

## **Behavioural Heterogeneity in Wine Investments<sup>†</sup>**

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### **Abstract**

We introduce a heterogeneous agent model to explain the dynamics of fine wine investments. Our results show evidence of the existence of both fundamentalists – those who trade on mean-reversion towards a fair value – and chartists – those who extrapolate recently observed price trends – in the wine market. Moreover, we document that market participants switch between the two trading strategies, allocating more weight to the strategy that has been the most accurate in forecasting wine index values in the recent past. This switching behaviour can explain the large variations in index values (bubbles and crashes) that are observed in the fine wine market.

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## 1 Introduction

*“The emotional and social attachment to treasure means that investors are extremely likely to make sub-optimal decisions about when to buy, sell or how much to pay.”*  
(Mitchell, 2012)

Collectibles as an asset class have received considerable attention in recent years. On average, high net-worth individuals hold nearly 6% of their assets in collectibles (see Knight Frank, 2017). Being a significant asset class, many studies have looked at the benefits of collectibles in a portfolio of financial assets (see e.g., Worthington and Higgs, 2004; Veld and Veld-Merkoulova, 2007; Campbell, 2008; Dimson and Spaenjers, 2014; Korteweg, Kräusl and, Verwijmeren, 2015). Others have made more direct comparisons with traditional financial assets and examined the risk-return characteristics of a variety of collectibles (e.g. Hiraki, Ito, Spieth and Takezawa, 2009; Dimson and Spaenjers, 2011; Dimson, Rousseau and Spaenjers, 2015; Coslor and Spaenjers, 2016; Martin, 2016). However, collectibles are also known to be affected by emotions, and are thus often referred to as emotional assets. This emotional aspect is shown to affect prices of collectibles (see Renneboog and Spaenjers, 2013), and can lead to speculative bubbles (e.g. Penasse and Renneboog, 2017; Kräusl, Lehnert and Martelin, 2016).

While much of the literature on bubble behaviour in collectibles has focused on art, another important collectible, fine wine, has received less attention in this regard. There is a growing interest in wine as an investment asset,<sup>1</sup> with more than 37% of high net-worth individuals around the world having invested in luxury goods such as fine

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<sup>1</sup>According to Wine Spectator sales at major wine auctions increased from 90 million USD in 2002 to 381 million USD in 2017.

wine (see Knight Frank, 2017). One common argument for investing in wine is that it provides diversification benefits, due to its relatively low correlations with financial assets (e.g. Sanning et al., 2008; Masset and Henderson, 2010; and Masset and Weisskopf, 2018a).<sup>2</sup> In addition, investments in wine produce attractive returns that are well in excess of government bonds (Dimson et al., 2015).<sup>3</sup> As a consequence, in recent years, we have seen the introduction of several Wine Funds (see e.g. Lucey and Devine, 2015) as well as the creation of several Wine Indices (e.g. the indices developed by Liv-Ex<sup>4</sup>).

But wine is also an emotional asset (such as art, vintage cars, rare stamps or historical coins), where market participants not only invest to pursue financial goals but also for the enjoyment they derive from it. This emotional aspect of wine can lead to bubble-like behaviour (Czupryna and Oleksy, 2015; Dimson et al., 2015; Jovanovic, 2013), as emotions can lead to irrational behaviours such as herding, and can cause prices to deviate from their fair value over prolonged periods of time. This, for instance, has been witnessed in the wine market in 2011.<sup>5</sup>

Another feature of wine investments is that deviations from intrinsic values cannot be arbitrated away due to market illiquidity, high transaction costs (storage, shipping, insurance, auction premia) and information asymmetries. More importantly, price differences can emanate from a base of heterogeneous customers (Häberle and Masset, 2016; Cardebat et al., 2016) who may trade in wine for different reasons

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<sup>2</sup>This low correlation with financial assets should be put in perspective as investing in fine wine is not as liquid as investing in traditional financial assets (Masset and Weisskopf, 2018b).

<sup>3</sup>Dimson et al. (2015) document a return of 10.9% p.a. over the period 1900-2012, compared with a 6.1% return p.a. on US government bonds.

<sup>4</sup>London International Vintners Exchange ([www.liv-ex.com](http://www.liv-ex.com)).

<sup>5</sup>See for instance <http://www.winespectator.com/webfeature/show/id/46287>. However, this bubble-like behavior has been recognized earlier. For instance, Robinson (1998) notes that: “*What is more extraordinary is the wild price variation at the very top end -fine wines. Demand bubbles up mysteriously, apparently fuelled by fashion and rumour as much as by intrinsic quality*”. We further note that bubble-like behaviour is also observed in other markets for emotional assets, such as the art market (see e.g. Kräussl et al. 2016 or Penasse and Renneboog, 2017).

(collection, investment, speculation or consumption) causing different price triggers based on their knowledge about fair values, access to information or beliefs of the future evolution of the market. Since the presence of these different types of investors could expose the wine market to extreme prices, understanding the behaviour of different types of investors in the wine market is of considerable importance.

The objective of this paper is to examine the dynamics, and bubble-like behaviour, on the market for fine wine by applying a heterogeneous agent model (HAM).<sup>6</sup> Using this model, we aim to assess whether there is evidence of behavioural heterogeneity in this market, and whether this behavioural heterogeneity can explain the dynamics that we observe in the market for fine wine. A HAM assumes that a market is populated with investors who form beliefs about the future value of an asset based on different strategies and switch between these different beliefs on signals they obtain from the past performance of their trading strategies. The model assumes that investors generally have two types of beliefs. The first belief is often referred to as fundamentalism, and is a belief in mean-reversion of prices towards a level which seems to represent a fair value. The HAM literature refers to this fair value as the fundamental value. Although we acknowledge that the concept of a fundamental value for wine is rather moot as wine investments do not generate cash flows, one should take this concept in a generic manner and interpret it as a fair price. If we believe that the price of wine reflects common attributes such as quality (vintages and producers), individual and collective reputation and natural endowments (producer) as shown in numerous studies on wine price determinants (see, e.g., Oczkowski and Doucouliagos (2014) for a review of this literature), then one could define a fair price as a reflection of the long-run average growth rate in the price of wine. The second belief is referred to as chartism

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<sup>6</sup>Although it is not the purpose of this paper to assess bubbles in the context of Phillips et al. (2011, 2015), in unreported tests, we find that there are indeed episodes with explosive behaviour in our wine index. These results are available on request.

or trend-following, a belief that recent trends in the market can be extrapolated into the future.

We assess bubble-like behaviour in the fine wine market by considering the deviations from its fair value. Theoretically, a speculative bubble appears when the dynamics of an asset cannot be explained by either the rent, asset and product cycle. Since wine does not provide any cash flows only the asset and product cycles are relevant. When we define a specification for the fair value, we capture the asset cycle by time trends (and in further robustness tests use time polynomials and moving averages as alternatives) and capture the product cycle through the inclusion of vintage dummies.<sup>7</sup> While it is our aim to describe the bubble-like behaviour in the fine wine market, we are not necessarily modelling the behaviour of emotional and non-emotional investors. Rather, we would argue that emotional behaviour can lead to deviations from fair values (due to irrationality, manifesting itself e.g. through herd behaviour) that traders can exploit by either following a chartist strategy or a fundamentalist strategy (see the model section for more detail).

We implement the HAM to explain the dynamics of the *Liv-Ex Fine Wine Investables* Index which tracks the most investable wines in the fine wine market, and find significant evidence for the existence of both types of traders in this market.<sup>8</sup> Moreover, we find evidence of significant switching behaviour between fundamentalist and chartist beliefs, where investors follow the belief that has been the most accurate in forecasting prices in the recent past.<sup>9</sup> This switching behaviour can explain index deviations from fair values observed in the fine wine market. Specifically, we document

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<sup>7</sup>We thank the referee for pointing this out to us.

