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Abstract:

We examine the impact of aging on wine prices and the performance of wine as a long-term investment, using a unique historical database for five long-established Bordeaux wines that we construct from auction and dealer prices. We estimate the life-cycle price patterns with a regression model that avoids multicollinearity between age, vintage year, and time by replacing the vintage effects with annual data on production yields and weather quality. In line with the predictions of an illustrative model, we observe the highest rates of appreciation for young high-quality wines that are still maturing. The findings suggest that the non-financial "psychic return" to holding wines that are substantially beyond maturity is at least 1%. Using an arithmetic repeat-sales regression, we estimate an annualized return to wine investments (net of insurance and storage costs) of 4.1%, in real GBP terms, between 1900 and 2012. Wine underperforms equities over this period, but outperforms government bonds, art, and stamps. Wine and equity returns are positively correlated.

JEL classification codes: C43; D44; G11; G12; Q11; Z11.

Keywords: alternative investments; luxury goods; price indexes; psychic return; consumption; storage.

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1. Introduction

Among wealthy individuals, fine wine is a mainstream investment. A recent survey by Barclays (2012) indicates that about one quarter of high-net-worth individuals around the world owns a wine collection, which on average represents 2% of their wealth. To satisfy increasing investment demand, several wine funds have sprung up. In light of the long-standing yet rising status of high-end wines as an investment—and given the debate on the role of alternative investments in portfolio choice more generally (e.g., Swensen, 2000; Ang, Papanikolaou, and Westerfield, 2010)—a study of long-term price trends in this market and a comparison with more mainstream assets is timely.[1]

By considering historical prices over many decades, we bring a longer-term perspective to studying the price dynamics of fine wine in the spirit of recent research on the performance of other "emotional assets" such as art (e.g., Goetzmann, 1993; Mei and Moses, 2002), stamps (Dimson and Spaenjers, 2011), or violins (Graddy and Margolis, 2011), as well as earlier work on long-term equity and bond returns (e.g., Schwert, 1990; Siegel, 1992; Jorion and Goetzmann, 1999; Dimson, Marsh, and Staunton, 2002) and on vintage effects in equities (Jovanovic and Rousseau, 2001).

We also investigate how aging affects wine prices independently of changes in market conditions. Identifying the effects of aging requires separating them from effects related to particular vintages (and years of sale), and this is another dimension upon which our contribution is unique. A few studies on cross-sectional variation in wine prices show that older wines tend to command higher prices (Di

[1] There is a small literature on the returns to storing wine starting in the late 1970s but the findings are mixed and depend on the period being investigated. Based on four years of auction data, Krasker (1979) finds that average returns to holding red Bordeaux and California wines are no larger than returns on Treasury bills after transaction costs. Jaeger (1981) expands the time frame by four years and finds the opposite. Later studies apply more sophisticated methods for constructing prices indexes, but also work with 15 years or less of data. Burton and Jacobsen (2001), for example, estimate returns on red Bordeaux wines from 1986 to 1996 and find returns to be low and relatively volatile. Masset and Weisskopf (2010) study a number of wines from 1996 to 2009 and conclude that adding wine to an investment portfolio can increase its return while lowering risk.

Vittorio and Ginsburgh, 1996; Ashenfelter, 2008), but do not separate effects of vintage quality from age. Indeed, to our knowledge there are no other papers that study the relation between a wine's life cycle and prices or returns.

One particular reason why it is interesting to look at the effects of aging is that even wines that have lost their gastronomic appeal can be valuable as they provide enjoyment and pride to their owners. Estimating the size of such non-pecuniary benefits along with pure financial returns is relevant from a broader asset pricing perspective since non-financial utility may also play a role in the markets for entrepreneurial investments (Moskowitz and Vissing-Jørgensen, 2002), prestigious hedge funds (Statman, Fisher, and Anginer, 2008), socially responsible mutual funds (Bollen, 2007; Renneboog, Ter Horst, and Zhang, 2011; Dimson, Karakaş, and Li, 2013), and art (Stein, 1977; Mandel, 2009).[2]

This paper begins by presenting a simple model of price dynamics that accounts for fluctuations in a wine's consumption value and attractiveness as a collectible asset over its life. The model proposes that, in general, a wine's fundamental is governed by the maximum of three measures: (i) the value of immediate consumption, (ii) the present value of consumption at maturity plus the non-financial "ownership dividends" received until consumption, and (iii) the present value of lifelong storage. The model ties the values of consumption and ownership dividends to financial wealth, which reflects the discretionary nature of luxury goods (Aït-Sahalia, Parker, and Yogo, 2004; Goetzmann and Spiegel, 2005). It also implies that, abstracting from changes in quality, the price appreciation of wines over time is determined by the growth rate of wealth. Cross-sectionally, the model delivers different predictions for the price patterns of low-quality and high-quality wines (or vintages) over their respective life cycles. The price of a wine that does not improve by maturing initially falls due to a decline in its consumption value, until the present value of the enjoyment associated with infinite ownership (i.e., the value as a

[2] Heinkel, Kraus, and Zechner (2001) and Hong and Kacperczyk (2009) show that the non-pecuniary *dis*advantages associated with holding particular stocks may also affect expected returns.

collectible) exceeds that of consumption. Prices of high-quality wines, which improve in quality after bottling, rise until maturity and then follow a V-shaped pattern. For all wines, financial returns reflect both the effects of growth in wealth and of aging on prices. The expected return on wine is always below the appropriate discount rate because the non-financial dividends received while storing a bottle endogenously lower the required capital gain. This is especially relevant for wines that are long beyond maturity as their fundamental values are determined by the future stream of ownership dividends (i.e., by their value as a collectible) and not by their consumption value.

We next construct a historical database of prices for five long-established Bordeaux wines, namely Haut-Brion, Lafite-Rothschild, Latour, Margaux, and Mouton-Rothschild—the so-called "First Growths." We consider two types of price information: transaction prices realized at auctions organized by Christie's London, and retail list prices of the London-based wine dealer Berry Bros. & Rudd. The data are hand-collected from various sources, including archived auction catalogues, dealer price lists, and company publications and websites. The database includes 36,271 prices for 9,492 combinations of sale year (e.g., 2007), château (e.g., Latour), vintage year (e.g., 1982), and transaction type (dealer or auction) between end-1899 and end-2012.

We then use this unique new dataset to study the returns to holding wine and the effects of aging on wine prices empirically. The exact multicollinearity between age, vintage year, and year of sale prevents us from estimating a hedonic regression model that simultaneously includes variables for all three dimensions. We therefore parameterize the vintage effects by replacing them with variables reflecting annual variation in production (higher yields correlate with lower prices, ceteris paribus) and weather quality (better weather correlates with higher prices, ceteris paribus). The life-cycle price dynamics implied by the coefficients on age and its interactions with quality are generally consistent with our model. High-quality vintages appreciate strongly for a few decades, but then prices stabilize until the wines become antiques, after which prices start rising again. For low-quality vintages, prices are relatively flat over the first few years of the life cycle, but then rise in a near-linear fashion. By considering the difference in financial returns between pre-maturity and post-maturity wines, we estimate that a collectible—not necessarily drinkable—wine delivers a non-financial or "psychic return" of at least 1%. Our findings are robust to alternative specifications of the hedonic model.

To estimate the financial returns realized by investors over the long run, we apply a value-weighted arithmetic repeat-sales regression to all price pairs (i.e., combinations of prices for the same château and vintage year at different points in time) in our data. The resulting index picks up both the effects of aging on prices and time-series changes in the demand for wine. We find that inflation-adjusted wine values did not increase over the first quarter of the 20th century, experienced a boom and bust around the Second World War, and have risen substantially over the last half century. Overall, we find an annualized real return of 5.3% between 1900 and 2012, but correcting for the insurance and storage costs incurred by wine investors lowers the estimated return to 4.1%.

Equities have been a better investment than wine over the past century, and it is likely that accounting for differences in transaction costs would lower the relative performance of wine investments even further, especially over short horizons. At the same time, returns on wine have exceeded those on government bonds as well as art and stamps. (However, we note that art and stamps may have higher "psychic returns" compensating for the lower returns from capital gains.) As our model suggests, we also find a substantial positive correlation between the equity and wine markets.

We conclude by observing that the annualized return on First Growths that we report is best considered as an upper bound on the long-term investment performance of wine more generally, as the relative popularity of the First Growths may have risen over our time. Over the last four decades, we indeed find slightly lower returns for a well-known sweet white wine and for a small selection of vintage ports.

The paper proceeds as follows. Section 2 provides an illustrative model of wine prices. Section 3 describes our data. Section 4 examines the impact of aging on prices, while Section 5 studies the long-term investment performance of wine. Section 6 concludes.

2. A simple model of wine prices

How can we expect the price of a wine to change over time? How do returns differ between low-quality vintages that decline in quality quickly and high-quality ones that spend several decades maturing? And how can we disentangle the impact of aging on prices from time effects? In this section, we present a simple model that suggests answers to these questions.

Suppose that a representative collector-investor has wealth W_0 in period 0, with wealth growing at a constant rate z so that $W_t = W_0 \times (1+z)^t$. The value of consuming a j-year old bottle of wine i at time t can be defined as a function of the wine's drinkability $c_{i,j}$ and the investor's wealth, i.e., $C_{i,j,t} \equiv c_{i,j} \times W_t$, where i represents the wine's quality type. The dependence of consumption value on wealth reflects the discretionary nature of luxury consumption (Aït-Sahalia, Parker, and Yogo, 2004). We assume two quality types. Low-quality wines deteriorate over time so that $c_{L,j} = a^j \times c_{L,0}$ for each age $j > 0$, where $a < 1$ is the rate of deterioration.[3] By contrast, high-quality wines improve monotonically by maturing until age M, i.e., $c_{H,j} = b^j \times c_{H,0}$ for each age $j \leq M$, with $b > 1$. After maturity, high-quality wines' drinkability declines, i.e., $c_{H,j} = a^{j-M} \times c_{H,M}$ for each age $j > M$.

