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ABSTRACT

What Determines the Future Value of an Icon Wine? New Evidence from Australia*

To what extent can the future price of icon wines be anticipated from information available at the time of their initial sale by wineries? Using a hedonic model we show that weather variables and changes in production techniques, along with the age of the wine, have significant power in explaining the secondary market price variation across different vintages of each of three icon Australian red wines. The results have implications for winemakers in determining the prices they pay for grapes and charge for their wines, and for consumers/wine investors as a guide to the prospective quality of immature icon wines.

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What Determines the Future Value of an Icon Wine?
New Evidence from Australia

I Introduction

The Australian secondary wine auction market is characterised by large variations in price between different vintages of the same wine, relative to the wineries' initial release prices of these wines. Thus, there exists the potential for buyers to improve their investment returns by choosing to purchase those vintages that are under-priced at the time of release, relative to their future secondary market value. Similarly, wine producers could improve profits either by charging higher prices for the better vintages (reflective of the price those wines will receive later in the secondary market), or by holding back some of the better vintages to sell later as the wine's future quality becomes more obvious.

An important question for both these producers and buyers is: to what extent can the future prices of such icon wines be anticipated from information available at the time of first release? Tasting the young wine, even by professionals, is unreliable because the high tannin content makes them astringent to the palate in their early years.

Weather conditions during the grape-growing season, long recognised by vignerons as a determinant of the quality of a vintage, may provide an objective and easily quantifiable guide (Gladstones 1992). Econometricians have tested that hypothesis for Bordeaux wines and found it is strongly supported (Ashenfelter, Ashmore and Lalonde 1995). A more-limited test on just one Australian wine (Grange) using only three years of auction data gave promising results as well (Byron and Ashenfelter 1995). The purpose of the present paper is to make use of the much larger database now available to test this hypothesis for a broader range of icon wines using additional years of auction data.

Specifically, a seemingly unrelated regression model is used to explain the variation in the secondary (auction) market price between different vintages of particular wines, using several weather variables plus dummy variables for capturing changes in winemaking and grape growing techniques over time (based on interviews with the chief winemakers of the relevant wineries). The model is estimated using auction price data for three South Australian icon red wines: two by Penfolds

(Grange and St Henri), and one by Henschke's (Hill of Grace).[1] This attempt to explain the variation in price between different vintages of the same wine label is in contrast to numerous studies that seek to explain the variation in price between the same vintages of different wineries (see Oczkowski (2001), Schamel and Anderson (2003) and the references therein).

The paper is structured as follow. We first review previous studies that attempt to quantify the relationship between weather conditions during the growing season and wine prices. We then discuss our choice of variables for explaining the relationship between quality and weather, production techniques and wine age. The next section presents the empirical results, while the final section draws out conclusions, offers some implications for winemakers and consumers/investors, and suggests areas for future research.

II Previous Literature

Ashenfelter, Ashmore and Lalonde (1995) were the first to attempt an empirical explanation of the variation in price between different vintages of the same wine. They consider the variation in price between different vintages of a representative sample of thirteen Bordeaux wines (used to create a vintage price index). The paper uses weather conditions during the growing season that produced the wine. Ashenfelter et al. also include age as an explanatory variable to capture the effect of increasing scarcity and the opportunity cost of holding wine. They find that age alone can explain 21 per cent of the variation in the price index between vintages. However, the inclusion of three weather variables in the model increases the model's explanatory power (as measured by R^2) to 83 per cent.

The 'Bordeaux Equation' was modified for a single wine by Byron and Ashenfelter (1995) in a study of Penfold's icon wine, Grange, and by Fogarty (2000) in a study of an icon West Australian wine, Moss Wood. These studies found a number of weather variables and age to be significant explanators of variation in price of these wines (with $\bar{R}^2$ of 0.83 and 0.88, respectively). In addition, the models were demonstrated to have strong out-of-sample predictive power. The findings of these studies support the Ashenfelter et al. hypothesis that the secondary market price of a given vintage depends on the weather conditions that produce the vintage.

Jones and Storchmann (1999) more clearly articulate the relationship between weather and wine quality. They adopt a two-step approach to modelling the price variation of Bordeaux wines, both between different wines and across vintages.

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[1] Some information on these classic wines is provided in Appendix 1 of Wood and Anderson (2003). For more details see Halliday (1998) and Read and Caillard (2000).

Firstly, they estimate a model to explain variation in sugar and acid content at harvest by climatic variables. Secondly, they use these two endogenously determined variables as explanatory variables in the price regression, thus highlighting the channel through which weather influences quality and hence price. Another contribution made by this paper is recognition of the contribution of winemaking techniques to quality variation.

III The Model

What factors explain the variation in quality (and hence price) between different vintages of the three icon wines in this study? The potential quality of a wine is a product of the quality of the inputs (particularly grapes) and the winemaking techniques used to transform these inputs into the final product. The quality of grapes in turn is determined by the interaction of soil, topography, climate and grape growing techniques. Given that we are attempting to explain variation in price of different vintages of the same wine label, it is reasonable to treat soil quality, aspect, slope and altitude as constant between vintages. Thus, this study focuses on variations in weather and changes in grape growing and winemaking techniques as explanators of potential quality differentials. However, the actual quality of the wine at any point in time depends on whether it has yet reached or has passed its peak, and thus we also discuss the importance of age in explaining quality variation across vintages at any point in time.

Weather

The influence of weather conditions during the growing period on grape quality has been well established. In recognition of the importance of climate, winemakers develop grape growing techniques to maximise the beneficial aspects of climate while reducing weather-based fluctuations in quality. Smart (2001) argues that while all climate parameters can be important in influencing grape quality, temperature is undoubtedly the most important. Gladstones (1999) suggests an average daily temperature during the growing season (mid-September to March in southern Australia) of 20-22ºC is optimal for the formation of colour, flavour and aroma compounds in red table wines. Thus, we assume that grapes grown under these optimal conditions will be of the best quality, and vintages produced from these grapes will receive the highest prices.