<sup>8</sup>Note that throughout the paper we use the terms “index value” and “price” interchangeably. Where we use the term “price” in the context of our analysis, we essentially refer to index values.

<sup>9</sup>This switching behavior can be interpreted in two ways. Either investors change their beliefs and instead of following one strategy decide to follow another strategy, or there is heterogeneity among investors, and investors with different beliefs (e.g. investors, consumers and collectors) choose to trade at different times when they realize that their trading strategy is more accurate.

that any large positive or negative deviations from fair values coincide with the majority of investors trading on the basis of a chartist belief. Further robustness testing reveals that our results do not hinge on the particular model we use to define the fair value as our results hold using alternative specifications. This alleviates any concerns about the precise definition of a fair value of wine as its definition does not appear to impact our findings.

We further refine and extend our analysis to a set of Liv-Ex indices covering several distinct winegrowing regions from across the world, and document that the heterogeneity in beliefs of investors is strongest for the *Liv-Ex Fine Wine Investables* Index. This result is expected as Bordeaux wines – which are the constituents of the *Liv-Ex Fine Wine Investables* Index – are the best-known wines and are most prone to speculative investing due to their status and emotional value. This index also tends to display the highest heterogeneity in terms of market participants as compared to smaller, more complex regions analysed (such as Rhone or Italian wines). Overall, our model and results provide an explanation for bubble and crash behaviour in fine wine prices and the observed high volatility in wine as documented by Dimson et al. (2015).

Our findings contribute to the literature in several ways. To the best of our knowledge, we are the first to implement a HAM on collectables, in general, and the wine market, in particular. This model appears especially useful to study and explain the dynamics of the fine wines values in the presence of diverse clients with different beliefs and informational characteristics. While some papers have looked into the pricing of fine wine (Oczkowski and Doucouliagos, 2014) and its benefits as an asset class (Storchmann, 2012), the importance of segmentation and the accompanying effect this may have on the price dynamics of the wine market has not received due attention. Furthermore, the use of wine indices covering multiple wine-growing regions in which

different customer segments operate deepens our analysis. The application of our model clearly demonstrates that it is especially those sub-markets in which investors and/or speculators are active that display the highest heterogeneity and switching behaviour. Market segments for which price information is less readily available display a more homogenous behaviour. In addition, our paper contributes to the explanation of bubble-like behaviour in the fine wine prices. The presence of a bubble-like evolution in the Bordeaux and especially Lafite market has been put forward by practitioners (Serdarevic, 2012) and pointed out by academics (Masset and Weisskopf, 2016) but its existence or creation has not been investigated empirically.

The remainder of this paper is structured as follows. In Section 2, we discuss some of the related literature. In Section 3, we develop a heterogeneous agent model that allows for traders with different beliefs to be present in the market. In Section 4, we discuss our data. Section 5 discusses empirical results and highlights some of the implications of the model in terms of switching behaviour and the occurrence of bubbles and crashes. Finally, Section 6 concludes.

## **2 Literature**

In this Section, we first review some of the relevant literature related to investments in wine. Subsequently, we discuss the heterogeneous agent model literature.

### *2.1 Wine Investments*

Several studies have analysed the potential of fine wine as an investment (e.g. Faye et al., 2015; Masset and Henderson, 2010; Masset and Weisskopf, 2018a; Burton and

Jacobsen, 2001; Dimson et al., 2015; Sanning et al., 2008) or studied the determinants of wine prices.<sup>10</sup>

Previous research has tried to model the price of fine wine and has found several characteristics that explain, at least partly, the value of a specific bottle of wine. These include natural features such as the soil (terroir) (Gergaud and Ginsburgh, 2008) and especially the climate (Ashenfelter, 2010). This dimension is complemented by features which are specific to the respective producer, such as the winemaking techniques but also to the history and reputation of a producer (Hadj Ali and Nauges, 2007). All of this will have an effect on the aging potential and quality of the specific wine. Finally, the adherence to an appellation or a region also has some influence (Cardebat and Figuet, 2004). From a more macroeconomic viewpoint the overall economic situation (Masset and Weisskopf, 2018) or adverse FX movements (Jiao, 2017) have an effect on consumer spending and thus on the price customers are willing to pay for a bottle of fine wine. Overall, wine prices are thus driven by the quality of a wine, the individual and collective status of a producer and the economic environment.

These more objective criteria are able to explain a good proportion of fundamental wine prices. However, another proportion is less tangible and remains more difficult to quantify. It is related to the intrinsic behaviour of customers who may behave emotionally and therefore may either drive prices away from their fundamental value or lead producers to adapt their pricing strategy. More recent literature has started to study this part by looking into client segmentation which may display diverging behaviour and draw different utility functions out of a bottle of fine wine (Cardebat et al., 2017). Other studies examine the effects of marketing tools on the purchase

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<sup>10</sup>See Oczkowski and Doucouliagos (2014) for a recent survey on wine price determinants.



behaviour of customers and how these lead to a differentiated willingness to pay (Danner et al., 2016).

While there is still no consensus about the exact definition of the intrinsic value for fine wine, we have a good understanding of the drivers of fine wine prices. However, studies on fine wine also call for a more thorough examination of the price dynamics underlying this market. While fine wine prices can be reasonably well described through hedonic models (Rosen, 1974), price dispersion and deviations are more difficult to explain. Fine wines are emotional assets whose prices are formed by factors unique to each investor. A common feature of such an asset is the existence of an emotional premium that an investor is willing to pay to capture the emotional wealth expected to arise from its holding.

A few studies have looked into price dispersion and deviations from the law of one price, and as an extension, at the segmentation of the wine market. For instance, Jaeger and Storchmann (2011) analyse wine price dispersion across retail outlets in the US and find that deviations from the law of one price are common. They indicate even stronger deviations for the high-priced wines due, amongst others, to diverging state regulations. This evidence is complemented by Cardebat et al. (2014) in a study on the role of wine experts who state that the law of one price very often fails to hold, especially if experience goods,<sup>11</sup> such as fine wines, are involved.

Häberle and Masset (2016) classify wine market participants into four distinct categories: investors, collectors, inexperienced buyers and wine lovers. They show that different wine regions and types will attract different buyers and thus lead to a segmentation of the wine market potentially generating differing price dynamics comparable to evidence from traditional financial markets. Similarly, Cardebat et al.

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<sup>11</sup>Wine can be considered a prime example of an experience good as a consumer can only elicit its true intrinsic quality once purchased and consumed.

(2016) look at the drivers of price dispersion in the wine auction market based on taxonomic theory and the presence of heterogeneous agents. They suggest that different agents (investors, collectors and consumers) in the wine market display diverging attributes and goals. Finally, Masset et al. (2016) show indirect evidence of a geographical segmentation of the market with Asian buyers paying a premium of up to 60% at Hong Kong wine auctions as opposed to wine proposed at non-Asian auction locations.

Research on the existence of price bubbles in the wine market is scarce. Some studies have examined the efficiency of the wine market which can indirectly be associated to bubble creation. Masset and Henderson (2010), for instance, cannot reject the hypothesis of a unit root in a portfolio that invests in fine wines. Erdős and Ormos (2013) use more advanced and diverse techniques to perform an in-depth study of weak-form efficiency of the wine market. Initial results confirm those of Masset and Henderson (2010), i.e. the wine market does not appear to be efficient. However, their study suggests that fine wine has a stationary and random walk component leading to positive auto-correlations. Finally, Bouri et al. (2016), accounting for shifts and breaks in wine price data, conclude that the wine market is inefficient.

As mentioned before, the emotional aspect and inefficiency of fine wine makes it prone to bubble-like behaviour (Czupryna and Oleksy, 2015; Dimson et al., 2015; Jovanovic, 2013). That is, a fine wine, as a non-reproducible and exhaustible commodity with strong emotional charge, seems to be vulnerable to exaggerated upward price movements, which, together with the impossibility of short selling, can lead to the emergence of speculative bubbles. In a traditional sense, such bubbles occur when prices strongly deviate from their intrinsic value over a prolonged period of time.