Before the sale of his liquor collection, a Dutch collector recently noted that he was afraid that a buyer would drink the bottles, which he thought would be "just barbaric" (The Telegraph, 2012). This

[3] In practice, even relatively bad vintages of high-end châteaus usually improve in quality for a few years. But the differences in life cycles between low-quality and high-quality vintages remain striking. For example, at the end of 2012, Robert Parker's website labeled the 90-point 1997 vintage of Mouton-Rothschild "late," while the 100-point 1982 vintage was considered "young" and even the 100-point 1959 vintage merely "mature."

illustrates that, just like an artwork or a precious diamond, an unopened bottle can be a source of enjoyment. We capture this with the parameter $d_{i,j}$ (with $d_{H,0} > d_{L,0}$) that grows with age at a constant rate g, reflecting the higher enjoyment of owning older and rarer bottles.[4] The financial value of the psychic "ownership dividend" for a bottle of quality type i and age j in period t is defined as $D_{i,j,t} \equiv d_{i,j} \times W_t$. Our set-up resembles the model in Goetzmann and Spiegel (2005) in which art values depend on collectors' wealth. Under the assumptions outlined above, the non-financial dividend grows at the rate $k \equiv (1+g)\times(1+z)-1$, which is assumed to be smaller than the appropriate discount rate r.[5]

In this set-up, at each point in time t, the price of a j-year old bottle of the low-quality type should be the maximum of two values, namely the value of immediate consumption and the present value of all future ownership dividends received conditional on never consuming:

$$P_{L,j,t} = \max\left(C_{L,j,t}\,,\ \frac{D_{L,j+1,t+1}}{r-k}\right) \tag{1}$$

For the high-quality type, as long as the wine has not reached maturity, the price is the maximum of three measures, namely (i) the value of immediate consumption, (ii) the present value of consumption at maturity plus the present value of all ownership dividends received until consumption, and (iii) the present value of infinite storage:

4 To the extent that the growth in non-financial dividends reflects the increasing rarity of a wine, it is linked to the cumulative aggregate consumption over the life cycle. However, we take the paths of the probabilities of consumption—and thus of the ownership dividends—over age as exogenous. We thus assume that individuals investors do not take into account the marginal effect of their personal consumption on the attractiveness of the remaining bottles when deciding whether to drink or to store. Jovanovic (2013) provides an equilibrium model that endogenizes this decision. (Moreover, to keep our model as simple as possible, we assume that the ownership dividends increase linearly over time, even if many bottles are consumed around maturity.)

5 In the model, tastes and the growth rate of wealth do not vary over time, and the discount rate may equal the risk-free rate. If wealth is risky, the positive correlation between shocks to wealth and wine prices will imply a required return close to that on the market portfolio. Uncertainty about future tastes may further drive up the discount rate. We consider the magnitude of the relevant discount rate an empirical issue.

$$P_{H,j,t} = \max\left(C_{H,j,t}\,, \frac{C_{H,M,t+M-j}}{(1+r)^{M-j}} + \frac{D_{H,j+1,t+1}}{r-k} \times \left(1 - \left(\frac{1+k}{1+r}\right)^{M-j}\right),\ \frac{D_{H,j+1,t+1}}{r-k}\right) \text{ if } j < M \quad (2)$$

If the high-quality wine is at or beyond maturity, the price is the maximum of the value of consumption and the present value of all future ownership dividends:

$$P_{H,j,t} = \max\left(C_{H,j,t}\,,\ \frac{D_{H,j+1,t+1}}{r-k}\right) \text{ if } j \geq M \quad (3)$$

Figure 1 shows an example of the resulting (log) price dynamics. We set *j* and *t* equal to zero in the first period. For the low-quality wine in Panel A, the price decreases initially due to the decline in consumption value, until the present value of ownership dividends (i.e., the value as a collectible) exceeds the value of consumption. After this, the price grows at a constant rate *k*. In Panel B, we show the dynamics for a high-quality vintage that grows in drinkability for 40 years and declines in consumption value thereafter. If the growth in consumption value prior to maturity exceeds the discount rate *r*, the price increases at a rate that approaches *r* as the wine nears maturity. After maturity, wine prices decrease with consumption utility until the present value of ownership dividends takes over, after which the price grows at a rate equal to *k*.[6] Our simple model thus predicts very different price patterns for bad and good vintages. By comparing the two panels in Figure 1, we can also see that the cross-sectional premium for quality may be smaller for very old wines.

[Insert Figure 1 here]

[6] A natural question is why all bottles are not consumed at (or around) maturity? Different frictions could help explain why the probability of consumption is below one. Wine bottles may be forgotten in large cellars. Collectors may also hold more wine at the optimal drinking age than they can physically consume (and by high transaction costs be discouraged from selling to others with more drinking capacity). For some individuals a private value component could make the total utility from lifelong ownership always exceed the consumption value, even at maturity. Such "disagreement" could encourage speculators to store in the expectation of higher prices in the future (Harrison and Kreps, 1978). We do not explore these possibilities further here.

It is easy to see that, in our model, the non-financial dividend yield *D*/*P* on those wines for which the price is determined by the value of lifelong storage (i.e., by their value as a collectible) equals *r* minus *k*. This suggests that the "psychic return" on (low-quality or high-quality) wines substantially beyond maturity can be approximated by its underperformance relative to high-quality wines that are still maturing. As such, our model closely relates to studies that attribute the underperformance of art relative to financial assets with the same risk profile to the "viewing pleasure" (Stein, 1977) or "conspicuous consumption utility dividend" (Mandel, 2009) associated with art ownership.

In Figure 1, the price dynamics over age and over time are one and the same. Nevertheless, it is straightforward to decompose the returns into time and age effects. Abstracting from aging-induced variation in quality (i.e., holding *j* constant), wine values grow with wealth over time, as the (future) consumption value and the (future) ownership dividends all rise at the constant rate *z*. Therefore:

$$\frac{P_{i,j,t+1}}{P_{i,j,t}} = 1 + z \qquad (4)$$

By contrast, abstracting from the effects of time—and thus changes in wealth—on valuations (i.e., keeping *t* constant) delivers cross-sectional life-cycle patterns similar to those illustrated in Figure 1, although the relative price differences between two consecutive age groups are of course lower than before:

$$\frac{P_{i,j+1,t}}{P_{i,j,t}} = \frac{P_{i,j+1,t+1}}{P_{i,j,t}} \times \frac{1}{1+z} \qquad (5)$$

Identifying the life-cycle price patterns of wines of different qualities will be the first main goal of our empirical analysis. Afterwards, we turn to estimating the total returns realized by wine investors since the beginning of the 20th century.

3. Data

3.1. Selection of wines

We study transactions for five red Bordeaux wines: Haut-Brion, Lafite-Rothschild, Latour, Margaux, and Mouton-Rothschild. The Bordeaux region has long been among the world's leading wine areas, and the production of fine wines developed quickly after the introduction of bottles and corks in the late 17th century (Simpson, 2011). The important châteaus already had established reputations in the 18th century—a time when most other wine was still sold under the name of the shipper rather than the grower. In 1855, wine brokers compiled a classification of wines for the Universal Exhibition of that year based on historical prices, and labeled Haut-Brion, Lafite-Rothschild, Latour, and Margaux as the four red "First Growths" ("Premiers Crus"). By the end of the 19th century, this 1855 classification was well known. Mouton-Rothschild was classified as the first of the Second Growths but was widely believed to have the quality of a First Growth and traded at similar prices. The château was finally upgraded to the top category in 1973.

There is not much time variation in the perceived quality of these wines; today, they remain among the most highly-appreciated and frequently-traded in the world. One reason for the relative stability in rankings is the importance of natural conditions, such as climate and soil, to the potential quality of a wine.

3.2. Data collection

We compile a long-run price history for the five wines listed above, starting in 1899. Two other criteria guide the data collection. First, we focus on vintages since 1855. The compilation of the classification in that year makes it a natural starting point. Moreover, Simpson (2011) notes that until the mid-19th century even the best Bordeaux wines were often blended with other wines (or spirits) before export. The second half of the 19th century also saw the introduction of estate bottling for high-quality wines, along with their distinctive labels and corks. Second, we only gather prices for standard-sized bottles, for a number of reasons: they make up a very large majority of all transactions historically; non-standard bottles like magnums or double magnums are more likely to be valued for their uniqueness; and the aging process is affected by the size of the bottle, so excluding non-standard bottle types simplifies the analysis.

We collect two types of historical price data: prices realized at auctions in the London sales rooms of Christie's (and W. & T. Restell, an auction house bought by Christie's in the 1960s), and retail list prices at Berry Bros. & Rudd (BBR), a London dealer of wines and spirits. At least until the First World War, "an important quantity" (Simpson, 2011) to "nearly all" (Penning-Rowsell, 1975) of the best Bordeaux wines were sold to British buyers. By focusing on one auction house and one dealer over the long term, we mitigate concerns that our findings are affected by temporal changes in the nature of the price data.