Ashenfelter, Ashmore and Lalonde (1995) report a positive linear relationship between average temperature during the growing season and price for Bordeaux red wines. However, when considering the warmer Barossa region of South Australia where the average growing season temperature regularly exceeds the suggested optimum, Byron and Ashenfelter (1995) find a quadratic function to be the most appropriate way to model the effect of temperature on wine prices. The quadratic function they estimate is concave with a turning point of 19.05 degrees, just slightly below the temperature range Gladstones puts forward as optimal.

Temperature also has the potential to affect quality and yields through its variation. Gladstones points out that the biochemical processes of grape development are favoured by a low diurnal temperature range (ie. the difference between the daily maximum and the nightly minimum temperatures). His argument is supported by Byron and Ashenfelter, who find a significant negative relationship between the price of Grange and the average temperature differential during its growing season.

The fact that diurnal temperature variability has the potential to affect grape quality suggests that average daily temperature (the average of the daily maximum and minimum temperatures) may not be the most appropriate index to test the affect of temperature on grape quality. For example, even though one vintage year may have a lower average temperature than another, this may simply be because the minimum temperatures are lower (and hence the diurnal temperature range larger). The average maximum temperature during the growing season therefore may be a more reliable index than simply the average temperature to quantify the affect of temperature on a particular grape vintage.

The number of hours of sunshine is another variable important to grape quality, both directly and for its interaction with temperature. Gladstones (1992) suggests that sunshine hours during the growing season, particularly in early spring, have a positive influence on quality. However, previous statistical analyses (Ashenfelter et al. 1995, Byron and Ashenfelter 1995, and Fogarty 2000) fail to identify any statistically significant relationship between hours of sunshine and icon wine prices. This failure is likely to be linked to the correlation between sunshine hours and temperature, which makes isolating their separate effects difficult.

After temperature, Smart (2001) ranks rainfall as the next most important climatic determinant of grape quality. As Gladstones (1992) points out, it is the seasonal distribution of rainfall that is important. Rainfall during winter and early spring aids grape development, particularly since the three wines considered come from vineyards that rely wholly or mostly on precipitation. On the other hand, rainfall in the period prior to harvest can waterlog the soil and thus prove detrimental to both grape yield and quality. These effects find statistical support in the study by Ashenfelter et al. (1995), who report evidence of a negative relationship between rainfall prior to harvest and Bordeaux wine prices, and a positive relationship between rainfall during the winter preceding the vintage and price. While the study of Grange prices by Byron and Ashenfelter (1995) also finds statistical evidence of the detrimental effect of rainfall prior to harvest, they do not find any statistically significant relationship between winter rainfall and price.

Gladstones (1992) also suggests there is a positive relationship between wine quality and relative humidity in February, the last month of the growing season. This relationship is particularly important in the relatively warm wine regions in Australia where afternoon humidity is necessary to encourage ripening when February temperatures are high.

The final climatic variable listed by both Gladstones (1992) and Smart (2001) as important to grape quality is windiness. Wind can have both a positive and negative influence on quality. On the positive side, wind can help prevent frosts and provides air circulation to the vines (which lowers humidity). However, strong winds have the potential to harm grape quality (Hamilton 1988). In South Australia, added dangers arise from hot, dry summer winds because they can cause imperfect ripening.

Vineyard management techniques

In addition to these weather influences, changes in vineyard management techniques can explain quality differences between the grapes used to produce different vintages. Gladstones (1992) details a range of practices important to both grape yield and quality. The spacing of vines determines the exposure of vines to sunlight, water and soil nutrients and therefore affects both yield and quality. Also affecting sunlight exposure is the orientation of rows. The height of vines is also important, because it determines the amount of heat the vine is exposed to via radiation from the soil. Further improvement of the efficiency of light use can come from the adoption of a suitable trellising system and canopy management. Irrigation, fertilisation, artificial drainage and windbreaks are other vineyard management techniques that may be important influences on grape yield and quality.

Winemaking techniques

High-quality grapes are an essential but not sufficient condition for producing high-quality wines. It is only when quality grapes are combined with superior winemaking techniques that excellent wines are produced. The first important facet of winemaking is the selection of the grapes, followed by any blending. For the three Penfold wines considered in this study, the blends change with each vintage along with changes in grape quality from different sites. For Henschke’s Hill of

Grace, a single-vineyard wine, the absence of the option to blend to offset quality variation means that the choice of grapes is of utmost importance.

Another important aspect of making icon wines is the oak in which the wine is matured. Changes in the type of oak and the length of maturation can alter the distinctive quality of the wine as well as the cost of production and thus its market price. Also important is whether the barrels are new or used.

Age of the wine

A characteristic of icon wine of the sort considered in this study is their ability to develop and improve with age. These wines are characterised by a high content of tannins in their youth, making them unpleasant for early drinking. Then as the tannin content recedes, the quality gradually improves until the maximum quality is reached. This state can persist for a number of years or even decades before the quality begins to decline.

Age is also related to price because the scarcity of a given vintage is non-decreasing with time. As a wine ages, more of the given vintage stock is consumed so that scarcity, and hence price, increases. For this reason, icon wines past their optimal drinking age can still command increasing prices over time.

Although previous studies model the relationship between quality and age linearly (Ashenfelter et al., Byron and Ashenfelter, and Fogarty), it seems reasonable, given the nature of the maturation process, to model age as a cubic function: prices rising when the wine is young, plateauing out around optimal drinking time, before increasing again in value as the wine becomes an ‘antique’ wine.[2]

IV The Data

Price data

Wine auctions are the principal secondary market for icon wines in Australia, aided by the fact that the liquor licensing laws in many states prohibit private sales of wine. Auction prices provide a comparatively high degree of price transparency, and therefore provide the best indication of the equilibrium value of a particular vintage of wine at any point in time. In addition, these auctions are of the ‘silent bid-written tender’ kind and thus circumvent many of the problems of auctions as a

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[2] We thank an anonymous referee for this suggestion.

price determination mechanism. Langtons represent over 70 per cent of the wine auction market in Australia,[3] and they have kindly provided the price data for this study.

The data provided are the high and low sale price and the date for every occasion on which each of the three icon wines was traded over the period 1988-2000. From this, the unweighted average of the sale price for each vintage in each auction year is calculated for each of the three wines. The prices are unweighted because data on the volume of wine traded at each date are, unfortunately, not available. However, in so far as differences in volumes traded are not large and are randomly distributed for a given vintage, this should not unduly affect the analysis.