Wine prices, being subject to both rational and irrational factors, can thus fluctuate widely leading to price bubbles and busts.

While current research does not allow us to exactly define the intrinsic value for fine wine, the wine literature does let us identify the drivers of fine wine prices. We also know that customer segmentation and the behavioral aspect of wine market participants has an impact on the wine market. This article therefore wants to build on these findings by examining how the time-varying activity of different market participants present on the wine market may explain wine price dynamics.

## *2.2 Heterogeneous agent models and bubble-like behaviour*

One approach taken in the literature to model bubble-like behaviour in financial assets is that of heterogeneous agent models, with one of the seminal papers in this area by Brock and Hommes (1997). In that paper, the authors introduce a heterogeneous agent model (HAM), where agents can choose between an inferior, but free forecaster of the price of an asset versus a superior forecaster that comes at a small cost. Brock and Hommes (1997) demonstrate that the presence of a small cost to the superior forecaster and a high sensitivity to relative past profits based on the different forecasters can lead to price dynamics that can explain bubble and crash scenarios. Brock and Hommes (1998) extend their original model to a setting of financial markets, and define concepts of fundamentalist beliefs - investors who believe in mean-reversion in the price of an asset to its fundamental value - and chartist beliefs - investors who believe in extrapolation of recently observed price patterns. Brock and Hommes (1998) demonstrate, through numerical simulations, the existence of both types of beliefs and trading strategies that are sensitive to the past profitability of the different beliefs leading to bubbles and crashes in financial markets.

The above mentioned papers, being purely theoretical in nature, use simulations to demonstrate the interesting dynamics that can be generated by these HAMs, such as bubbles, crashes, and excess volatility. The first empirical estimation of a HAM was carried out by De Grauwe and Grimaldi (2005a) who develop an empirical specification based on the existence of fundamentalists and chartists to explain the dynamics of exchange rates.<sup>12</sup> This model does not allow traders to switch between trading rules, but the authors use this model to demonstrate how such a simple specification can explain some of the empirical puzzles related to exchange rate movements. De Grauwe and Grimaldi (2005b) extend this model by allowing traders to switch between trading rules using a discrete choice framework similar to Brock and Hommes (1998). Finally, De Grauwe and Grimaldi (2006) further extend this model for exchange rates by including the impact behavioural heterogeneity has on exchange rate volatility.

Boswijk et al. (2007) derive an empirical specification of the Brock and Hommes (1998) model and estimate this model to explain the dynamics of the S&P500 over the period 1871 to 2003. The authors demonstrate the existence of both fundamentalist and chartist beliefs in the stock market, and find that investors switch between these beliefs based on the past profitability of either the fundamentalist or chartist belief.

Following these initial empirical papers, studies have applied HAMs to explain the dynamics of various assets. For instance, Ter Ellen and Zwinkels (2010) use a HAM to explain the dynamics of oil prices while Baur and Glover (2014) use a HAM to explain the dynamics of gold prices. Similar to fine wine, both commodities do not produce cash-flows, and thus, depend on supply and demand in its purest sense. Likewise, Kouwenberg and Zwinkels (2014) implement a HAM to model the price

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<sup>12</sup>Other empirical frameworks that consider fundamentalists-chartists have been considered in the literature, such as Westerhoff and Reitz (2003) and Menkhoff et al. (2009) who look at the impact of fundamentalist/chartist beliefs on the dynamics of exchange rates.

dynamics of US real estate prices. These studies provide strong empirical evidence of heterogeneity in beliefs and switching behaviour based on past forecasting performance of the different beliefs.<sup>13,14</sup>

A key feature of the empirical application of HAMs is that these models can capture substantially more of the dynamics observed in assets compared with traditional linear models. HAMs can do this in very parsimonious ways, often by including only a single additional. Given that there is evidence of bubble and crash behaviour in the prices of fine wines and different types of agents that are active in this market, a HAM is well-suited to explain the price dynamics of fine wines.

### **3 Methodology**

In this section, we develop a heterogeneous agent model (HAM) to capture the dynamics of changes in the value of a fine wine index. This model builds on the theoretical works of Brock and Hommes (1997; 1998), and has close similarities to the empirical works of Ter Ellen and Zwinkels (2010), and Kouwenberg and Zwinkels (2014). Specifically, we assume that the market for fine wine has two distinct types of

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<sup>13</sup>Chen et al. (2012) provide an excellent overview on the empirical HAM literature.

<sup>14</sup>Several competing approaches used to detect bubble-like behaviour have been employed on tangible or alternative asset classes. A common method is the superior-ADF (SADF) test of Phillips, Wu, and Yu (2011). For instance, Gilbert (2010) applies the SADF procedure to three CBOT future prices, wheat, corn and soybeans, concluding that during the commodity boom and bust of 2007–2008 there was explosive behaviour in soybean future prices. Phillips et al.'s SADF test is also used by Etienne et al. (2014). They find that there are speculative bubbles in 12 agricultural markets. More in line with our study, Czuprina and Olesksy (2015) find explosive behaviour in the Liv-ex 50 index. Figuerola-Ferretti et al. (2015) use a multi-bubble generalization of the SADF test, GSADF, proposed by Phillips, Shi and Yu (2015) to examine the price behaviour of the six main London Metal Exchange non-ferrous metals prices. They detect periods of mild explosivity in copper, nickel, lead, zinc and tin, but not in aluminium. Similarly, Tsvetanov et al. (2016) apply the GSADF test to crude oil prices, finding significant bubble periods. Alternative bubble detection methodologies have also been used, such as Zhou and Sornette's (2009) D-test (oil price in Zhang and Yao, 2016); van Norden and Schaller's (1993) switching regression model (grains, softs, animals and woods, precious metals, and energy in Brooks et al., 2015); or the momentum threshold autoregressive (MTAR) approach (US corn, soybean and wheat prices) of Adämmer and Bohl (2015).

investors: speculators who trade in fine wine purely for their potential financial gains; and collectors/consumers, who buy fine wine for non-financial benefits they derive from owning the wine.

Within the group of speculators, we assume that investors can follow two strategies: a so-called fundamentalist strategy, where, based on market experience, information and knowledge investors expect mean-reversion of wine values towards a fair value. The second strategy considered in our HAM is a trend-chasing strategy, where investors believe in continuations of recently observed price trends (investors who follow this belief are often referred to as chartists as they look at price charts and extrapolate from those).<sup>15</sup>

More formally, we can specify the beliefs of the different types of investors (fundamentalists or chartists) in terms of their expectations about the value of wine. For fundamentalists, who rely on mean-reversion towards a fundamental value, we can specify their expectation of the future price index value as follows

$$E_t^F(P_{t+1}) = P_t + \alpha(P_t - V_t), \quad (1)$$

where  $E_t^F(P_{t+1})$  is the expectation that is formed at time  $t$  about the value of the wine index at time  $t + 1$  by the fundamentalists,  $P_t$  is the current value of the wine index and  $V_t$  is its fundamental value. The coefficient  $\alpha$  captures the degree of mean-reversion that the fundamentalist expects to occur, and is expected to be between 0 and -1. If  $\alpha = 0$ , then fundamentalists expect to see no mean-reversion towards the fundamental value, whereas if  $\alpha = -1$ , fundamentalists expect the value of the wine index to mean-revert fully towards the fundamental value in the next period. Any value of  $\alpha$  between 0 and -1

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<sup>15</sup>Of course, collectors and consumers may also behave as speculators, or their demand can be random as captured by the noise term in Equation (7).

indicates a gradual mean-reversion of the value of the wine index towards its fundamental value.