3.3. Auction prices: Christie's

Christie's is one of the world's two leading auction houses. Its first sale was held in December 1766 in London, and consisted of "the property of a Noble Personage deceas'd." The auction included furniture, jewelry, and firearms, but also a few dozens of "fine claret" (lots 30–34)—claret is the British name for red Bordeaux wine—and "fine old madeira" (lots 35–38). Christie's held its first session dedicated solely to wine in 1769. In the early decades, detailed descriptions of the bottles being auctioned were often lacking. Indeed, for a long time, wine was sold anonymously or under the name of the merchant who had imported it (Penning-Rowsell, 1972). It was not until 1788 that a Christie's catalogue (mis)named the Bordeaux châteaux "Lafete" and "Margeau" (Penning-Rowsell, 1973). Vintage quality became increasingly relevant only in the early 19th century, when Christie's catalogues regularly started to include information on both château and vintage year. For example, a sale in June 1825 included "three dozens of excellent and well-flavoured claret (Lafitte) of the vintage of 1819."

In 1941, the Christie's premises on King Street were destroyed by a fire bomb, forcing the firm to move (Sheppard, 1960). There were occasional wine sales at the temporary offices, but these stopped altogether in 1945 and did not resume when Christie's returned to its original location in 1953. In 1966 the auction house renewed its wine business and acquired W. & T. Restell, the only other wine auctioneer in London at the time (Broadbent, 1985). Wine auctions remain an important part of Christie's activities in London today, with wine sales conducted on a near-monthly basis.

The long tradition of auctioning wines makes Christie's a unique source of information, but building a database of wine prices is challenging due to lack of a data source that covers the firm's entire history and the fact that it did not hold wine auctions continuously. We thus need to draw upon a number of different documents and sources.

For the period 1899–1971, we use data from archived catalogues containing the results of sales at Christie's (before 1945 and 1966–1971) and Restell (1941–1965). Figure 2 shows an excerpt from an auction catalogue, annotated by the auctioneer, of a sale from 1935. For 1972–1979, we obtain price data at London auctions from the annual *Christie's Wine Review*, which is a publication that lists prices paid, generally at Christie's, over the previous calendar year. If more than a single lot of a particular wine and vintage was sold, the *Wine Review* includes the lowest and highest price, and sometimes more price points. If no sale took place for a given wine-vintage pair, the *Wine Review* repeats older price information, and we eliminate these duplicates.

[Insert Figure 2 here]

For the years 1980–1984 and 1988, we collect data from the *Christie's Vintage Wine Price Index* books, which succeeded the *Wine Review*. We obtain data from auctions at Christie's London for 1985–1987 and 1989–1998 from David Ashmore at Liquid Assets. Finally, we collect data on all wine sales in London over the period 1999–2012 from the Christie's website. Throughout our analysis, we focus on homogenous lots and do not consider mixed lots that include wines from different châteaux or vintage years.

We make two important comments about the auction data. First, the U.K. government has historically taxed sales of alcohol through excise duties. The payment of the duty (and value added tax), however, can be postponed by keeping the wine "in bond." Duty is paid only when the bottle is removed from a bonded warehouse for delivery to a private address. Thereafter, the wine can be traded without additional taxes. We assume that all prices are "duty-paid," and thus do not try to correct price levels for transactions in bond or "free on board" (for sales from cellars overseas).[7]

Second, Christie's London introduced a "buyer's premium" in its wine auctions in the Fall of 1986. This additional fee, payable by the winning bidder, initially equaled 10% of the hammer price of the lot, but has gradually increased to 15% in 2012. When necessary, we transform the observed prices so that they are inclusive of the premium. Since buyers take the premium into account as they bid, it can be considered as a transaction cost imposed on the seller (Ashenfelter and Graddy, 2005). Therefore, the evolution of hammer prices exclusive of buyer's premium would underestimate the growth in the willingness to pay for wine.

3.4. Dealer prices: Berry Bros. & Rudd

In 1698, a small grocery store was founded at 3 St. James' Street in London, not far from where Christie's is located today. By the early 19th century, the shop had come into the hands of George Berry, son of a wine merchant, who transformed it into a wine business, and the Berry family has been active in the company ever since. Price lists show that French and German wines, spirits (e.g., brandy, whiskey, gin), and fortified wines (e.g., port, sherry, madeira) were the backbone of the business in the early

[7] Inferring the relevant tax regime for each transaction would be difficult. Moreover, auction prices have traditionally been largely duty-paid. In any case, for high-end wines like the ones considered here, excise duty is relatively unimportant quantitatively. At the end of 2012, the duty stood at 1.80 GBP per bottle.

1900s. Hugh Rudd, also from a family of wine merchants, joined the company in 1914. Shortly after the First World War, the company started selling wines from California, Spain, and other "new" wine regions. Today, BBR still operates a shop on St. James' Street, but has expanded its operations with multiple offices in Asia, an online wine shop, and an online brokering service for fine wines.

As is the case for Christie's, the history of BBR offers a long-run perspective on the evolution of wine prices. Since the early 20th century, BBR has generally issued price lists in the Spring and Fall of each year, though it recently reduced the frequency to once per year. For the period 1905–1978, we can collect data on the five Bordeaux wines that we study from a set of 11 bound volumes of price lists. We use loose copies of the relevant price lists for a number of years not included in the bound volumes and for the period since 1978. All documents were consulted at the London headquarters of BBR. Figure 3 reproduces two pages from the May 1909 price list.

[Insert Figure 3 here]

Each list typically includes from a handful to a few dozen prices useful for our study. Unfortunately, during the late 1980s and the 1990s, the lists sometimes include relevant wines but no prices, which are listed as available "on application" or "on request." Also, in the early 2000s, the regular price lists start to include fewer high-end wines. However, around that time, BBR introduced so-called "blue lists," which were available from the company upon demand, with prices for "the finest reserve wines and wines for laying down." Prices from these alternative lists also enter our database. In recent years, the BBR website has assumed the role once played by the regular price lists; the latest paper price lists contain relatively few entries. We therefore update our database with November 2012 prices taken from the BBR website.

A few further comments on the dealer price data are in order. From the 1920s until the 1960s, the lists often included both "credit" and "cash" prices, and we work with the latter. Our prices are also duty-paid and inclusive of value added tax (which we add when necessary), and thus reflect the total cost to domestic buyers who take physical possession of the wine. Whenever possible we use prices per bottle rather than per case. We also ignore quantity discounts because we lack detailed information on them for each period, and do not take into account other discounts such as for less-than-perfect quality or seasonal promotions offered by BBR. For these reasons, prices in the retail lists are likely an upper bound on the true underlying values, just like catalogue prices in other collectibles markets. At the same time, we are mainly interested in quantifying the trends in prices, and a systematic upward bias in all prices would not affect these trends.

3.5. Construction of final database and descriptive statistics

In total, we hand-collect 36,271 prices from the different Christie's and BBR sources. If we know that an auction sale took place or that a dealer issued a price list in the first half of the year, we assign the accompanying price points to the previous year-end. In all other cases, we date the price to the end of the year. Next, to not overweigh certain periods or transaction types, we average prices per bottle by quartet of year-end (e.g., end-2007), château (e.g., Latour), vintage (e.g., 1982), and transaction type (dealer or auction). Our final database contains price information for standard-sized bottles on 9,492 such combinations—our units of observation from now on—since end-1899.[8]

Table 1 presents some descriptive statistics of our data set. Panel A of Table 1 shows the number of observations per transaction type and per château for each decade since the 1900s (where 1899 is added to the first period). The growth of the database in the 1970s reflects the increasing availability of auction sources. Panel B gives more information on the distribution of the averaged prices in British pounds (GBP) for each decade, in nominal and real (year 1899) terms. Until the early 20th century, no wine sold for more than one pound. For the most recent years (2010–2012), the average price level per

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[8] If we assume that all wines can be sold as of the first year after the vintage, there are 114,570 combinations of year-end (1899–2012), château, vintage year (1855–2011), and transaction type for which prices could in theory be observed. Our database thus covers 8.3% of the population of values.

bottle is 758.46 GBP, with prices ranging from 80.50 to 8,510 GBP. The summary statistics for the deflated prices suggest much stronger price increases in the second half of the twentieth century than in the first half.

[Insert Table 1 here]

4. Aging and prices

4.1. Methodology

Ideally, we would like to examine the effect of aging on wine prices, controlling for other determinants of price levels, with a regression of the following form:

$$\ln\left(P_{i,j,l,t}\right) = \alpha_i + \alpha_j + \alpha_l + \alpha_t + \boldsymbol{\beta}'\boldsymbol{X}_{j,t} + \varepsilon_{i,j,l,t} \ , \qquad (6)$$

where $P_{i,j,l,t}$ is the price of a wine from château i and vintage year j at sale location l (i.e., the transaction type: dealer or auction house) in year t. The different α denote fixed effects, and $\boldsymbol{X}$ is a polynomial age function. The estimated coefficients on the age variables in $\boldsymbol{X}$ would show how prices vary over the wine's life cycle. Model (6) is a hedonic regression (Rosen, 1974), a method that relates prices to its value-determining characteristics. Hedonic models are commonly used to study price formation in markets for infrequently traded assets such as real estate (e.g., Campbell, Giglio, and Pathak, 2011) and art (e.g., Renneboog and Spaenjers, 2013).

