. Better vintages, defined strictly by the weather, have paid a higher return, although this effect should not be exaggerated. The results in column 2 of Table 4 indicate that a vintage with a higher quality index by 10 index points would have earned about a 1.2 per cent greater rate of return. In column three we simply enter the weather variables as additional regressors. A joint test of the significance of these four weather regressors is significant at the 0.08 level, but not at the 0.07 level.

The last two columns of Table 4 report the results of fitting a relaxed specification of the equation determining returns. Here we report the results of regressions of the form:

$$\ln \text{price} = a + b\,(\ln \text{release price}) + c\,\text{Age} + dX + e \qquad (7)$$

where X represents the weather variables whose effects we test. In an efficient market, $a = 0$, $b = 1$, and $d = 0$, with the coefficient on c measuring the rate of return. Tests of this hypothesis in either column 3 or column 4 of Table 4 strongly reject it.

From the data on release prices displayed in Table 2 it is easy to see why the tests reject the market efficiency hypothesis. For example, the release prices of the 1970, 1971, 1972, and 1973 vintages were all identical. However, the weather data (and subsequent auction prices) indicate that 1971 was by far the superior vintage among these four. As a result the investor who bought the 1971 vintage purchased a better investment than the buyer of the other vintages and this should have been known at the time of the release of the wines. Examples as extreme as this are unusual, although it appears that buyers of the 1987 vintage might well have been better served by buying any of the surrounding vintages instead.

It seems apparent that the initial prices of the Grange have not historically been adjusted to reflect the variability in the growing season weather that produced the wines. Despite this, the eventual auction prices of the wines do reflect the weather during the growing season. In this regard the market for the young Granges is no different than the market for young Bordeaux wines, which also are not priced to reflect the weather during the growing season that produced the vintage. The evidence for Bordeaux is that it takes at least a decade, and sometimes longer, before the auction prices begin to reflect the weather that produced the growing season of a vintage. It remains a puzzle as to why this information is ignored in the pricing of the young wines both in Australia and elsewhere.

[10] Retail prices are typically 35 per cent higher than wholesale prices, and the returns to a retail buyer would have to be reduced accordingly. Wholesale prices are from Thomson's Liquor Guide, as reported in Penfold's *The Rewards of Patience* (1990).

TABLE 4
*Test of the Predictability of the Returns to Ageing of Grange**
(t-values in parenthesis)

	Dependent Variable:				
Independent Variable:	Return on Grange:			ln Price:	
Constant	0.18 (32.72)	0.075 (2.08)	−3.60 (.97)	2.12 (2.12)	−54.0 (2.16)
ln Release				0.205 (0.97)	0.402 (1.80)
Holding Period Age				0.070 (2.25)	0.101 (2.97)
Qual		0.0012 (3.0)		0.012 (4.0)	
Rain			−0.00033 (1.94)		−0.003 (2.50)
Temp			0.415 (1.05)		6.23 (2.41)
Temp^2			−0.0106 (1.01)		−0.16 (2.32)
Dif temp			−0.087 (7.43)		−0.210 (2.41)
R^2	—	0.36	0.46	0.85	0.89

* Qual is the 'estimated quality index' referred to in Figure 3.

VI Conclusions

The role played by weather in determining the price (and quality) of Grange Hermitage does not appear to be as strong as for the Bordeaux wines. Nevertheless, the weather effect is there—a warm spring and summer makes a positive difference, a wet summer has a negative impact and stable temperatures are a plus. The only difference to the Bordeaux results is that no winter rainfall effect was discovered. The interesting part of the study is the prediction it makes possible, the '87 will not be a memorable wine, but the '89 and '90 will be outstanding, probably the best Granges in the last 25 years. The '85 and '92 also look good and even the three downturn years, the '91, '93 and '94, appear to be at the same index level as the '76 to '84 period. All this, and not a single tasting—blind or otherwise!

Considering Grange as an investment, the return varies between 12-13 per cent (nominal) in the (cross-section) regression results and 18 per cent in the time-series regressions based on release and wholesale prices derived from non-auction sources. In both cases the advantage of correctly predicting the quality of a young Grange is highlighted. However, the market does not appear to be efficient: the release prices of young Granges do not seem to reflect their ultimate quality, so the weather influences quantified here, which reflect the conventional wisdom in the industry, do not get factored into the release prices or even the price of a young Grange at auction. The same is true of young Bordeaux wines.

In some ways the most important results of this study are the implications it contains for the plantation of future vineyards. The Grange is an example of a 'new world' wine that has been a major success in the market. Producing more successes of this type will require the matching of grape types to appropriate climates. The results in this paper provide some important clues about how best to do this.

DATA APPENDIX

TABLE 5

*Auction Prices (Australian Dollars) and Weather Data**

vintage	sale91	sale92	sale93	temp	rain	diff
1959	218.09	223.29	450.33	18.18	28.70	6.76
1960	nt	210.50	277.67	18.73	55.70	6.73
1961	131.50	131.44	132.00	18.76	20.30	7.36
1962	156.00	162.15	180.91	18.81	41.00	7.21
1963	118.00	149.31	180.50	17.98	42.10	6.84
1964	92.78	124.79	115.05	18.53	41.10	7.76
1965	119.56	148.08	157.00	18.62	0.50	8.38
1966	135.08	172.31	153.46	19.38	39.10	7.26
1967	80.38	122.89	131.03	18.01	35.80	6.88
1968	75.06	90.74	99.57	19.72	67.50	7.20
1969	69.40	76.79	74.80	17.78	120.70	6.58
1970	78.06	84.64	90.61	17.85	27.00	7.47
1971	126.82	141.29	181.33	18.89	5.90	7.28
1972	63.15	68.17	74.67	17.53	62.40	7.08
1973	67.03	78.63	97.57	19.18	115.60	7.02
1974	75.00	93.36	109.77	19.11	138.40	6.31
1975	71.81	84.56	104.91	17.83	14.20	6.86
1976	83.34	100.20	124.67	18.89	63.80	6.76
1977	74.36	85.71	101.73	18.55	40.20	6.85
1978	54.28	81.60	101.30	19.02	35.20	7.18
1979	60.47	71.27	79.47	19.24	64.40	7.11
1980	59.46	73.89	83.40	18.39	9.40	7.16
1981	53.31	58.73	72.37	19.68	30.40	6.91
1982	61.35	81.26	92.77	19.43	22.10	7.07
1983	58.15	72.65	92.67	19.85	8.00	7.42
1984	48.75	62.00	71.16	18.48	19.80	7.26
1985	50.86	66.79	65.35	18.93	5.60	7.11
1986	nr	91.00	100.08	18.34	9.20	7.09
1987	nr	nr	65.00	17.38	50.60	6.90
1988	nr	nr	nr	18.94	37.00	7.13
1989	nr	nr	nr	19.17	2.40	6.88
1990	nr	nr	nr	18.98	23.60	6.84
1991	nr	nr	nr	19.28	28.80	7.43
1992	nr	nr	nr	18.48	11.00	6.93
1993	nr	nr	nr	18.00	69.20	6.03
1994	nr	nr	nr	18.14	21.40	6.78
average				18.67	39.11	7.05

* Note, nt means 'not traded', nr means 'not yet released'.

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