Because the wine auction market in Australia only really developed in the last decade, many of the vintages were not traded every year, particularly in the first few years. Thus, only the auction years which provide a sufficient number of observations are considered for each wine. They are 1992-2000 for Grange, 1994-2000 for St Henri, and 1995-2000 for Hill of Grace.

In addition, some of the earlier vintages of each wine are excluded from the analysis because they were too infrequently traded. The vintages that are included are: 1960-1986 for Grange, 1965-1991 for St Henri, and 1971-1991 for Hill of Grace (except no 1974 vintage exists for Hill of Grace).

For the later auction years for each wine, price data for a number of additional vintages are available. For example, in 2000, vintages of Grange up to 1995 were traded, yet only prices for vintages up to 1986 are included in our data set to ensure a balanced sample. This provides scope to test the out-of-sample forecast power of the model.

The unweighted average nominal price in each auction year is converted into real price using the Consumer Price Index with base year 2000.

Weather data

The weather data are sourced from the Australian Bureau of Meteorology’s Climate Station at Nuriootpa in the heart of the Barossa Valley in South Australia. A major issue is determining the weather conditions during the growing season for Penfolds grapes, because they are sourced from various regions but in different proportions each vintage. Because the exact percentages of grapes used from each region to

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[3] Details are given in Langton (2001 and earlier editions).

produce a given vintage are not publicly available, it is not possible to create a weighted average weather index for each vintage. Mike Farmilo, the Chief Winemaker at Penfolds, suggested the Nurioopta Climate Station would be the most representative site for Grange, and indeed Byron and Ashenfelter (1995) found that the data from this station provided the best fit. Hence this study will also use Nurioopta as a representative Climate Station for Grange. St Henri, like Grange, also uses grapes primarily sourced from the Barossa region and so Nurioopta will be used as the representative station for this wine also. For Hill of Grace, a single site wine, Nurioopta is the closest Climate Station with sufficient data available.

Technological change data

Data on the major changes in viticultural management and winemaking techniques were collected by interviewing the Chief Winemakers at Southcorp (the producer of Penfolds) and Henschke. In the interviews John Duval from Penfolds and Stephen Henschke discussed what they considered to be the major changes in their grape growing and winemaking techniques over the sample period.

In recognition of the importance of grape quality to all its blended wines, Penfolds introduced the star quality system in 1983. This system helps overcome the possible principal-agent problem with their grape growers, by offering them substantial bonuses in line with the number of stars (a measure of quality) that their grapes achieve. Penfolds management adopted this system to maintain the integrity of their top wines, by introducing a minimum star requirement for the grapes used to produce each wine. However, while it is likely the plan has improved quality (and reduced quality risks) since its introduction, the fact that it was phased in over a number of years makes it less likely to show up as significant than if it was introduced overnight.

Another innovation introduced across the two Penfolds wines was a change in grape-pressing techniques in 1990, again aimed at improving the quality of the wine produced.

Langtons 1998 *Fine Wine Investment Guide* suggests that early vintages of Hill of Grace (1971-1977) are not considered as distinguished as vintages produced from 1978 when Stephen and Pru Henschke took over the family winery. Thus, we include a dummy variable with a break at 1978 to see whether the data suggest this is indeed the case.

In addition, Stephen Henschke detailed a number of changes introduced during his period of managing the winery that may have improved the quality and hence the demand for the wines. In 1983, refrigeration was introduced into the winery. In the same year, the wine was matured in new French Oak barrels for the first time. And in a further attempt to improve grape quality, a new trellising system was introduced in 1990.

It should be noted however, that many of the changes in viticultural management and winemaking techniques described would have lead to higher production costs. For example, the new French oak adopted for the maturation of Hill of Grace is substantially more expensive than the new American oak that was used prior to 1983. These higher production costs would be reflected in a higher release price for the wine, and all else being equal, higher secondary market prices. Thus, any evidence of higher secondary market prices for vintages employing these improved techniques may reflect a ‘pass through’ of higher production costs along with a premium buyers are willing to pay for the superior quality of the wine.

V Estimation Methodology

Following the approach of Byron and Ashenfelter (1995), the relationship between price and the age, weather and technique variables are first estimated separately for each auction year using an unconstrained seemingly unrelated regression (SUR) model. Because the regressors in each equation are identical, this is equivalent to equation by equation OLS (Greene 2002).

A log linear functional form is adopted, reflective of the fact that the magnitude of the effect of age, weather and technique would be expected to rise with the price of the wine (Byron and Ashenfelter 1995).

Wald coefficient tests are used to test whether the coefficients on the explanatory variables are identical across equations. Given that we would expect that the effect of age and quality on price should not differ substantially across auction years, this is an important step in establishing the credibility of the explanatory variables and the functional form (Byron and Ashenfelter 1995). The constants in each equation, however, would not necessarily be the same across auction years. Rather these capture ‘shifts’ in prices across all vintages, due to macroeconomic conditions or changes in demand for a given brand of wine, for example.

The explanatory variables considered for each wine are:

Age_{it}: Age of vintage ‘t’ in auction year ‘i’;

$AgeS_{it}$ Age of vintage ‘t’ in auction year ‘i’ squared;

$AgeC_{it}$ Age of vintage ‘t’ in auction year ‘i’ cubed;

$RainH_t$: Total rainfall in January, February and March, (the period just prior to harvest) in the year that produced vintage ‘t’;

$Temp_t$: Average daily growing season temperature, calculated by taking the average daily temperature (maximum +minimum)/2 and averaging these over the months October- March;

$TempS_t$: Temp squared,

$TempD_t$: Average daily growing season temperature variation, calculated by taking (average monthly max – average monthly min) and averaging over the months October-March,

$Humid_t$: Average daily 3p.m. relative humidity in February (last growing month),

$Wind_t$: Average daily wind speed in November and December,

$WindS_t$: Wind squared,

Sun_t: Total hours of bright sunshine during spring (September-November).