The main problem with the proposed hedonic model lies in the multicollinearity between age, vintage year, and year of sale that prohibits us from simultaneously including dummy or linear variables for all three dimensions. We address multicollinearity by placing parametric restrictions on the vintage effects. Specifically, we assume that the effects of vintage year on prices are proportional to variables picking up annual variation in production (as a larger supply can be expected to be related to lower prices) and quality. We then replace the vintage dummies in Equation (6) with these new variables.[9] With respect to production, we use annual yields from Chevet, Lecocq, and Visser (2011), measured in hectoliters per hectare, for an anonymous First Growth between 1855 and 2009. Next, we use information on the weather in each vintage year to proxy for quality. Ashenfelter, Ashmore, and Lalonde (1995) and Ashenfelter (2008) show how weather data can predict the quality and prices of Bordeaux wines. Using daily data from a weather station in Bordeaux (Météoclimat, 2012), we measure the average temperature between April and August (the growing season) and total rainfall in August and September (the harvest season) for each vintage year between 1873 and 2011.[10] We then sort all vintages in deciles according to both measures, and assign a score of one to 10 to each vintage year for each measure, where higher temperatures and less rainfall are associated with higher scores. Our weather quality variable sums the two scores.[11]

A second concern with the hedonic model in Equation (6) relates to potential differences in aging dynamics between high-quality and low-quality vintages. We argued before that the relation between age and price levels may depend crucially on whether the wine improves in consumption quality by

[9] The multicollinearity problem in this paper is very similar to the one faced by household finance research that tries to disentangle age, year, and cohort effects in financial market participation decisions and portfolio choice (Ameriks and Zeldes, 2004). Malmendier and Nagel (2011) break the multicollinearity by using the stock returns experienced over the lifetime as a proxy for cohort effects—an approach similar in spirit to ours.

[10] Weather data for Bordeaux are available since 1880. For the seven years preceding this (1873–1879) and for a few others where data are missing (e.g., 1915–1920 and 1940–1945), we impute values using linear regression models to relate monthly data on temperatures and rainfall in Bordeaux to data for Paris and Marseille (and Nantes, when possible) and month fixed effects over the period 1880–2011.

[11] For a warm growing season and dry harvest season, the vintage year weather quality variable will thus take a value that approaches 20, while for a cool growing season and wet harvest season, it will be close to two. No vintage is ranked in the top decile on both measures, but the weather quality variable equals 19 for six vintages: 1895, 1899, 1906, 2000, 2003, 2005, and 2009. There are two vintages that fall in the bottom decile on both weather measures, namely 1931 and 1965.

maturing. We therefore include interactions of our newly-created weather quality variable with the age polynomial in our hedonic model.

Our final regression model thus looks as follows:

$$\ln\left(P_{i,j,l,t}\right) = \alpha_i + \alpha_l + \alpha_t + \varphi Y_j + \psi W_j + \boldsymbol{\beta}'\boldsymbol{X}_{j,t} + \boldsymbol{\gamma}'\left(\boldsymbol{X}_{j,t} \times W_j\right) + \varepsilon_{i,j,l,t} \qquad (7)$$

where Y_j measures the production yield in year j, W_j picks up the quality of the weather in the same year, and the other variables were defined before. In our baseline model, $\boldsymbol{X}$ is a fourth-degree polynomial.

4.2. Results

We estimate Equation (7) using ordinary least squares. We use the price level in real GBP as the dependent variable. The fifth column in Table 2 summarizes the results. The R-squared statistic is 0.74. This is substantially higher than the explanatory power of a model that only includes time dummies and a transaction type dummy (first column), or models that combine these variables with either château dummies, vintage variables, or the age polynomial (second to fourth columns).

[Insert Table 2 here]

Before we study the effect of aging on prices in depth, we review the results for the other variables included in our hedonic model. The coefficient on the transaction type dummy indicates that dealer prices exceed auction prices on average. It could be that BBR only offers bottles of the highest quality, but we also noted earlier that the dealer list prices should be considered an upper bound on the true transaction prices. Next, we see that Mouton-Rothschild carries a premium relative to the other four wines in our sample. Haut-Brion, which is omitted from the regression due to multicollinearity, is the least expensive, ceteris paribus. The results also indicate strongly significant relationships between our proxies for vintage effects and prices, with the coefficients relating lower production and better weather to higher prices as expected. Finally, the exponents of the coefficients on the time dummies (not reported) allow us to gauge how wine values have changed historically, independent of aging effects.

We find that, keeping wine characteristics—including age—constant, wine prices have risen at an annualized rate of 2.9% in real GBP terms over the period 1900–2012. We provide a more detailed description of historical price trends in the wine market in the next section.

We now turn to the relation between age and price levels. An F-test shows that the coefficients on the interaction terms between age and quality are jointly significant. This suggests that wines of low and high-quality vintages exhibit quite different life-cycle patterns. Figure 4 shows the life-cycle price patterns implied by the coefficients on the weather quality variable, the age polynomial, and the interaction terms, for otherwise identical wines of the lowest and highest weather quality categories. We rescale the predicted price of the lowest-quality wine at age zero to unity, and show results up to an age of 100 years (fewer than 3% of our observations are for wines older than a century). Figure 4 also shows the confidence intervals around the predicted price levels.

[Insert Figure 4 here]

For the lowest-quality vintages, prices increase little over the first few years of the life cycle—the geometric average price appreciation over the first 10 years implied by the regression results is only 0.5%—but prices rise afterwards in a near-linear fashion.[12] In contrast, the highest-quality wines appreciate strongly while they are maturing over three to four decades after the vintage; we estimate a geometric average price appreciation of 3.0% over the first 25 years. This estimate is consistent with earlier studies: Di Vittorio and Ginsburgh (1996) and Ashenfelter (2008) report returns to aging of 3.7% and 2.4% respectively. Prices stabilize once high-quality wines are fully mature, and their increase in value between age 50 and 80 is very limited. As the wines turn into antiques, we start observing new price increases. For very old wines, the difference in price levels between high-quality and low-quality vintages is not as large as for younger wines.

[12] Both here and later in this paper, the estimates for older low-quality vintages should be interpreted with care, as there are virtually no transactions of wines older than 50 years for the lowest weather quality categories.

The patterns in Figure 4 are generally consistent with the model presented in Section 2 and illustrated in Figure 1. Of course, the dynamics are much smoother, as we would expect for a number of reasons: each quality category groups together a range of wines that age slightly differently; even low-quality vintages generally improve in quality by aging for a few years; and it can be hard to tell when exactly a wine is at its best. Moreover, the finding that the prices of high-quality wines do not decrease after reaching maturity suggests that most of these wines "keep" for a long time.

According to our model, the financial outperformance of high-quality wines that are approaching maturity relative to wines that are long beyond maturity—and for which the price is thus determined by its value as a collectible—should give us an estimate of the psychic return to holding the latter category of wines. Between the age of 15 and 25, a high-quality vintage is still maturing, while a typical low-quality vintage will already be beyond maturity. In Figure 4, the difference in geometric average return between (pre-maturity) high-quality vintages and (post-maturity) low-quality vintages as they age from 15 to 25 years is 1.6%. Alternatively, taking somewhat longer intervals, we can compute a difference of 1.0% between the average returns on high-quality vintages from bottling to 25 years and those on low-quality vintages between 15 and 50 years of age. This exercise thus suggests that a collectible—but not necessarily drinkable—wine worth 1,000 GBP "pays" a non-financial dividend of between 10 and 16 GBP to its owner over the course of a year.

4.3. Robustness checks

We now check the sensitivity of our results to a number of alternative specifications of the hedonic model. First, we replace the fourth-order age polynomial with a third-order or a fifth-order polynomial. Second, we construct an expanded measure of weather quality. Ashenfelter (2008) shows that, in addition to temperature in the growing season and the rainfall during the harvest season, rainfall during the winter preceding the vintage may affect wine quality to some extent. More winter rain is associated with better wines in the next vintage. We therefore create a score from one to 10 based on the decile to which each vintage year belongs when sorted on cumulative rainfall in the period from October to March, and add half of this score to the previously-constructed weather quality variable. Third, to account for the possibility that the price discrepancy between the dealer and the auction market has changed over time, we extend our baseline model with an interaction term of the dealer dummy with a linear time trend.

Table 3 shows estimates of the geometric average price appreciation in the time series (based on the coefficients on the time dummies), and over different segments of the life cycle (based on the coefficients for the age and age-weather variables) for these alternative specifications. It also compares the results with our benchmark model. The results indicate that our estimate of the historical increase in price levels, controlling for variation in age and other characteristics, is robust to alternative specifications. We find small differences in the estimates of the average rates of price appreciation over the life cycle, but in each specification the general patterns are similar to those in the benchmark results.

[Insert Table 3 here]

5. The long-term investment performance of wine

5.1. Methodology

The results in the previous section show that the financial return of a wine investor depends on the part of the wine's life cycle over which it is held. But that analysis does not offer a precise estimate of the historical returns to holding wine. In this section we evaluate this investment performance over the past 113 years—a performance that reflects changes in market conditions in addition to price increases related to aging.

To build a returns index, we apply a repeat-sales regression to the 8,582 price pairs in our database for which the château and vintage (and transaction type) are identical.[13] The standard repeat-sales regression (e.g., Bailey, Muth, and Nourse, 1963) estimates the return on an underlying portfolio of assets by relating the log returns implied by the individual price pairs to the periods over which the assets are held. An advantage of the methodology is that it explicitly controls for the uniqueness of each combination of château and vintage year. There is thus no need to estimate the average premia associated with, for example, different categories of weather quality. However, an issue with the standard repeat-sales model is that—just like the log-linear hedonic model of which it is a special case—it estimates an equal-weighted index that is based on the geometric (rather than arithmetic) average of prices in each period. As this is undesirable, we follow the variant of the method proposed by Shiller (1991), which works with absolute prices instead of log returns. The result is a value-weighted arithmetic repeat-sales index that more accurately tracks the total value of all wines held by collectors.