The second group of investors, whose belief relies on the extrapolation of recent price patterns, can be formalized as follows,

$$E_t^C(P_{t+1}) = P_t + \beta \sum_{l=1}^L (P_{t-l+1} - P_{t-l}), \quad (2)$$

where  $E_t^C(P_{t+1})$  is the expectation that is formed at time  $t$  about the value of the wine index at time  $t + 1$  by the chartists,  $\beta$  is the autoregressive coefficient, and  $L$  is the total number of lags that the chartists look back.  $(P_{t-l+1} - P_{t-l})$  captures the change in the value of the wine index over the lagged period,  $l$ . A positive coefficient for  $\beta$  implies that chartists extrapolate the pattern they observed in the recent past, and that they trade on the expectation of momentum (i.e. index values will continue in the direction recently observed). A negative value for  $\beta$  implies that chartists expect index values to move in the opposite direction of what has recently been observed and is in line with a so-called contrarian belief, where investors buy an asset because it has decreased in value and therefore is relatively cheap.

With these two different beliefs, fundamentalism and chartism, we can move towards the development of a model that can explain the overall dynamics of the wine index we consider. If we denote  $w_t^F$  as the proportion of wine investors with a fundamentalist belief and  $w_t^C = 1 - w_t^F$  as the proportion of wine investors with a chartist belief, we can write the expectation at time  $t$  of the price of wine at time  $t + 1$  as,

$$E_t (P_{t+1}) = w_t^F (P_t + \alpha(P_t - V_t)) + (1 - w_t^F) \left( P_t + \beta \sum_{l=1}^L (P_{t-l+1} - P_{t-l}) \right), \quad (3)$$

where the first term on the right-hand side reflects the beliefs of the fundamentalist, and the second term the beliefs of the chartists. Thus, the expectation of the future value of the wine index is a weighted average of the different beliefs that the investors may have about its value.

A key feature of a HAM is that the weights on the fundamentalist and chartist strategies can vary over time. The HAM literature defines a specific form in which these weights evolve. Specifically, the HAM literature assumes that the dynamics in weights are driven by the past profitability or accuracy of a specific belief. For instance, if a fundamentalist belief as an investment strategy has led to superior performance, then agents who are following a chartist belief may change their investment strategy, and start to follow a fundamentalist belief. Vice versa, a relatively better performance of a chartist strategy may entice fundamentalists to become chartists. Thus, depending on the past performance of the different investment beliefs, investors may switch from one belief to another.<sup>16</sup> This particular aspect introduces time variation in the weights,  $w_t^F$  and  $w_t^C$ , which may lead to additional dynamics in the value of the wine index.

To formalize the evolution of weights on the specific investment beliefs, we follow Kouwenberg and Zwinkels (2014) by considering the relative forecast accuracy of the different investment strategies. Specifically, we define the forecast accuracy as the absolute forecast error, i.e.,

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<sup>16</sup>Alternatively, there may be heterogeneity between investors, and specific types of investors may trade at different points in time depending on how well their strategy performs.



$$Z_t^F = \sum_{k=1}^K \left| E_{t-k}^F (P_{t-k+1}) - P_{t-k+1} \right|, \quad Z_t^C = \sum_{k=1}^K \left| E_{t-k}^C (P_{t-k+1}) - P_{t-k+1} \right|, \quad (4)$$

where  $Z_t^F$  and  $Z_t^C$  are the forecast accuracies of the fundamentalist and chartist beliefs, respectively, and  $K$  captures the number of periods that investors look back to examine the forecast accuracy of their specific trading rule.

Investors are allowed to switch between the different beliefs depending on the relative performance of one belief versus the other. To model the switching behaviour of the investors, we follow the original works of Brock and Hommes (1997, 1998), where the switching behaviour is modelled according to a multinomial switching function (see Manski and McFadden (1981)), but implement this function by looking at relative forecast errors as in Kouwenberg and Zwinkel (2014). Specifically, we define the weights on the fundamentalist strategy as

$$w_t^F = \left[ 1 + \exp \left( \gamma \left\{ \frac{Z_t^F - Z_t^C}{Z_t^F + Z_t^C} \right\} \right) \right]^{-1}, \quad (5)$$

where  $\gamma$  is the so-called intensity of choice parameter. This switching function has some desirable features that makes it attractive for the inclusion in an empirical heterogeneous agent model. First, the function specified in Equation (5) is bound between 0 and 1, which is the permissible range for weights on the fundamentalist strategy. By definition,  $w_t^C = 1 - w_t^F$ , so  $w_t^C$  is also bounded between 0 and 1, thus no additional restrictions need to be imposed on the weights of the chartists.

The intensity of choice parameter,  $\gamma$ , captures the degree of switching behaviour of investors and measures how sensitive the switching behaviour is with regards to past

forecast accuracy of the specific belief. If  $\gamma = 0$ , agents are completely insensitive to past forecast accuracy of the trading rules and do not switch between the different beliefs. If  $|\gamma| \rightarrow \infty$ , agents are infinitely sensitive to past relative performance of the different beliefs and switch immediately and fully between the different beliefs. If  $\gamma > 0$ , agents switch towards the beliefs that had the best performance in the recent past, while if  $\gamma < 0$  agents switch away from the belief that had the best performance in the recent past (perhaps based on a belief that there is some degree of mean-reversion).

With these definitions of forecast errors and weights on the different beliefs, we can complete the specification of the dynamics of the fine wine index values. Specifically, we can rewrite Equation (3) in terms of expected returns, i.e.,

$$E_t (R_{t+1}) = w_t^F (\alpha(P_t - V_t)) + (1 - w_t^F) \left( \beta \sum_{l=1}^L (R_{t-l+1}) \right), \quad (6)$$

where the return,  $R_{t+1} \equiv (P_{t+1} - P_t)$ .<sup>17</sup> We can further take this specification from expectations into realization, by adding a drift and a noise term,  $\varepsilon_{t+1}$ , to Equation (6), i.e.,

$$R_{t+1} = c + w_t^F (\alpha(P_t - V_t)) + (1 - w_t^F) \left( \beta \sum_{l=1}^L (R_{t-l+1}) \right) + \varepsilon_{t+1}. \quad (7)$$

One can think of this noise term as representing liquidity demand, i.e. consumers or collectors whose demand for fine wines may affect prices due to consumption.

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<sup>17</sup>Note that in the empirical estimation we use logs of index values and so  $R_t$  is the continuously compounded return.

Equations (7), (4) and (5) represent the HAM that we estimate empirically by Quasi-Maximum Likelihood.<sup>18</sup>

## 4 Data

In this Section, we provide details of the data used in the main part of our analysis, i.e., the Liv-Ex Fine Wine Investables Index. Subsequently, we detail how we define the “fundamental value” for this index.

### 4.1 *Liv-ex and the Liv-Ex Fine Wine Investables Index*

Liv-ex, a London-based company, has established itself as the premier source for information on the fine wine market with the construction and communication of a multitude of wine indices, reports and blog entries. Today, the indices are used as the natural benchmark for wine market studies in practice and academia (Cevik-Sedik, 2014; Qiao et al., 2014) and are reported both on Bloomberg and Thomson Reuters DataStream. According to Masset and Weisskopf (2018b) and the Liv-ex website, the indices are calculated following a composite index approach (i.e. the same as for most stock indices) and are available for the general wine market, the Bordeaux market and other important wine-growing regions. All indices are updated on a monthly basis apart from the Fine Wine 50 which is updated daily. The exact calculation of the indices is proprietary information, but the methodology followed is clearly outlined and is complemented by information on the wines tracked, the weights allocated to the different wines and the rules of inclusion and exclusion. These follow generic rules (e.g.