$Press_t$: A dummy variable for Penfolds wines with break at 1990, the year in which Penfolds changed their pressing technique,

SP_t: A dummy variable for Hill of Grace with a break at 1978, the year Stephen and Prue Henschke took over the family winery,

$Fridge_t$: A dummy variable for Hill of Grace with break at 1983, the year refrigeration was introduced in the winery, and also the year from which the wine was matured in new French Oak, and

$Trellis_t$: A dummy variable for Hill of Grace with break at 1990, the year a new trellising system was introduced.

To test a proposition outlined in section III — that maximum temperature may be a better predictor of grape quality than average temperature — we also estimate the models using average daily maximum temperature over the growing season in place of average daily temperature.

VII Results

The estimates from the unconstrained SUR models are presented in Tables 1, 2 and 3 for Grange, St Henri and Hill of Grace, respectively. The preferred models are derived using a general-to-specific modelling approach, using selection criteria such as log likelihood, to provide a guide to the best fitting model across all auction years.

Diagnostic tests (for heteroscedasticty, serial correlation and normality) are performed on the residuals from the OLS equations for each wine across each auction year. These results are also presented in the relevant tables. There is evidence of heteroscedasticty for some auction years for Grange. This is corrected for using White's heteroscedasticty correction (White 1980), and the corrected standard errors are presented below the estimates.

Wald coefficient tests are performed to test whether the coefficients on the explanatory variables are identical across auction years. For the majority of coefficients these restrictions cannot be rejected, suggesting that preferences for particular characteristics of the wine (as imparted by the weather conditions during the grape-growing season) have not changed over the auction years considered. This implies that a constrained SUR model can be estimated. The estimates from the constrained SUR model are presented in Tables 4, 5 and 6. These results are discussed in more detail below.

Age

The estimated effect of age on price is not directly comparable across Grange, St Henri and Hill of Grace because of the different functional forms adopted. For both St Henri and Hill of Grace, age is estimated to effect the secondary market price in a cubic fashion. The coefficients are significant for both wines, and remarkably similar between the two wines. The coefficients suggest that prices rise with age initially, reach a plateau, and then begin to rise again.

This result is consistent with the hypothesis that while quality determines the price of these wines in the initial years after their release, but eventually relative scarcity becomes the price driver. The optimal drinking age should occur around the turning of the cubic function (where prices plateau). For both St Henri and Hill of Grace the estimated turning point (at age 22.6 for St Henri and 19.7 for Hill of Grace), is within the optimal drinking range for most of the vintages considered in the sample (Read and Caillard 1994). After these wines have passed their optimal drinking time their 'icon status' means they still have collector value well beyond their potential for drinking. That is, the vintages of St Henri still in circulation but possibly past their prime for drinking are mainly in the market as antiques, rather than as part of the market for fine drinking wine, with consumers implicitly valuing highly their scarcity.

For Grange, on the other hand, age is estimated to effect the secondary market price in a linear fashion. The age coefficient of 0.022 is significant and suggests that an extra year of aging corresponds to an average 2.2 per cent increase in the real price, ceteris paribus. This is slightly lower than previous studies (Ashenfelter et al., Byron and Ashenfelter, and Fogarty) which report estimated coefficients (based on nominal prices) of 0.035, 0.041 and 0.03, respectively.

Why should prices for St Henri and Hill of Grace rise at a diminishing rate over the first twenty years and eventually plateau before beginning to rise again, while prices for Grange continue to grow linearly with age? The longer-term cellaring potential for Grange may provide some explanation for this. According to Read and Caillard (1994), all but four of the vintages of Grange in our sample were still at their peak or were yet to reach their peak in the auction years considered. This is in contrast to St Henri and Hill of Grace for which many of the older vintages were well past their optimal drinking age. It may also be that Grange’s longevity is such that, well before the quality begins its eventual deterioration, the wine has already achieved ‘antique’ status — that is, it is sufficiently old and rare to be viewed as a collector’s item. Because of the large number of years it takes for the wine to reach its peak, and then the large number of years for which it can maintain it (Read and Caillard 1994), it is conceivable that a given vintage could be quite rare even when only in the middle of its ‘recommended drinking age’ period. In that case, the plateau in price as quality falls would not occur because the price will continue to be driven upward by the relative scarcity, resulting in a linear relationship between age and price.

Temperature

Temperature is found to have a significant effect on the secondary market price variation of the vintages for all three icon wines considered. No significant difference was found between the explanatory power of the models using average daily maximum temperature compared with using average daily temperature, so we report the results based on average daily temperature for easier comparison with previous studies.

For Grange, and St Henri, the relationship between average daily growing season temperature and price is found to be best modelled linearly, with coefficients of 0.026 for Grange and 0.048 for St Henri. This suggests that a one degree increase in the average maximum growing temperature leads to a 2.6 per cent increase in the price of Grange and a 4.8 per cent increase in the price of St Henri. These estimates should be viewed in the context of the stability in average temperatures in the region. For example, over the period 1960-1986 the standard deviation in average daily temperature was only 0.69.

For Hill of Grace, the relationship between secondary market price and average maximum growing season temperature is found to be best approximated by a quadratic. That is, higher average maximum temperatures lead to higher secondary market prices up to the 18.6˚C optimal level, but for temperatures higher than 18.6 degrees, the opposite is true. This is slightly below the 20-21 degree range that Gladstones suggests is optimal.

The diurnal temperature range is also found to be significant in explaining the variation in price between vintages for all of the wines considered. Consistent with the viticulture literature, the estimated relationship in each case is negative, suggesting that a large temperature range has a negative affect on the quality of the grapes in a particular vintage year.

Rainfall

The estimated effect of total rainfall in the period prior to harvest was remarkably consistent across the two Penfolds wines. In line with viticultural expectations, higher rainfall during this period has a negative effect on grape quality and thereby on secondary market prices. We estimate a one-millilitre increase in the total rainfall prior to harvest leads to an average 0.4 per cent decrease in the secondary market price of Grange and a 0.3 per cent decrease for St Henri. These estimates are also remarkably similar to those estimated in other studies (0.4 per cent for Ashenfelter et al. and 0.3 per cent for Byron and Ashenfelter). However, rainfall in the period prior to harvest was not shown to have a significant effect on the price for Hill of Grace.