5.2. Results

Figure 5 show the price index, in real GBP, that we obtain with the arithmetic repeat-sales technique. The index is set equal to unity at the start of 1900. We geometrically interpolate the index values for the years 1912, 1916, 1917, and 1947, for which we have no transactions that enter the estimation. The index shows that, despite the positive average effect of aging on the consumption value and attractiveness of wines, wine prices did not increase in real terms over the first quarter of the 20th century. Figure 5 further shows that the value of wines boomed during the Second World War; prices increased by more than 600% between 1940 and 1945. Many factors probably played a role: the war upset the trade in high-end French wines, with the port of Bordeaux and many châteaus occupied by

[13] One example of a price pair is the following: the average transaction price of a bottle of Margaux of vintage year 1945 at auction was 133.51 GBP in 1985 and 168.48 GBP in 1986. For many château-vintage combinations, we observe prices for long series of consecutive years.

Nazi Germany (Kladstrup and Kladstrup, 2001); the U.K. government prohibited sales of wines and spirits by unlicensed auction houses; Christie's had to limit its sales activities after its main offices were bombed; and many wine bottles were sold through Red Cross charity auctions that are not included in our data but may have pushed up price levels. The boom was followed by sharp decreases in wine valuations in the years after the end of the war. In the second half of our time frame, wine prices grew strongly, although the price rises were punctuated by drops in real price levels of more than 20% in 1973–1975, 1980, 1990–1992, 2003, and 2011–2012. Over the complete 1900–2012 period, we find a geometric average annual real return of 5.3%. For completeness, Figure 5 also shows the nominal return for each year, against the right axis. The geometric average annual nominal return over our time frame equals 9.4%.

[Insert Figure 5 about here]

The index values are rather precisely estimated. The standard errors on the last index values imply a 95% confidence interval around the annualized return estimate that is about one percentage point wide. Moreover, for the time frames that overlap with earlier research on wine returns, i.e., 1969–1976 (Jaeger, 1981), 1986–1996 (Burton and Jacobsen, 2001), and 1996–2009 (Masset and Weisskopf, 2010), the estimated trends are broadly in line with those reported by others.

5.3. Accounting for storage and insurance costs

The condition of a bottle of wine is determined by factors such as temperature and humidity. A poor storage environment may cause bottles to start leaking or evaporating, wines to become oxidized, and labels and packaging to incur damage. Such wines are less likely to be included in our database. Auction houses would nowadays typically not even sell bottles that have a questionable provenance, even if they appear to be in a decent condition. The returns reported in the previous paragraph have therefore probably been realized only by investors who stored their wines properly. Today, storing wine bottles does not need to cost much; Robinson (2010) mentions a cost of 10 to 20 GBP per dozen bottles per annum at professional storage providers. However, relative to the price of the average bottle of wine considered, wine storage was more expensive before the increases in wine values of the last decades. For example, the BBR price list of March 1940 shows that a case of wine could then be stored at a price of 1.6 shilling, or 0.075 GBP, per year—a cost equivalent to 0.94% of the average end-1939 price for a dozen bottles. Repeating this exercise in 1950, 1960, 1970, 1980, 1990, and 2000 results in estimates of 0.83%, 0.88%, 0.39%, 0.13%, 0.24%, and 0.23%. We can use these estimates of transaction costs at the start of each decade to correct our annual returns.[14]

Additionally, it is clear that the reported returns only concern those bottles that were unaffected by—or insured against—fire, flood, accidental breakage, theft, and other hazards. Wine storage contracts often do not include insurance, or not against all risks and at full market value. Meltzer (2005) notes that, although the exact policy and cost is a function of the insurer, premiums are fairly standard: a typical wine insurance contract costs close to 0.5% of the market value of the collection per year.

In Figure 6, we show our deflated price index after accounting for these storage and insurance expenses. We now find an annualized real return of 4.1% between 1900 and 2012.

[Insert Figure 6 about here]

5.4. Comparison with other assets

Figure 6 also shows returns to a number of other financial assets and collectibles. Data on British equities and government bonds are from Dimson, Marsh, and Staunton (2013). For the art market we use an index for Great Britain from Goetzmann, Renneboog, and Spaenjers (2011), updated until end-2012 using data from Artprice (2013). Data for British stamp prices are from Dimson and Spaenjers (2011),

[14] We use the 1940 cost estimate for the years prior to 1940, while for 2010–2012 we use the 2000 estimate. Wine lovers may of course only reap the highest possible non-financial dividends of ownership by keeping their collection in a more expensive private cellar.

updated using returns on the Stanley Gibbons GB30 index. Table 4 shows summary statistics for the different distributions of returns in both nominal and real terms.

[Insert Table 4 here]

The annualized real return (net of storage and insurance costs) of 4.1% for wine over the period 1900–2012 is equivalent to an annualized nominal return of 8.2%. Annualized real returns are 5.2%, 2.4%, and 2.8% for equities, art, and stamps respectively. Over our time frame, wine has thus underperformed equities, although the exceptionally low returns on equities and the high returns on wine over the last decade have narrowed the difference in cumulative appreciation since the start of the 20th century. When comparing average returns on wine to those on financial assets, however, it is important to bear in mind that transaction costs may lower the relative performance of wine investments more than trading costs depress the returns on investment in financial assets, and especially over short holding periods. For example, the buyer's premium at Christie's London was 15% at the end of 2012, while the commission paid by the seller can be as large as 10%. So a seller may only receive about 75% of the amount that the winning bidder pays out. These estimates may still underestimate true costs, as purchasers and sellers of wine may incur expenses related to transportation, handling, and administration when moving the wine from one storage facility to another.

At the same time, Table 4 and Figure 6 show that wine has not only outperformed government bonds, but also art and stamps, even when ignoring the costs associated with investments in those types of collectibles. The reported annualized returns for art and stamps are much closer to the previously-estimated geometric average price appreciation of wine when controlling for age effects (2.9% over 1900–2012). This may not be surprising as art and stamps are luxury collectibles for which age in itself is not a primary determinant of the pleasure they provide.[15] An apt analogy here is the difference between constant-dividend stocks and growing-dividend stocks in the standard Gordon growth model. The former will have lower capital gains rates but higher dividend yields than the latter. Similarly, we can expect art and stamps to provide lower financial returns but higher psychic returns than wine.

Finally, Table 5 shows that our wine index is quite volatile, although the standard deviation falls to a level similar to equities when we remove the boom and bust caused by the Second World War.[16]

5.5. Equity markets and wine prices

In the model presented in Section 2, time effects in wine prices reflect growth in the wealth of wine investors, as drinking and collecting wine are both forms of discretionary luxury consumption. To examine whether wine prices indeed respond to wealth shocks, we run a regression (without constant) of the real wine returns (before costs) against the returns on equities, which results in a market model beta of 0.44. The (aggregated) slope coefficient increases to 0.73 when taking into account non-synchronicity in returns by adding a lagged and a leading equity return to the regression, following Dimson (1979).[17] Excluding the period 1941–1948, the aggregated market model beta equals 0.57. These results point to a relation between the creation of financial wealth and wine prices.

[15] The most expensive bottles of wine are generally the older ones. By contrast, in the art market, there is no clear correlation between age and prices; contemporary art is often more expensive than older art. For stamps, rarity is a determining factor, but this may be a vintage rather than an age effect.

[16] Excluding the years 1941–1948, the standard deviation of the real returns on wine falls to 20.3%, which is close to the 19.8% observed for equities. Even so, standard deviations may still overestimate the true volatility of returns to holding wine until the 1970s because of the relatively low number of observations upon which return estimates are based for the first half of our sample (Bocart and Hafner, 2012). On the other hand, the use of dealer price lists and the aggregation of prices over one-year periods may lead to artificial smoothing in the return series.

[17] Non-synchronicity between equity returns and wine returns may arise due to several issues. For example, while equity returns can be measured exactly at year-end, wine returns are estimated based on (infrequently observed) auction and dealer prices both before and after the turn of the year. Moreover, dealer list prices may be “sticky”.

5.6. Exploring the impact of success bias

In this paper, we have estimated the returns to the best red Bordeaux wines. Although these wines were well known and highly appreciated before the start of our time frame, a few other types of wine have historically been popular as well, even for the purpose of investment. For example, the *Christie's Wine Review* of 1972 noted that vintage port "has been *the* wine, par excellence, for the English [to] lay down—to invest in—and to drink." So if today's professionally managed wine portfolios invest more than 80% of their funds in only eight red Bordeaux wines (Miles, 2009), it is not unlikely that such a strong focus on claret would have seemed unnatural to wine buyers a century—and even a few decades—ago. The returns on red First Growths reported in this paper should therefore probably be considered as an upper bound on the long-term investment performance of wine more generally.

To get a better sense of the importance of this "success bias," we perform two checks. First, for the years since end-1971, we were able to collect auction and dealer prices for Château d'Yquem, a "Superior First Growth" sweet white wine from Bordeaux, from the same sources as before. The data allow us to estimate 40 years of returns for this very different type of wine. A value-weighted arithmetic repeat-sales regression generates a geometric average return estimate of 4.8% between start-1972 and end-2012. This compares to 6.9% for the wine price index presented earlier. Second, for each vintage port that was included in the 1972 *Wine Review*, we check whether we can find a transaction at Christie's London during the last three years of our time frame (2010–2012). We find five such cases (Croft 1945, Fonseca 1966, Warre 1955, and Taylor 1945 and 1963) and compute the geometric average real return for each price pair, which gives an arithmetic average of 6.0%.

This suggests that the returns on other types of wine may indeed have been somewhat lower over the last few decades. Yet the differences are not dramatically large, and even Yquem has performed as well as government bonds over the last four decades (net of storage and insurance costs). We leave a more detailed comparison of the long-term performance of different types of wine to future research.