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<sup>18</sup>Equations (4), (5) and (7) can be combined into a single (non-linear) equation and estimated directly using quasi-maximum likelihood. This is possible as Equation (7) is a non-linear polynomial of  $R_{t+1}$ , with the fundamental price  $V_t$  given as an exogenous variable (see Kouwenberg and Zwinkels, 2014).

on the wine region, entry and exit dates, etc.) but are ultimately dependent on a selection committee composed of experts who review the indices on a quarterly basis. Compared to other index providers this can be considered as a very transparent approach which allows wine market participants to track and replicate indices even though it is currently not possible to directly invest in them through an ETF-type instrument.

The Liv-Ex Fine Wine Investables Index tracks the most "investable" wines in the market. It includes 200 single wines representing bottles from different vintages from the 24 top Bordeaux chateaux. The inclusion of a wine in the index follows a two-step process. To be considered in the index, a wine must be produced by one of the 24 top Bordeaux chateaux, and further, have scored at least 95-points from a leading expert (Robert Parker). The top eight Bordeaux Châteaux – the five First Growths from the Médoc, Ausone, Cheval Blanc and Petrus – can be included on the basis of a score of 93-points or above. The constituent wines are then chosen on a quarterly basis based on the evaluation of a panel of wine experts and the trade values on the Liv-ex trading platform. This ensures that only wines meeting a minimal quality and liquidity criterion are included to reach the ultimate goal of the index which is to replicate a typical wine investment portfolio.<sup>19</sup>

Once the component wines are chosen, Liv-Ex makes use of their trading platform to price each wine. According to Liv-ex, the index uses the Mid-Price between the current highest bid and lowest offer price on the Liv-Ex trading platform. If there has been a transaction on Liv-Ex within the last 30 days and the transaction price sits within the bid-offer spread, then that price is used as the Mid-Price. Once the price of each component wine is calculated, Liv-Ex builds the index based on a price-weighted

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<sup>19</sup>Portfolio constituents as at the end of our sample period are shown in Appendix A.

scheme. They also apply a scarcity weighting to vintages older than 15 years, adjusting these weights to account for the low average production levels of certain fine wines (as in the weightings of Petrus and Ausone). This scarcity weighting procedure controls for consumption and production levels of the portfolio constituents. For the empirical analysis, we obtain monthly data for this index from Thomson Reuters DataStream from its inception date January 1988 to October 2016.

In Table 1, we report statistics for the levels and log returns of the Liv-Ex Fine Wine Investables Index. The index level obtained its minimum value at the beginning of the sample in January 1988 and its maximum of 369.81 value in June 2011. The index levels exhibit positive skewness and negative excess kurtosis, and the null hypothesis of normality is rejected by the Jarque-Bera test. In the last column of Table 1, we report the statistics for the monthly returns. The index has an annualized mean return of 10.30% and annualized standard deviation of 10.44%. Finally, the monthly returns exhibit positive first-order autocorrelation.

**Insert Table 1 here**

#### *4.2 Calculation of the fundamental value*

Although it is not obvious how to define a fundamental or intrinsic value of wine (as an investment in wine does not generate cash flows over time), there is a general agreement that the price of wine to some extent should reflect its pedigree and vintage condition (see, e.g., Oczkowski and Doucouliagos, 2014). In defining a fundamental value, we therefore follow a very agnostic approach. Specifically, given that the index is built to mirror the performance of a typical wine investment portfolio, we use a model

inspired by the literature on hedonic pricing models to determine the fundamental price.<sup>20</sup> These models essentially state that in the long-run, on average, the price is a fair reflection of its characteristics, such as quality dependent on producer and vintage. We follow the wine economics literature (Ashenfelter et al., 1995; Di Vittorio and Ginsburgh, 1996; Dimson et al., 2015) and include two components: (1) a constant plus a trend component which captures the aging effect of the index; and (2) a vintage dummy which captures fixed effects related to the vintage of the component wines (e.g. production levels, weather). We run the following OLS regression for the full sample,

$$\log(Wine\_Index_t) = \alpha + \beta \cdot t + \theta \cdot Vintage_t + \epsilon_t, \quad (8)$$

where  $t$  is a trend variable and  $Vintage_t$  is a dummy variable equal to one on (1990, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2008, 2009, 2010, 2011, 2012),<sup>21</sup> zero otherwise.

### **Insert Table 2 here**

In Table 2, we report the results for the fundamental value. This regression explains 93.89% of the variance in log prices, both the trend and the vintage being positive and highly significant. The fundamental value is the fitted price from Equation (8). Figure 1 plots the evolution of the *Liv-Ex Fine Wine Investables* Index and its fundamental price over the sample period. Both appear to follow a similar evolution over time.

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<sup>20</sup>We consider a range of alternative definitions of the fundamental value. We present the results for these alternative definitions in Section 5.3. Our main results are not altered by these alternative definitions.

<sup>21</sup>These are the vintages that are included in the index (see Appendix A), which, to a varying degree coincide with good vintages.

**Insert Figure 1 here**

## **5 Empirical Results**

In this section, we report the main results of the paper. We estimate the HAM developed in Section 3 by Quasi-Maximum Likelihood. We estimate this model using all possible combinations of lags  $L$ , and of different lookback periods  $K$ , where  $K, L = \{1, \dots, 12\}$  and report the results for the combination that resulted in the highest log-likelihood value, which turns out to be  $K = 1$  and  $L = 2$ .

### *5.1 Estimation Results*

To determine whether there is evidence of heterogeneous beliefs and switching in beliefs, we first estimate a static model, where we impose the restriction of non-switching, i.e.,  $\gamma = 0$ . Subsequently, we estimate the dynamic HAM where  $\gamma$  can take any value. The results of both the static and dynamic models are reported in Table 3.

**Insert Table 3 here**

The results for the static model, reported in the first column of Table 3, show that there is indeed evidence of both a mean-reverting and an extrapolative term in the returns of the wine index. However, the mean-reverting term, which reflects the degree of mean-reversion according to the fundamentalists is only significant at the 10% level, and the coefficient is very small in absolute terms, suggesting some evidence of mean-

reversion. The autoregressive term, on the other hand, is highly significant and positive, suggesting that there is positive persistence in the returns of the wine index. This finding confirms prior results that the wine market is not efficient. Overall, the model produces an adjusted  $R^2$  just below 10%.

In the second column of Table 3, we report the results for the HAM, where we allow agents to switch between the two different beliefs based on the past forecast accuracy of that belief. If we consider the Likelihood Ratio (LR) statistic of this model versus the static model, we observe that the addition of one parameter,  $\gamma$ , leads to a highly significant increase in the log-likelihood of the model by 22.41. In addition, the adjusted  $R^2$  increases to over 15% as we move from the static to the dynamic model. This observation provides strong evidence that the HAM can better explain the dynamics of the fine wine index. Furthermore, our finding confirms the existence of both types of beliefs in the market and switching between these beliefs that is driven by the past forecasting performance of these.

When we consider the parameter estimates for the dynamic model, we find strong evidence of mean-reverting behaviour in the price dynamics of wine, with a mean-reversion coefficient of -0.26. Thus, fundamentalists have a strong belief of mean-reversion. However, when we consider the coefficient on the chartist belief, we observe minor changes compared with the static model, the coefficient remains positive and highly significant. Finally, the intensity of choice parameter,  $\gamma$ , is positive and highly significant. This observation implies that investors do indeed switch between the different beliefs based on the past forecasting performance of the different beliefs and switch towards the belief that had the best forecasting performance in the recent past.

Overall, the results of the HAM show that there is evidence of trading on the basis of both mean-reversion and price extrapolation in this wine index. In addition, the



model shows that there are shifts in beliefs where investors switch between fundamentalism and chartism based on the past forecast accuracy of the different beliefs and switch to the strategy that yielded the highest forecast accuracy in the recent past.

## 5.2 *Switching Behaviour*

The estimation results documented in Section 5.1 show that there is strong evidence for the existence of heterogeneous beliefs among fine wine investors and switching between those beliefs based on the past forecasting performance of the different beliefs. In this section, we explore some of the implications of the switching behaviour.