Winter rainfall in the Ashenfelter et al. study was found to be significantly positively related to the secondary market price of Bordeaux wines. We find it to be positive but insignificant for all three Australian icon wines.

Other weather variables

Humidity, sunlight, and windiness were all discussed in section III as potentially important to wine quality. Humidity and sunshine hours were tested as explanators of secondary market prices in Byron and Ashenfelter (1995). They, like us, found those variables not to be statistically significant. However, we find windiness to be significant in explaining the price variation of all three wines we considered. In each case we found the variable to be best modelled as a quadratic, consistent with viticultural theory. The optimal wind speeds were estimated to be 11.8 kms per hour for Hill of Grace and slightly higher at 16.5 and 17.5 for Grange and St Henri, respectively. The model suggests that wind impacts negatively on the secondary market price once these optimal speeds are reached.

Technological change

Improvements in production techniques introduced by viticulturists and oenologists are shown to have a positive effect on the secondary market prices of their wines where they are significant. For Hill of Grace, consumers are increasingly willing to pay for vintages produced since the time that Stephen and Prue Henschke took over their family winery in 1978. Further, the improvement in grape quality as a result of a new trellising system in 1990 is also reflected in the secondary market prices of vintages produced from that year onwards. However, as noted earlier, if this change in technique increased production costs, the higher price may to some extent reflect the passing through of these higher costs.

Goodness of fit

The signs of all the coefficients in our model are in line with viticultural expectations. In addition, there are other indications that our model is explaining well the price variation between different vintages of the same wine. Firstly, the R^2 for both the constrained and unconstrained SUR models for each wine are quite high. This indicates that the weather and changes in production techniques, along with the age of the wine, explain from 24 to 77 per cent of the variation in prices for any given auction year.

Using pooled Ordinary Least Squares[4] to estimate the models provides a single R^2 for each model. These are 0.82 for Grange, 0.70 for St Henri and 0.76 for Hill of Grace. The models in each case demonstrate significantly superior explanatory power compared to models estimated with age as the only explanatory variable. The R^2 for the models with weather and technological change variables excluded are 0.62, 0.58 and 0.67 for Grange, St Henri and Hill of Grace, respectively. This suggests weather variation in Australia is less important in explaining prices than is the case for fine Bordeaux wines. Ashenfelter, Ashmore and Lalonde show that introducing weather variables into their model improves the R^2 from 0.21 based on age alone to 0.83. The greater importance of weather for Bordeaux is likely to be related to the much stronger variation in climatic conditions in that part of the world. For example, the temperature variation in Australia (0.69 over the period 1960-1986) is considerably less than that in Bordeaux (0.xx). Also, because Ashenfelter, Ashmore and Lalonde did not experiment with alternative functional

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[4] Using cross-section specific constants and cross-sectional SUR weights, such that the estimates are identical to the constrained SUR estimates reported.

forms for the age variable, it is possible that the low explanatory power of their model based on age alone reflects the fact that age does not influence price in a linear fashion.

Our model is found to be particularly robust to alternative specifications in each case. For each wine the regression was re-estimated by systematically dropping one of the vintage observations at a time. The coefficients in each of the models exhibited minimal variation, and there was shown to be no statistically significant change in the models' explanatory power (as measured by R^2) any of the times that each model was re-estimated. The coefficient values attributable to each of the explanatory variables were also shown to be remarkably robust to the inclusion of insignificant explanatory variables in each model.

Also, the actual price was almost always within the 95 per cent confidence bands around the estimated price for the in-sample estimates (see Figures 1, 2 and 3). Although in some cases the confidence intervals are quite large, the fact that the model tracks the peaks and troughs of the auction price data closely provides further evidence that it is capturing weather- and age-driven quality variations.

The out-of-sample forecast power of the models is also demonstrated in these figures. For Hill of Grace and St Henri, the out-of-sample vintages fall within the 95 per cent confidence interval estimates; for Grange, however, the actual prices in a few cases break out on the upper side of this interval. This suggests that our model is under-predicting the prices of more-recent Grange vintages. While we were unable to obtain precise release price data for our study, anecdotal evidence suggests that release prices have increased strongly over the past decade for Grange (and more recently have also increased for Hill of Grace and St Henri). In that case, secondary market prices would be expected to rise if investors delay selling their product in the hope of achieving their expected return on their investment (Basedon historical returns when release prices were lower).[5]

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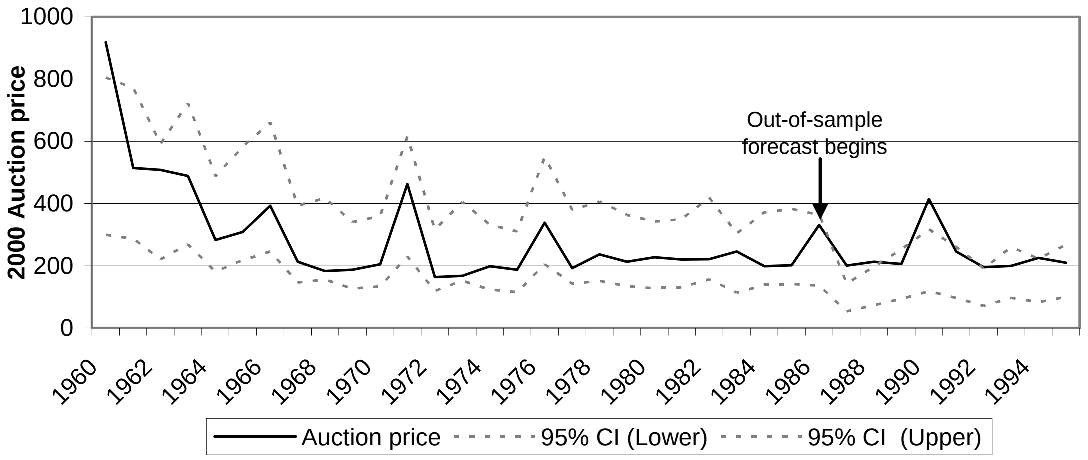
[5] It would be interesting to see whether more-recent vintages of St Henri and Hill of Grace are similarly selling for prices above those that would be estimated using historical data. If this were to be the case, then the release price or recommended retail price of the wines is an omitted variable in the estimated models. This does not invalidate our model as a predictor of vintage quality, however.