6. Conclusion

The main contributions of this paper lie in documenting how financial returns change over a wine's life cycle, and estimating the long-term returns in the market for high-end wines. We first outline a simple model of wine prices that results in predictions of how prices change differently over the life cycle for low-quality and high-quality vintages. We then construct a database containing prices for 9,492 combinations of château, vintage year, year-end, and transaction type since end-1899, and use these data to estimate age effects in wine prices. To avoid multicollinearity between age, vintage year, and time in our hedonic regression model, we parameterize the vintage effects by replacing them with proxies for production yield and weather quality. The life-cycle price patterns implied by our results are generally consistent with our model. High-quality wines appreciate strongly for a few decades, but then prices stabilize until the wines become antiques, after which prices start rising again. By contrast, wines from low-quality vintages appreciate little during the first years after bottling, but then show a near-linear price appreciation over the life cycle. We find lower financial returns on wines that are beyond maturity; our results suggest a psychic, non-financial return of at least 1% on collectible wines.

Next, we apply a value-weighted arithmetic repeat-sales regression to the price pairs in our database to construct a price index in real GBP terms. We find a geometric average real return of 5.3% between 1900 and 2012. Taking into account storage and insurance costs lowers this estimate to 4.1%. Over our time frame, wine has been outperformed by equities, and we note that transaction costs may further reduce the relative attractiveness of wine. However, the performance of wine has been better than that of art and stamps—assets for which aging matters much less. In line with expectations, we also find evidence of positive correlation between the equity and the wine market.

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Table 1. Descriptive statistics

Table 1 shows descriptive statistics for our database. Historical prices of the five red Bordeaux First Growths were collected for Christie's London (an auction house) and Berry Bros. & Rudd (a dealer). The unit of observation is the average price (in GBP) per bottle per quartet of year-end, château, vintage, and transaction type. Panel A shows the number of observations per transaction type and per château for each decade since end-1899. Panel B shows summary statistics for the distributions of nominal and real prices for each decade since end-1899. Inflation data come from Dimson, Marsh, and Staunton (2013).

Panel A. Number of observations per transaction type and per château

Period	Transaction type		Château					Total
	Auction	Dealer	Haut-Brion	Lafite	Latour	Margaux	Mouton	
1899-1909	179	47	12	88	36	48	42	226
1910-1919	37	69	10	40	10	24	22	106
1929-1929	54	86	9	52	25	45	9	140
1930-1939	62	141	24	38	47	74	20	203
1940-1949	88	15	18	24	21	24	16	103
1950-1959	47	131	24	60	42	36	16	178
1960-1969	163	96	47	44	91	45	32	259
1970-1979	1,568	89	251	383	442	304	277	1,657
1980-1989	1,839	96	341	436	419	344	395	1,935
1990-1999	1,956	198	360	477	452	361	504	2,154
2000-2009	1,830	254	320	448	475	347	494	2,084
2010-2012	409	38	63	125	91	76	92	447
Total	8,232	1,260	1,479	2,215	2,151	1,728	1,919	9,492

Panel B. Summary statistics of prices per bottle (in GBP)

	Nominal				Real			
Period	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
1899-1909	0.25	0.17	0.07	0.88	0.23	0.16	0.06	0.86
1910-1919	0.36	0.20	0.07	1.00	0.26	0.15	0.06	0.87
1929-1929	0.51	0.24	0.06	1.50	0.24	0.12	0.03	0.73
1930-1939	0.53	0.28	0.13	1.33	0.30	0.16	0.07	0.75
1940-1949	1.88	1.09	0.35	4.38	0.80	0.47	0.15	1.85
1950-1959	1.51	0.66	0.42	3.50	0.45	0.22	0.15	1.19
1960-1969	4.31	9.65	1.25	150.00	0.82	1.86	0.24	29.09
1970-1979	29.96	58.30	1.33	1,050.00	2.22	3.83	0.16	53.75
1980-1989	90.84	157.45	3.33	2,090.00	2.96	4.97	0.13	62.56
1990-1999	174.05	358.15	11.00	7,150.00	3.55	6.97	0.25	135.10
2000-2009	300.34	542.81	26.21	8,250.00	4.86	8.95	0.39	132.03
2010-2012	758.46	1,161.84	80.50	8,510.00	10.04	15.63	1.04	110.42

Table 2. Baseline hedonic regression results

Table 2 presents estimates from our baseline hedonic regressions using ordinary least squares. The dependent variable is the average price (in real GBP) per bottle per quartet of year-end, château, vintage, and transaction type. Yield data (for an anonymous First Growth) come from Chevet, Lecocq, and Visser (2011). The weather quality variable is based on temperature during the growing season and rainfall during the harvest season of each vintage year. All age variables are converted from years to centuries: age has been divided by 100, age^2 by 10,000, etc. Robust standard errors are clustered at the year level and reported in parentheses below the coefficient. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 level respectively.

	(1)	(2)	(3)	(4)	(5)
Time dummies	[Included]	[Included]	[Included]	[Included]	[Included]
Transaction type dummy					
Dealer	0.0197	0.0664	0.2260 ***	0.4935 ***	0.4869 ***
	(0.0742)	(0.0683)	(0.0655)	(0.0629)	(0.0527)
Château dummies					
Lafite		0.4254 ***			0.1616 ***
		(0.0426)			(0.0326)
Latour		0.2564 ***			0.1726 ***
		(0.0319)			(0.0153)
Margaux		0.1051 ***			0.0410 **
		(0.0192)			(0.0169)
Mouton		0.3610 ***			0.3104 ***
		(0.0369)			(0.0369)
Proxies for vintage effects					
Ln(yield)			-0.7100 ***		-0.1918 ***
			(0.0397)		(0.0196)
Weather quality			0.0793 ***		0.0544 ***
			(0.0043)		(0.0126)
Age and age-weather variables					
Age				1.4826 **	-0.1103
				(0.7421)	(1.9104)
Age^2				4.1541 *	2.8019
				(2.4179)	(7.0255)
Age^3				-6.4647 **	1.9369
				(2.9472)	(8.8404)
Age^4				2.9690 **	-2.5382
				(1.1595)	(3.6116)
Age × weather quality					0.1458
					(0.1830)
Age^2 × weather quality					0.0382
					(0.6557)
Age^3 × weather quality					-0.7152
					(0.8149)
Age^4 × weather quality					0.5100
					(0.3320)
F-test age variables				325.10 ***	35.02 ***
F-test age-weather variables					8.37 ***
N	9,492	9,492	9,224	9,492	9,224
R-squared	0.43	0.45	0.61	0.69	0.74

Table 3. Alternative specifications of the hedonic model

Table 3 shows estimates of the geometric average price appreciation in the time series (based on the coefficients on the time dummies) and over different segments of the life cycle (based on the coefficients on the age and age-weather variables) for our benchmark model (reported in the last column of Table 2) and for a number of alternative specifications of the hedonic model.

		Estimates of annualized price appreciation over…								
		…time	…life cycle							
			Lowest weather quality				Highest weather quality			
	R^2	1900-2012	0-25	25-50	50-75	75-100	0-25	25-50	50-75	75-100
Benchmark model	0.74	2.9%	0.9%	2.2%	2.9%	2.3%	3.0%	1.9%	0.5%	1.5%
Use third-order age polynomial	0.74	2.9%	0.8%	2.2%	2.8%	2.6%	3.7%	1.5%	0.8%	1.6%
Use fifth-order age polynomial	0.74	2.9%	0.1%	2.3%	2.2%	3.5%	2.4%	2.0%	0.2%	1.9%
Add winter rainfall to weather quality	0.73	2.8%	1.2%	2.4%	2.9%	2.3%	2.5%	2.0%	0.7%	1.6%
Add dealer-time interaction to model	0.74	2.6%	0.9%	2.2%	2.9%	2.3%	2.9%	1.9%	0.5%	1.5%

Table 4. Wine versus other assets 1900–2012

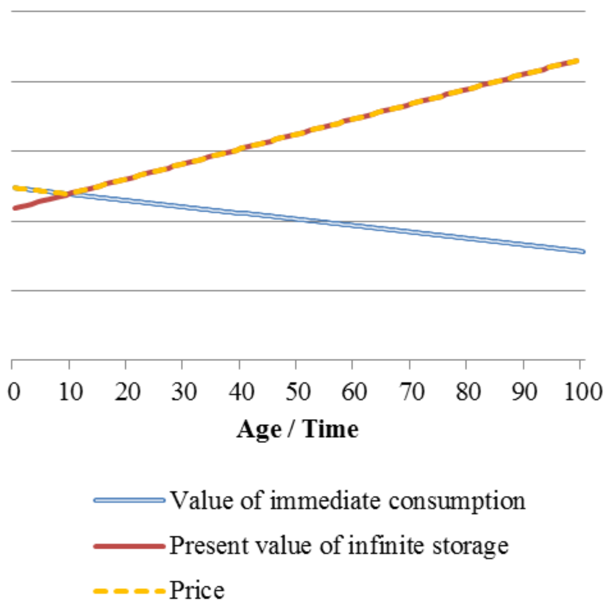
Table 4 shows the distribution of returns (in nominal and real GBP) for wine and other assets over the period 1900–2012. A deflated wine price index is estimated by applying a value-weighted arithmetic repeat-sales regression to the price pairs in our database. The resulting return estimates are corrected for storage and insurance costs. Data on British equities, government bonds, and inflation come from Dimson, Marsh, and Staunton (2013). Art return data come from Goetzmann, Renneboog, and Spaenjers (2011), updated until end-2012 using data from Artprice (2013). Stamp return data come from Dimson and Spaenjers (2011), updated using the Stanley Gibbons GB30 index.