Figure 2 provides a scatterplot that shows the weights on the fundamentalist strategy,  $w_t^F$ , versus the relative forecast performance of the fundamentalist vis-à-vis the chartist strategy, that is,

$$Z_t = \frac{Z_t^F - Z_t^C}{Z_t^F + Z_t^C}.$$

The graph shows that the function takes on an S-shaped form, where the weight on the fundamentalist strategy gradually increases as the forecast accuracy of the fundamentalist strategy increases. This positive relation between past relative forecast performance of the fundamentalist strategy and the weight on the fundamentalist strategy is driven by the positive value for the intensity of choice parameter,  $\gamma$ . The S-shaped curve also demonstrates that investors do not switch immediately from one belief to another when its forecast accuracy is better. When the fundamentalist belief is 20% more accurate than the chartist belief, the weight in the fundamentalist belief is about 80%, whereas when the chartist belief is 20% more accurate than the fundamentalist belief, the weight on the fundamentalist belief is about 20%. These

findings illustrate that it takes some time for market participants to change their respective beliefs. This could be due, for instance, to the difficulty for a chartist to fully learn the exact features and working of the wine market and to obtain inside information in a short time span. Finally, irrespective of their belief, market participants appear to decide to trade or shun the market if their respective belief is yielding sub-optimal outcomes. This fact leads to periods in which neither a fundamentalist nor chartist overhang can be detected in the wine market.

### **Insert Figures 2 and 3 here**

In Figure 3, we provide time series plots of the log difference between the price and the fundamental value of the wine index (left y-axis), and the weights on the fundamentalist strategy (right y-axis). First, the weights on the fundamentalist strategy display considerable time variation, with relatively prolonged periods where the market is dominated by the chartist belief which may be explained by the emotional feature of fine wine. This observation is further confirmed in Figure 4, where we plot the histogram of the fundamentalist weights. Second, we observe that there are substantial deviations in the wine index from its fundamental value, which persists over prolonged periods of time. These deviations range from close to -40% to up to 80%. Third, we note that the periods where we observe deviations from the fundamental value typically go hand in hand with increased weight on the chartist strategy. This last observation strongly suggests that the deviations from fundamental values are due to the chartist behaviour of wine investors, who, due to their extrapolative behaviour of recent price patterns, continue to push prices away from their fundamental values.<sup>22</sup>

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<sup>22</sup>Although a comparison between competing bubble-detection approaches is beyond the scope of this paper, we have applied the generalized version of SADF test, *GSADF*, of Phillips, Shi and Yu (2015)

**Insert Figure 4 here**

### 5.3 *Alternative Fair Value Models*

As mentioned previously, the concept of a fundamental value of wine is rather moot. In this section, we assess the robustness of our results by evaluating the impact of different definitions of fundamental value for our results. Considering alternative specifications is important, as it can affect the degree of switching and the amount of behavioural heterogeneity we observe. Indeed, if our alternative specifications in this section capture the dynamics of the fair value more accurately and align more with the dynamics observed in actual wine values, then we could expect to find less evidence of behavioural heterogeneity, and we could expect the switching parameter,  $\gamma$ , to decrease in magnitude. Since the fair value of wine is driven by the asset and product cycles, the alternative specifications for the fair value will differ in this regard, i.e. by altering the specification for the price trend (to capture the asset cycle), and by altering the specification of the “vintage” effect (to capture the product cycle).

**Insert Table 4 here**

In Table 4, we present the estimation results for HAMs using different definitions of the fundamental value. The specifications of the alternative fundamental models are presented in the first column of Table 4. These alternative specifications differ mainly in how we capture any possible time trends using linear, quadratic and tertiary functions,

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which can detect the presence of multiple bubbles over the *Liv-Ex Fine Wine Investables* Index. The unreported results confirm the presence of explosive behaviour in wine index, detecting two significant bubbles, from June 1994 to November 1997, and from October 2005 to September 2007. These two bubbles coincide with an average fundamentalist weight of 23.12% which represents a strong presence of chartists, confirming the main results of our paper.

and capture the impacts of the vintages in the index in different ways. First, we employ alternative polynomial trends/degrees to capture different definitions of the trend, maintaining the Vintage dummy. Second, we disaggregate the Vintage dummy and use 17 dummies, one for each vintage year. Doing this, we want to give more importance to each vintage year. Third, we change the definition of the vintage component and use a cumulative version of the Vintage dummy, *N-Vint*. As quantity and quality are often negatively correlated, we want to incorporate this in the vintage component not only for the effect of good vintage years but also for the effect of the quantity of good vintage years. Fourth, we re-define the Vintage dummy, focusing only exceptionally good years. Fifth, we remove the Vintage dummy, assuming that all the variation in fundamental price is due to the aging effect component of the index. Finally, we ignore the hedonic pricing approach and model the fundamental value as a moving average of past prices as in Ter Ellen and Zwinkels (2010).

The next two columns report the switching parameters and the LR statistics which compare the static to the dynamic model. Reassuringly, we observe that the main results of our paper do not depend on the choice of fundamental value model. Regardless of the model used, we find positive values for the intensity of choice parameter,  $\gamma$ , and significant increases in the LR statistic for all specifications.<sup>23</sup>

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<sup>23</sup>We observe that the switching parameter is insignificant in one case. It is important to point out that the t-statistic for the switching parameter is not well-defined as the parameter enters the model in non-linearly (Teräsvirta, 1994). Boswijk et al. (2007) also report an insignificant switching parameter. However, the Likelihood Ratio test is conclusive in assessing whether the switching model is better than the static model, and in the case of that particular insignificant switching parameter, the LR statistic is significant.

#### 5.4 *Alternative Wine Indices*

In this section, we extend our analysis by considering alternative wine indices. The main index used in our paper so far, the Liv-Ex Fine Wine Investables Index, is comprised only of wines from the Bordeaux region. Wines from this region may be more prone to bubble-like behaviour and chartism, as they attract more speculative investors and inexperienced buyers. Wines from other regions may attract more knowledgeable buyers such as collectors and we could thus expect to see different results.

We apply the HAM to alternative wine indices provided by Liv-Ex. These indices include and are referred to by Liv-ex as the *Bordeaux Legends 50* (a selection of 50 Bordeaux wines from exceptional older vintages, dating back to 1982), the *Champagne 50* (the most recent physical vintages for twelve Champagnes), the *Rhone 100* (the ten most recent physical vintages for five Southern and five Northern Rhone wines), the *Italy 100* (the ten most recent physical vintages for the five ‘Super Tuscans’ and five other leading Italian producers), the *Rest of the World 50* (the ten most recent physical vintages for five wines from Spain, Portugal, the USA, and Australia) and the *Burgundy 150* (the ten most recent physical vintages for 15 white and red Burgundy, including six Domaine Romanée Conti labels). The sample period for these indices ranges from December 2003 until October 2016.

To be consistent across the different wine indices and provide comparable results, we make use of four fundamental prices that do not include vintage dummies, i.e., only variations of the aging effect and moving average are included. For comparison, we also report the results for the *Liv-Ex Fine Wine Investables* Index for the sample after December 2003. Table 5 reports the results for the different indices,

where we report the LR statistics that compare the switching (dynamic) model with the non-switching (static) model.

### **Insert Table 5 here**

The first row reports the results for the *Liv-Ex Fine Wine Investables* Index for the common sample period (from December 2003 to October 2016). The *Liv-Ex Fine Wine Investables* Index presents evidence of both fundamentalist and chartist beliefs with switching among both from December 2003, confirming the results of the full sample. For each of the different fundamental prices, the *Bordeaux Legends 50*, *Rest of the World 50* and *Burgundy 150* present evidence of both fundamentalist and chartist beliefs with switching between these beliefs. However, we find no evidence of switching behaviour for the *Champagne 50*, *Rhone 100* and *Italy 100* wine indices. We attribute the stronger switching behaviour in the *Investables* index (and the *Bordeaux Legends 50* and *Bugundy 150* indices) to the presence of a more heterogeneous clientele for these wines including collectors, speculative investors or new customers from the Asian markets. The other regions, on the other hand, have been less used by investors or exposed to investments by new clients. These regions therefore show a more homogenous clientele, possibly mainly European and American collectors and wine connoisseurs, and thus less evidence of heterogeneity and switching behaviour.