Figure 1 **Actual and fitted auction prices: Grange**[a]



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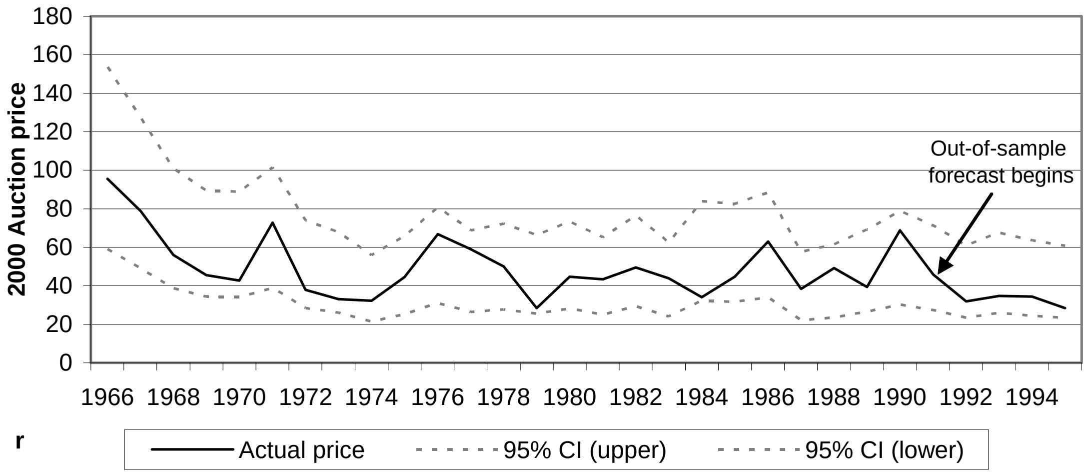
[a] The fitted price is the mid-point between the 95 per cent confidence interval bands. The out-of-sample forecast is from the 1987 to the 1995 vintages.

Figure 2 **Actual and fitted auction prices: St Henri**[a]



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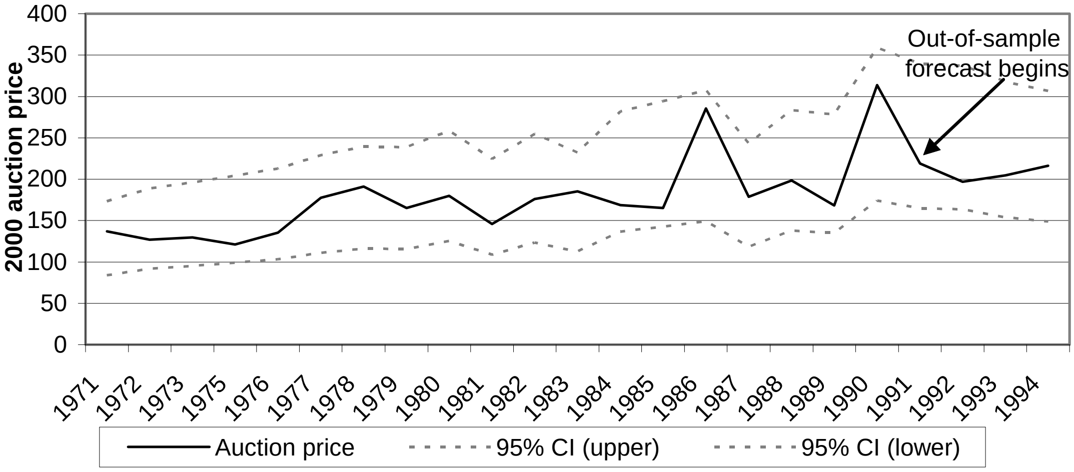
[a] The fitted price is the mid-point between the 95 per cent confidence interval bands. The out-of-sample forecast is from the 1987 to the 1995 vintages.

Figure 3 **Actual and fitted auction prices: Hill of Grace**



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[a] The fitted price is the mid-point between the 95 per cent confidence interval bands. The out-of-sample forecast is from the 1987 to the 1995 vintages.

VIII Summary and Conclusions

This study adds to the existing empirical literature on wine pricing by considering the determinants of secondary market price variation between different vintages of the same wine. We assume that the price of a given vintage on the auction market is determined by the quality of the wine. Therefore, the price variation between vintages can be explained by differences in quality, which affects the consumers' willingness to pay (and of sellers' willingness to sell). In particular, extending the framework of Ashenfelter, Ashmore and Lalonde (1995), we are able to explain econometrically these quality differences on the basis of weather conditions during the growing season and improvements in grape growing and winemaking techniques, in addition to age of the wine.

The theoretical plausibility of our models is supported by the fact that our estimates of the implicit prices imparted through superior weather conditions and winemaking techniques are in line with viticultural expectations. Our model is further validated by its robustness to alternative specifications, and by its high values for R^2.

Given that theoretical plausibility and statistical robustness of our models, we conclude that there is support for our hypothesis that the variation in consumers' willingness to pay for different vintages of aged icon wines is related to quality differentials across the vintages brought about by variations in age, weather and production techniques.

The findings of this study have implications for viticulturists, wine makers, wine consumers and investors. For viticulturists, the study provides an indication of the most appropriate climatic regions for growing ultra-premium wine grapes. In the past, this decision has been based mainly on the understanding of the relationship between terroir (physical and hydrological aspects of soil, macro- and meso-climates, topography, etc.) and quality. However, by quantifying the relationship between weather and price, our study may allow a more detailed cost-benefit analysis of grape-growing prospects in different areas, given their climatic history.[6] For winemakers buying grapes from independent growers, the price paid could be set in part on the basis of the weather variables using the equations presented in this study, pending the development of more-reliable quantitative indicators of grape quality such as grape colour, baume, and pH using NIRS technology.[7]

For the wine consumer, our study provides an objective guide to the quality of immature icon wines. While the consumer has a number of avenues for establishing the quality of the wine once mature, such as expert tasters' opinions (see, for example, Schamel and Anderson 2003), less information is available the further away are the peak drinking years of the wine. Since weather variables evidently provide a reliable indicator of future quality, our model provides a useful guide to the wine investor/consumer.