	Mean returns p.a.		Dispersion of annual returns				
	Geometric	Arithmetic	S.D.	Lowest		Highest	
Nominal returns							
Wine	8.2%	10.9%	26.9%	-34.92%	1949	144.3%	1942
Equities	9.4%	11.2%	21.6%	-48.85%	1974	145.6%	1975
Bonds	5.5%	6.1%	11.9%	-17.39%	1974	53.1%	1982
Art	6.4%	7.2%	13.2%	-31.17%	1930	46.6%	1968
Stamps	6.9%	7.6%	13.5%	-8.77%	1982	83.2%	1979
Inflation	3.9%	4.2%	6.5%	-26.02%	1921	24.9%	1975
Real returns							
Wine	4.1%	6.7%	26.3%	-37.11%	1949	145.6%	1942
Equities	5.2%	7.1%	19.8%	-57.07%	1974	96.7%	1975
Bonds	1.5%	2.4%	13.7%	-30.66%	1974	59.4%	1921
Art	2.4%	3.1%	12.4%	-29.67%	1915	38.4%	1968
Stamps	2.8%	3.5%	12.3%	-19.20%	1915	56.3%	1979

Figure 1. A simple model of wine price dynamics

Figure 1 shows examples of life-cycle log price patterns implied by the model described in Section 2 for a low-quality vintage that starts deteriorating in quality immediately after the vintage (in Panel A) and a high-quality vintage that first improves in quality for 40 years (in Panel B). The following parameter values were used: r = 10%, g = 3%, z = 2%, a = 0.96, b = 1.10, and $d_{L,1} = 0.75 \times d_{H,1} = 0.025 \times c_{L,0} = 0.025 \times 0.75 \times c_{H,0}$.

Panel A. Low-quality vintage



Panel B. High-quality vintage

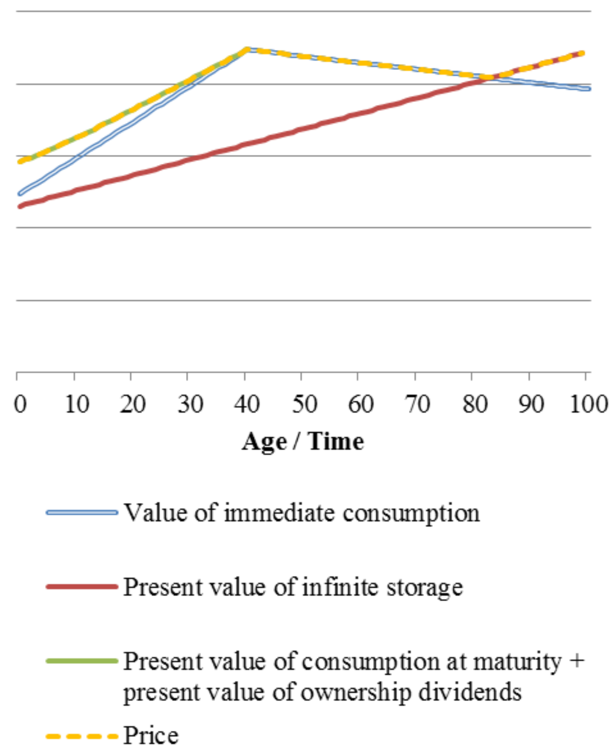
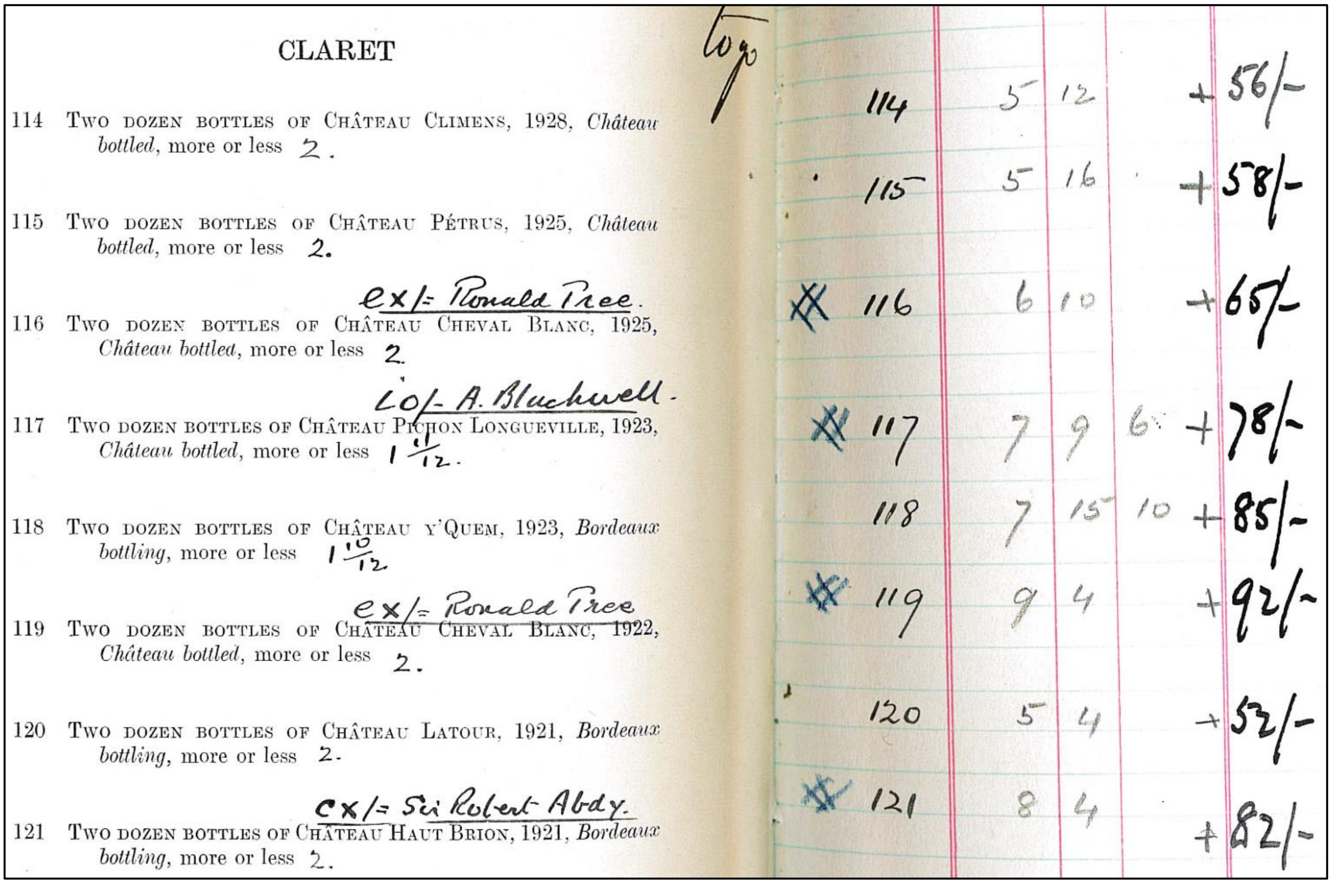


Figure 2. Christie's auction catalogue (9 December 1935)

Figure 2 shows an excerpt (lots 114–121) from the annotated catalogue of the wine auction that took place at Christie's London on 9 December 1935. The left page is from the original pre-sale catalogue, but also contains some handwritten notes of the auctioneer on the number of bottles for each lot and on commission bids submitted prior to the sale. The right page was added by the auctioneer and shows the price paid for each lot (in pounds, shillings, and pence) and the equivalent price (in shillings) per dozen bottles.



CLARET

114 TWO DOZEN BOTTLES OF CHÂTEAU CLIMENS, 1928, *Château bottled*, more or less 2.

115 TWO DOZEN BOTTLES OF CHÂTEAU PÉTRUS, 1925, *Château bottled*, more or less 2.

ex/= Ronald Tree.
116 TWO DOZEN BOTTLES OF CHÂTEAU CHEVAL BLANC, 1925, *Château bottled*, more or less 2.

L0/- A. Blackwell.
117 TWO DOZEN BOTTLES OF CHÂTEAU PICHON LONGUEVILLE, 1923, *Château bottled*, more or less 1 11/12.

118 TWO DOZEN BOTTLES OF CHÂTEAU Y'QUEM, 1923, *Bordeaux bottling*, more or less 1 10/12

ex/= Ronald Tree
119 TWO DOZEN BOTTLES OF ~~CHÂTEAU CHEVAL BLANC, 1922~~, *Château bottled*, more or less 2.

120 TWO DOZEN BOTTLES OF CHÂTEAU LATOUR, 1921, *Bordeaux bottling*, more or less 2.

cx/= Sir Robert Abdy.
121 TWO DOZEN BOTTLES OF ~~CHÂTEAU~~ HAUT BRION, 1921, *Bordeaux bottling*, more or less 2.

	114	5	12		+ 56/-
	115	5	16		+ 58/-
XX	116	6	10		+ 65/-
XX	117	7	9	6	+ 78/-
	118	7	15	10	+ 85/-
XX	119	9	4		+ 92/-
	120	5	4		+ 52/-
XX	121	8	4		+ 82/-

Figure 3. BBR price list (May 1909)

Figure 3 shows two pages from the May 1909 price list of BBR. Prices are quoted in shillings per dozen bottles.

Telephone : May, 1909
1788 MAYFAIR.
Telegrams :
"BERRINCHE, LONDON."

PRICE LIST.

BERRY BROS. & CO.,

Established in the XVII Century, at

3 ST JAMES'S STREET,

LONDON, S.W.

CELLARS:–
1, 2, 3, & 4 Pickering Place, S.W.
Hay's Mews Vaults, Berkeley Sq., W.
26 Savile Row, W.