## **6 Conclusions**

The main focus of this paper is to examine the dynamics of the fine wine market, and assess whether there is evidence of behavioural heterogeneity in this market. To

examine this, we introduce a heterogeneous agent model, HAM, to explain the dynamics of the *Liv-Ex Fine Wine Investables* Index. The results of our model show evidence of the existence of both fundamentalists – those who trade on mean-reversion towards a long-run fundamental or intrinsic value – and chartists – those who extrapolate recently observed price trends – in this market. Moreover, we document that investors switch between fundamentalist and chartist strategies, based on the strategy that has been the most accurate in forecasting prices in the recent past. This switching behaviour can explain the bubbles and crashes (i.e. large price deviations from intrinsic values) that are observed in this wine index. Specifically, we document that any large positive or negative deviation from their fair value coincides with the majority of investors trading on the basis of a chartist belief, suggesting that return-chasing behaviour of investors can explain bubble-like behaviour in fine wine prices. Our results are robust to alternative definitions of the fundamental or fair value of wine. We further demonstrate that the most investable wines in the *Liv-Ex Fine Wine Investables* indices are most prone to chartism and switching behaviour, a finding that we attribute to these wines being most susceptible to speculative trading. Overall, we find strong evidence that a HAM can explain the dynamics of the fine wine market well.

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**Table 1. Summary statistics**

	Wine Index	
	Levels	Returns
Mean (p.a.)	134.90	10.30%
Std. Deviation (p.a.)	103.35	10.44%
Max	369.81	22.04%
Min	16.54	-13.73%
Skewness	0.56	1.75
Excess Kurtosis	-1.06	14.64
JB-test	34.60***	3255.35***
$\rho(1)$	0.99***	0.26***
Observations	346	345

Note: This table reports summary statistics on the wine index data used in this paper in levels and log returns over the period January 1988 to October 2016. We report annualized averages and standard deviations, and monthly statistics on minimum, maximum, skewness and kurtosis. JB-test is the Jarque-Bera test for Normality which is asymptotically distributed as a  $\chi^2$  with two degrees of freedom, and  $\rho(1)$  is the first-order autocorrelation of the series which is asymptotically distributed as  $N(0, 1/\sqrt{T})$ . \*\*\* indicates significance at the 1% level.

**Table 2. OLS regression for fundamental prices.**

Fundamental Equation:		
	Coeff.	t-NW
<i>Constant</i>	2.744***	(39.31)
<i>t</i>	0.009***	(34.33)
<i>Vintage</i>	0.273***	(4.27)
<i>Adj-R<sup>2</sup></i>		93.89%

Note: This table reports the OLS results for the Equation 8. Adj-R<sup>2</sup> is the adjusted R<sup>2</sup> of the model. *Vintage* is a dummy variable equal 1 on (1990, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2008, 2009, 2010, 2011, 2012), zero otherwise. We report Newey-West corrected t-statistics in parentheses and indicate the significance at the 1% level by \*\*\*.

**Table 3. HAM regression Results**

	Static		Dynamic	
	coeff	t-NW	coeff	t-NW
$c$	0.0054***	(2.95)	0.0035**	(2.39)
$\alpha$	-0.0252*	(-1.77)	-0.2638***	(-7.52)
$\beta$	0.3825***	(4.41)	0.3379***	(11.22)
$\gamma$			7.2149***	(4.71)
Adj-R <sup>2</sup>		9.65%		15.38%
LL		728.48		739.68
LR-stat				22.405***

Note: This table reports the estimation results for the heterogeneous agent model derived in Section 3. Specifically, we estimate the model

$$R_{t+1} = c + w_t^F (\alpha(P_t - V_t)) + (1 - w_t^F) \left( \beta \sum_{l=1}^L (R_{t-l+1}) \right) + \varepsilon_{t+1}$$

$$w_t^F = \left[ 1 + \exp \left( \gamma \left\{ \frac{z_t^F - z_t^C}{z_t^F + z_t^C} \right\} \right) \right]^{-1}$$

$$Z_t^F = \sum_{k=1}^K |E_{t-k}^F (P_{t-k+1}) - P_{t-k+1}|, \quad Z_t^C = \sum_{k=1}^K |E_{t-k}^C (P_{t-k+1}) - P_{t-k+1}|$$

The coefficient  $\alpha$  captures the degree of mean-reversion towards the fundamental value,  $\beta$  captures the degree of persistence in the returns on the Wine index, and  $\gamma$  is the intensity of choice parameter, which captures the degree of switching behaviour between the fundamentalist and chartist beliefs. Adj-R<sup>2</sup> is the adjusted R<sup>2</sup> of the model, LL is the log-likelihood of the model, and LR-stat is the likelihood ratio statistic calculated as twice the difference between the log-likelihood of the dynamic and the static model. We report Newey-West corrected t-statistics in parentheses and indicate the significance at the 10%, 5%, and 1% level by \*, \*\*, and \*\*\*, respectively.

**Table 4. Robustness HAM regression: Alternative fundamental models**

Fundamental Equation	$\gamma$	LR-stat
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \theta \cdot Vintage_t + \epsilon_t$	10.61***	22.69***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \beta_2 \cdot t^3 + \theta \cdot Vintage_t + \epsilon_t$	6.20***	13.61***
$\log(Wine\_Index_t) = \alpha + \beta \cdot t + \sum_{y=1989}^{2012} \theta_y \cdot VINT\_YEAR_{y,t} + \epsilon_t$	1.52***	14.49***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \sum_{y=1989}^{2012} \theta_y \cdot VINT\_YEAR_{y,t} + \epsilon_t$	1.40***	10.95***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \beta_2 \cdot t^3 + \sum_{y=1989}^{2012} \theta_y \cdot VINT\_YEAR_{y,t} + \epsilon_t$	2.85***	8.70***
$\log(Wine\_Index_t) = \alpha + \beta \cdot t + \theta \cdot N\_Vint_t + \epsilon_t$	17.49	13.57***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \theta \cdot N\_Vint_t + \epsilon_t$	10.56***	14.45***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \beta_2 \cdot t^3 + \theta \cdot N\_Vint_t + \epsilon_t$	1366.93***	12.49***
$\log(Wine\_Index_t) = \alpha + \beta \cdot t + \theta \cdot Good\_Years_t + \epsilon_t$	1.50***	10.87***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \theta \cdot Good\_Years_t + \epsilon_t$	1.51***	10.94***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \beta_2 \cdot t^3 + \theta \cdot Good\_Years_t + \epsilon_t$	12.01***	19.63***
$\log(Wine\_Index_t) = \alpha + \beta \cdot t + \epsilon_t$	707.03***	17.73***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \epsilon_t$	10.56***	14.92***
$\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \beta_2 \cdot t^3 + \epsilon_t$	1.54***	11.28***
$\log(24 - month\ Moving\ average\ Wine\_Index_t)$	97.15**	11.50***

Note: This Table reports the estimation results for the heterogeneous agent model derived in Section 3 for alternative fundamental models. The coefficient  $\gamma$  is the intensity of choice parameter, which captures the degree of switching behaviour between the fundamentalist and chartist beliefs, and LR-stat is the likelihood ratio statistic calculated as twice the difference between the log-likelihood of the dynamic and the static model. We indicate the significance of the Newey-West corrected t-statistics at the 10%, 5%, and 1% level by \*, \*\*, and \*\*\*, respectively.  $VINT\_YEAR_{y,t}$  is a yearly dummy, e.g.,  $VINT\_YEAR_{1990,t}$  is a dummy equal one in 1990, and zero otherwise; likewise for (1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2008, 2009, 2010, 2011, 2012).  $Good\_Years_t$  is a dummy variable equal one in exceptional good years {1990, 1996, 1998, 2000, 2005, 2009, 2010}; zero otherwise.  $N\_Vint_t$  is the cumulative number of vintages in the portfolio,