Although not explored in this study, due to difficulties in obtaining release price data, wine investors and/or producers may be able to benefit from a study of the efficiency of the primary (release) markets for icon wines. If the release price of a wine does not fully reflect all the weather features of its vintage, then wine investors could exploit the publicly available weather information and make economic profits by choosing only to invest in those vintages that are under-priced at the time of their release. Alternatively, winemakers could use that same information not only in setting their grape purchase price but also the wine release prices and/or quantities. For example, if the winemaker knows the weather conditions were exceptionally good for her/his grapes relative to others' grapes in the same region in a particular year, s/he would benefit from withholding some of that vintage for later sale once consumers realize how exceptional is that vintage.

We have yet to go back through critics' ratings books to see the extent to which their ratings when these wines were first released provided better or worse guidance to consumers than the weather variables identified in the equations estimated in this study. Another interesting avenue for future research would be backcasting, to show the extent to which our model can track past auction price movements. Does the

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[6] See Ashenfelter (1997) on how this hedonic approach can be applied to vineyard site selection.

[7] See Golan and Shalit (1993). For details of the progress being made in Near Infra Red Spectroscopy (NIRS) in Australia, see GWRDC (2001).

actual price approach the price predicted by our model (from below in good vintages and from above in poor vintages) as the wine ages? Is the pace of that convergence increasing over time as investors/consumers/producers learn more about weather and other determinants of quality (and in particular as viticulturalists find more-precise ways to compensate for adverse weather conditions)? And why do producers vary the release price of their icon wines so much less from one vintage to the next relative to the fluctuations in weather conditions from year to year?

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Table 1 **Unconstrained SUR (OLS) estimates for Grange**[a]

By auction year

Variable	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*[b]	*1998*	*1999* [b]	*2000* [b]
Constant	1.73	2.16	-0.47	0.39	-0.16	-0.78	-2.03	-1.51	-0.75
	(1.48)	(1.50)	(1.43)	(1.69)	(1.55)	(1.48)	(2.06)	(1.96)	(1.79)
						(1.66)		(1.97)	(1.89)
Age	0.032**	0.034**	0.020**	0.017**	0.015**	0.011	0.020*	0.023**	0.026**
	(0.007)	(0.007)	(0.006)	(0.008)	(0.007)	(0.007)	(0.010)	(0.009)	(0.008)
						(0.009)		(0.011)	(0.010)
Temp	0.18**	0.24**	0.27**	0.24**	0.26**	0.30**	0.38**	0.38**	0.36**
	(0.067)	(0.07)	(0.06)	(0.07)	(0.07)	(0.07)	(0.09)	(0.09)	(0.08)
						(0.04)		(0.07)	(0.06)
TempD	-0.21**	-0.35**	-0.22**	-0.25**	-0.21**	-0.23**	-0.31**	-0.36**	-0.37**
	(0.09)	(0.09)	(0.08)	(0.11)	(0.10)	(0.09)	(0.18)	(0.12)	(0.11)
						(0.10)		(0.15)	(0.14)
RainH	-0.003**	0.004**	-0.004**	-0.005**	-0.005**	-0.005**	-0.006**	-0.006**	-0.006**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
						(0.001)		(0.002)	(0.002)
Wind	0.29**	0.36**	0.44**	0.46**	0.46**	0.52**	0.62**	0.63**	0.60**
	(0.11)	(0.11)	(0.11)	(0.13)	(0.12)	(0.11)	(0.16)	(0.15)	(0.14)
						(0.09)		(0.12)	(0.10)
WindS	-0.009**	-0.01**	-0.01**	-0.01**	-0.01**	-0.02**	-0.02**	-0.02**	-0.02**
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.005)	(0.004)	(0.004)
						(0.003)		(0.004)	(0.003)
R^2	0.79	0.81	0.78	0.71	0.74	0.76	0.72	0.76	0.79
DW Stat	2.36	2.56	2.49	2.34	2.43	2.24	2.03	2.13	1.99
White's hetero Test F stat	1.49	0.71	1.29	1.78	1.93	3.39**	1.75	2.21*	2.11*
Jarque-Bera Test Statistic	1.15	1.46	1.78	1.43	2.27	1.83	1.06	1.31	2.29

a n=27. Standard errors are reported in parentheses below the estimates. **b** There is evidence of heteroscedasticity for the 1997, 1999 and 2000 regressions. The second set of terms in parentheses under each coefficient are the White heteroscedasticity consistent standard errors (White 1980). * Statistically significant at the 0.10 level; ** statistically significant at the 0.05 level.

Table 2 **Unconstrained SUR (OLS) estimates for St Henri**[a]

By auction year

Variable	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Constant	1.08	3.66**	2.63**	1.71	2.99	3.52**
	(1.26)	(1.13)	(1.05)	(1.08)	(1.11)	(1.42)
Age	0.201**	0.217**	0.076	0.026	0.019	0.087
	(0.078)	(0.080)	(0.082)	(0.092)	(0.104)	(0.142)
AgeS	-0.013**	-0.013**	-0.006	-0.004	-0.003	-0.0007
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.007)
AgeC	0.0003**	0.0002**	0.0001	0.0001	0.000008	0.0001
	(0.0001)	(0.0001)	(0.00009)	(0.00009)	(0.00009)	(0.0001)
Temp	0.11**	0.006	0.017	0.11**	0.07	0.13**
	(0.63)	(0.05)	(0.05)	(0.05)	(0.05)	(0.06)
TempD	-0.14	-0.18 **	-0.07	-0.12	-0.11	-0.26**
	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)	(0.09)
RainH	-0.003*	-0.004**	-0.003**	-0.003**	-0.002**	-0.005**
	(0.001)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0011)
Wind	0.21 **	0.21**	0.21**	0.27**	0.19**	0.20**
	(0.09)	(0.08)	(0.07)	(0.07)	(0.07)	(0.09)
WindS	-0.007**	-0.006**	-0.006**	-0.008**	-0.006**	-0.006**
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
R^2	0.50	0.58	0.61	0.70	0.62	0.64
DW Stat	2.78	2.18	2.40	2.67	2.76	2.15
White's hetero Test F stat	0.40	0.96	0.59	0.71	0.49	0.59
Jarque-Bera Test Statistic	0.74	0.22	1.58	0.19	0.18	0.61

[a] n=26. Standard errors are reported in parentheses below the estimates. * Statistically significant at the 0.10 level; ** statistically significant at the 0.05 level.