BONDED WAREHOUSES:–
LONDON,
GLASGOW,
and
SOUTHAMPTON.

Bankers :–BANK OF ENGLAND.

6 BERRY BROS. & CO.

SAUTERNES.

		Per Doz.
Ch. D'Eyrans	... ...	16/6
Ch. La Roue, White Bordeaux	... ...	21/-
Domaine de Broustaret Light and Dry.	... ...	24/-
St Croix du Mont, 1893	... ...	36/-
Preignac, 1900	... ...	36/-
Ch. Ricaud, 1895	... ...	40/-
Ch. Carbonnieux, 1er Graves	... ...	42/-
Ch. Rieussic	... ...	60/-
Ch. Filhot, 1864	... ...	78/-
Ch. Yquem, 1893, Ch. Bottled	... ...	108/-
" " 1874, "	... ...	275/-

CLARET.

1904	**Ch. Constant Bages**	21/-	
	Ch. Belgrave	24/-	For Laying Down.
	Ch. Angludet ½ bots. only	15/-	For Laying Down.
	Ch. Talbot	30/-	For Laying Down.
	Ch. Pichon Longueville	33/-	For Laying Down.
	Ch. Gruaud Larose Sarget ...	34/-	For Laying Down.
	" " Ch. Bottled	38/-	For Laying Down.
	Ch. Canon, 1er St Emilion ...	36/-	For Laying Down.
1905	**Ch. La Mission Haut Brion** Ch. bottled	42/-	For Laying Down.
	Ch. Margaux, 1st growth "	54/-	For Laying Down.
	Ch. Latour, 1st growth "	50/-	For Laying Down.
	Ch. Mouton Rothschild, "	50/-	
	Ch. Haut Brion, 1st growth "	60/-	

3, St James's Street, London, S.W.

Figure 4. Aging and wine prices

Figure 4 shows the predicted life-cycle price patterns for the lowest- and highest-quality vintages, as implied by the coefficients on the weather quality variable, age variables, and their interactions in the benchmark model (reported in the last column of Table 2). The price level for the lowest quality category at age zero is set to unity. The dotted lines denote 95% confidence intervals.

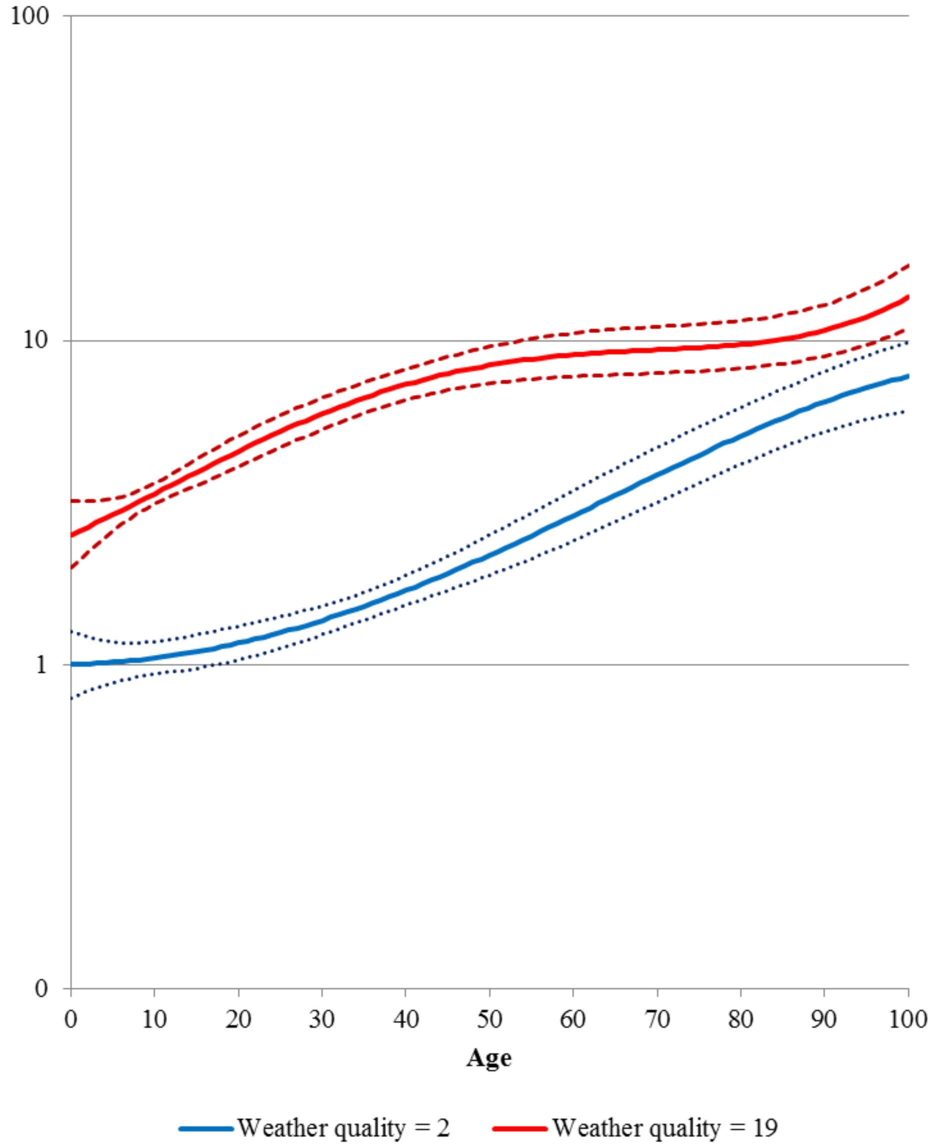


Figure 5. Deflated wine price index and nominal returns

The line in Figure 5 shows a deflated wine price index (against the left axis), which is estimated by applying a value-weighted arithmetic repeat-sales regression to the price pairs in our database, over the period 1900–2012. The index is set equal to unity at the start of 1900. The bars show the estimated nominal return for each year (against the right axis).

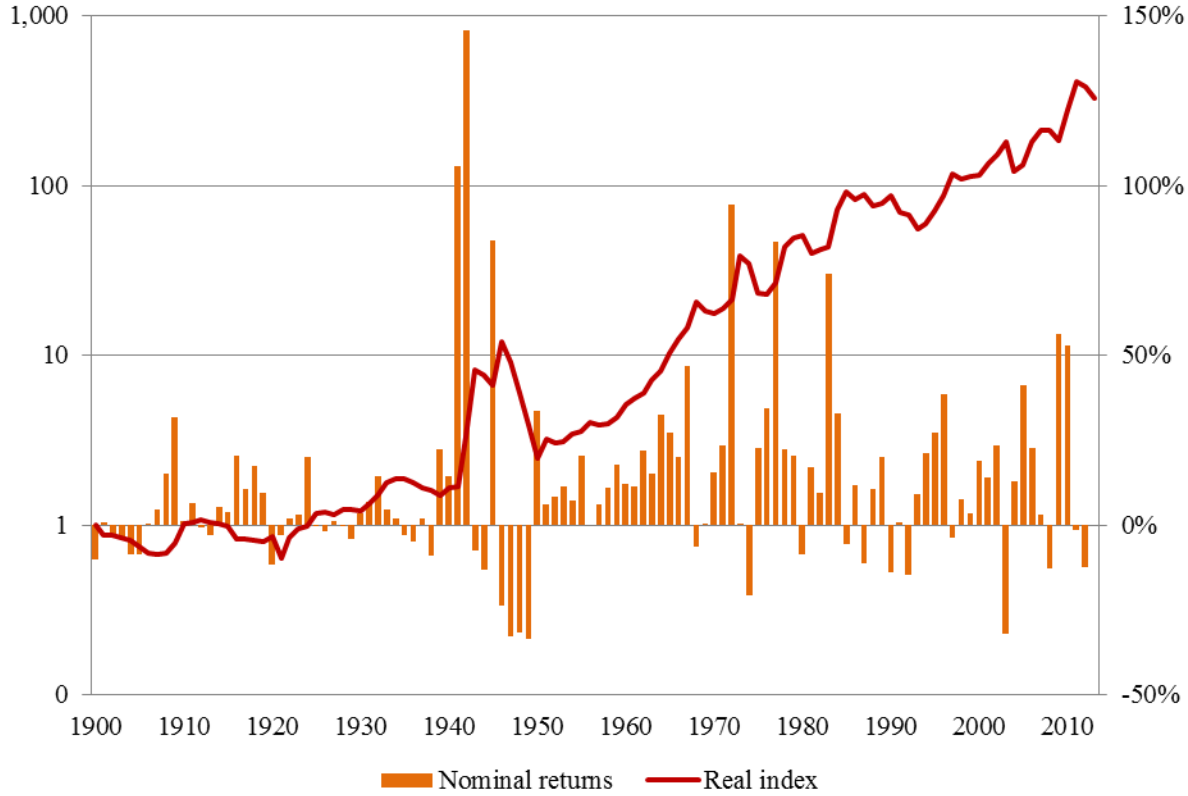


Figure 6. Wine versus other assets 1900–2012

Figure 6 shows price indexes in real GBP for wine and other assets over the period 1900–2012. A deflated wine price index is estimated by applying a value-weighted repeat-sales regression to the price pairs in our database. The resulting return estimates are corrected for storage and insurance costs. Data on British equities, government bonds, and inflation are from Dimson, Marsh, and Staunton (2013). Returns to art are from Goetzmann, Renneboog, and Spaenjers (2011), updated through the end of 2012 using data from Artprice (2013). Returns to stamps are from Dimson and Spaenjers (2011), updated using the Stanley Gibbons GB30 index. All indexes are set to unity at the start of 1900.