Table 3 **Unconstrained SUR (OLS) estimates for Hill of Grace**[a]

By auction year

Variable	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Constant	-31.06	-71.56**	-40.74	-72.85**	-40.41	-53.91*
	(23.07)	(22.37)	(25.67)	(26.28)	(27.46)	(23.68)
Age	-0.185	0.800**	0.557*	0.368	0.443	0.718*
	(0.213)	(0.236)	(0.306)	(0.352)	(0.409)	(0.389)
AgeS	0.011	-0.054**	-0.038*	-0.022	-0.026	-0.039*
	(0.015)	(0.015)	(0.019)	(0.020)	(0.023)	(0.020)
AgeC	0.0002	0.001**	0.0008**	0.0004	0.0005	0.0006*
	(0.00003)	(0.0003)	(0.0004)	(0.0004)	(0.0004)	(0.0003)
Temp	3.43	7.59**	4.14	8.09**	4.49	5.79**
	(2.41)	(2.32)	(2.66)	(2.71)	(2.81)	(2.40)
TempD	-0.091	-0.203**	-0.109	-0.217**	-0.121	-0.155**
	(0.065)	(0.062)	(0.071)	(0.072)	(0.075)	(0.064)
Wind	0.708**	0.493**	0.748**	0.125	0.303	0.236
	(0.254)	(0.254)	(0.280)	(0.285)	(0.295)	(0.253)
WindS	-0.030**	-0.025**	-0.035**	-0.007	-0.014	-0.011
	(0.011)	(0.011)	(0.012)	(0.012)	(0.013)	(0.011)
Trellis	0.41*	0.55**	0.41	0.44	0.45	0.57**
	(0.25)	(0.24)	(0.27)	(0.28)	(0.29)	(0.24)
SP	0.21	0.13	0.12	0.27	0.16	0.05
	(0.15)	(0.14)	(0.16)	(0.17)	(0.17)	(0.15)
R^2	0.61	0.59	0.69	0.67	0.65	0.75
DW Stat	2.03	2.23	2.65	2.28	2.32	2.07
White's hetero Test F stat	1.72	1.29	0.91	1.60	1.14	1.67
Jarque-Bera Test Statistic	0.41	0.24	0.47	1.31	0.10	0.17

[a] n=20. Standard errors are reported in parentheses below the estimates. * Statistically significant at the 0.10 level; ** statistically significant at the 0.05 level.

Table 4 **Constrained SUR estimates for Grange**[a]

By auction year

	1992	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Constant	-0.04	0.07	0.20	0.26	0.45	0.58	0.62	0.57	0.62
	(1.10)	(1.10)	(1.10)	(1.10)	(1.10)	(1.10)	(1.10)	(1.10)	(1.10)
Age					0.022**				
					(0.005)				
Temp					0.26**				
					(0.05)				
TempD					-0.24**				
					(0.07)				
RainH					-0.004**				
					(0.0009)				
Wind					0.43**				
					(0.08)				
WindS					-0.013**				
					(0.002)				
R^2	0.71	0.72	0.77	0.70	0.70	0.70	0.67	0.71	0.74
R^2 (pooled) **b**					0.82				

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[a] n=27. Standard errors are reported in parentheses below the estimates. * Statistically significant at the 0.10 level; ** statistically significant at the 0.05 level. [b] Pooled R^2 gives the unweighted R^2 of the pooled OLS model with cross-section specific constants and cross-sectional SUR weights.

Table 5 **Constrained SUR estimates for St Henri**[a]

By auction year

Variable	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Constant	1.73*	1.90**	2.06**	2.13**	2.18**	2.11**
	(0.91)	(0.91)	(0.91)	(0.91)	(0.91)	(0.91)
Age			0.16**			
			(0.03)			
AgeS			-0.010**			
			(0.002)			
AgeC			0.0002**			
			(0.00003)			
Temp			0.048			
			(0.040)			
TempD			-0.096*			
			(0.062)			
RainH			-0.0029**			
			(0.0008)			
Wind			0.21**			
			(0.06)			
WindS			-0.006**			
			(0.002)			
R^2	0.42	0.50	0.56	0.60	0.56	0.53
R^2 (pooled) **[b]**			0.70			

[a] n=26. Standard errors are reported in parentheses below the estimates. * Statistically significant at the 0.10 level; ** statistically significant at the 0.05 level. **[b]** Pooled R^2 gives the unweighted R^2 of the pooled OLS model with cross-section specific constants and cross-sectional SUR weights.

Table 6 Constrained SUR estimates for Hill of Grace[a]

By auction year

	1995	*1996*	*1997*	*1998*	*1999*	*2000*
Constant	-40.16**	-39.89**	-39.67**	-39.55**	-39.54**	-39.56**
	(13.35)	(13.35)	(13.35)	(13.35)	(13.35)	(13.35)
Age			0.167**			
			(0.066)			
AgeS			-0.010**			
			(0.004)			
AgeC			0.0002**			
			(0.00008)			
Temp			4.57**			
			(1.43)			
TempS			-0.123**			
			(0.038)			
Wind			0.284**			
			(0.131)			
WindS			-0.012**			
			(0.006)			
Trellis			0.169**			
			(0.097)			
SP			0.038**			
			(0.081)			
R^2	0.46	0.24	0.51	0.53	0.56	0.70
R^2 (pooled) [b]			0.76			

[a] n=20. Standard errors are reported in parentheses below the estimates. * Statistically significant at the 0.10 level; ** statistically significant at the 0.05 level. [b] Pooled R^2 gives the unweighted R^2 of the pooled OLS model with cross-section specific constants and cross-sectional SUR weights.