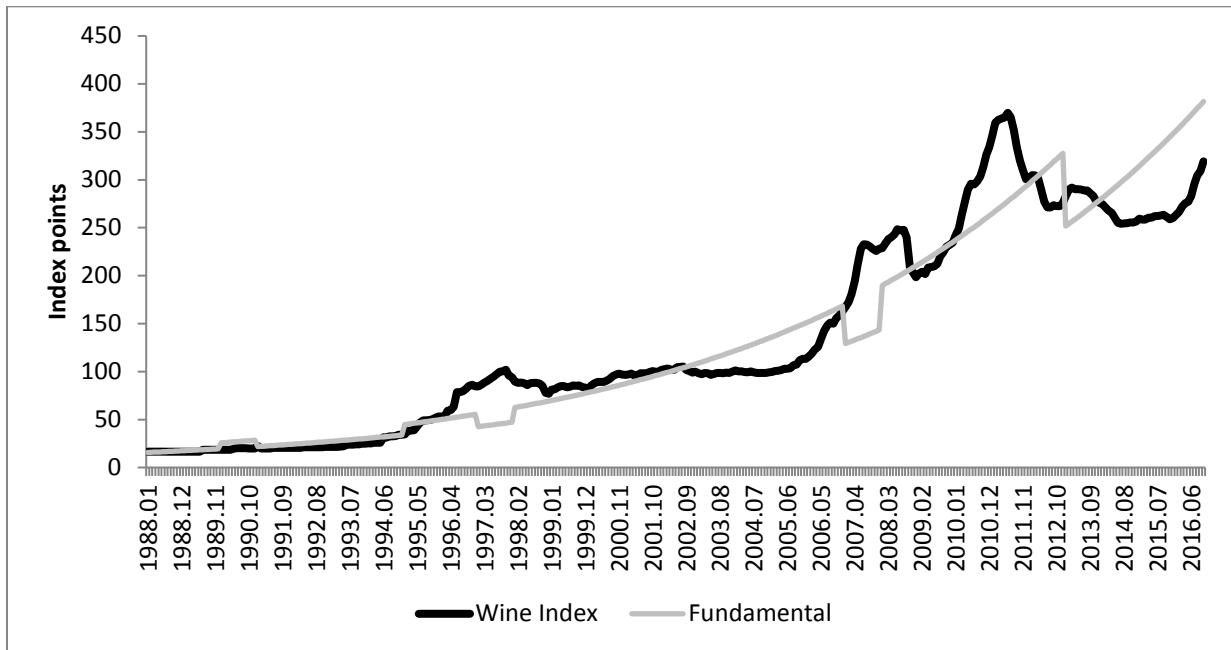
$$N\_Vint_t = \begin{cases} 0 & \text{iff } t < 1990 \\ 1 & \text{iff } 1990 \leq t < 1995 \\ 2 & \text{iff } 1995 \leq t < 1996 \\ 3 & \text{iff } 1996 \leq t < 1998 \\ 4 & \text{iff } 1998 \leq t < 1999 \\ 5 & \text{iff } 1999 \leq t < 2000 \\ 6 & \text{iff } 2000 \leq t < 2001 \\ 7 & \text{iff } 2001 \leq t < 2002 \\ 8 & \text{iff } 2002 \leq t < 2003 \\ 9 & \text{iff } 2003 \leq t < 2004 \\ 10 & \text{iff } 2004 \leq t < 2005 \\ 11 & \text{iff } 2005 \leq t < 2006 \\ 12 & \text{iff } 2006 \leq t < 2008 \\ 13 & \text{iff } 2008 \leq t < 2009 \\ 14 & \text{iff } 2009 \leq t < 2010 \\ 15 & \text{iff } 2010 \leq t < 2011 \\ 16 & \text{iff } 2011 \leq t < 2012 \\ 17 & \text{iff } t \geq 2012 \end{cases}$$

**Table 5. Robustness HAM regression: Alternative wine indices**

	I		II		III		IV	
	LR-stat	p-value	LR-stat	p-value	LR-stat	p-value	LR-stat	p-value
Liv-ex Investables	25.51***	0.0000	13.50***	0.0002	12.84***	0.0003	14.33***	0.0002
Bordeaux Legends 50	21.29***	0.0000	5.50**	0.0191	3.75*	0.0527	6.66***	0.0099
Champagne 50	1.36	0.2429	0.00	0.9807	1.14	0.2848	1.43	0.2323
Rhone 100	1.40	0.2362	1.54	0.2144	2.28	0.1309	0.16	0.6893
Italy 100	2.43	0.1189	0.03	0.8689	1.45	0.2289	2.33	0.1268
Rest of the World 50	4.52**	0.0334	3.94**	0.0472	5.11**	0.0238	3.75*	0.0527
Burgundy150	13.61***	0.0002	10.14***	0.0015	10.44***	0.0012	22.79***	0.0000

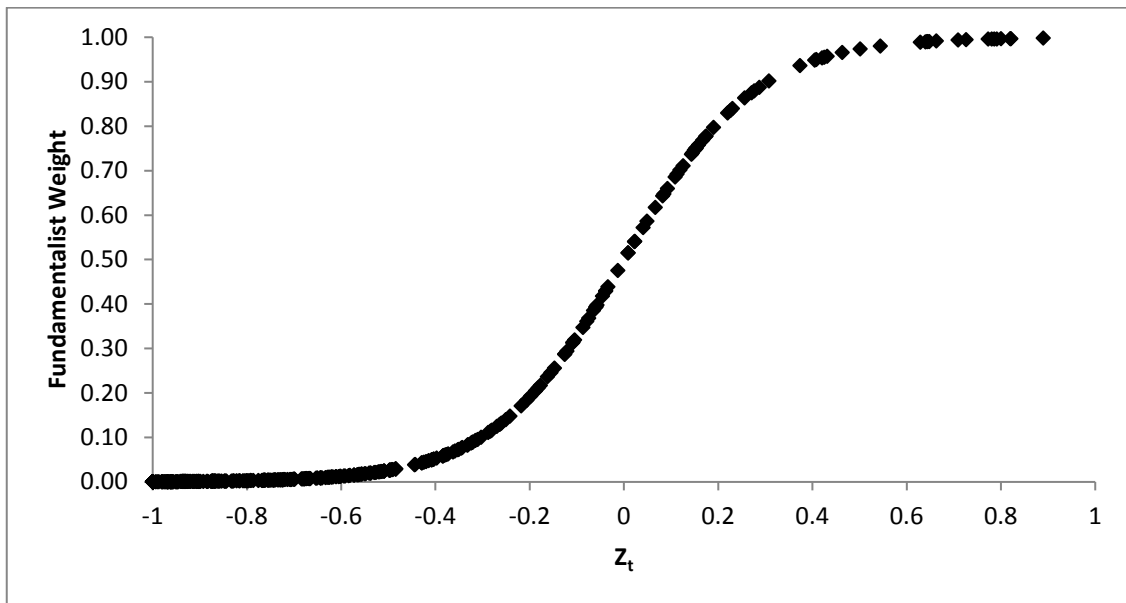
Note: This Table reports the estimation results for the heterogeneous agent model derived in Section 3 for alternative Wine Indices using as fundamental models: I)  $\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \epsilon_t$ ; II)  $\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \epsilon_t$ ; III)  $\log(Wine\_Index_t) = \alpha + \beta_0 \cdot t + \beta_1 \cdot t^2 + \beta_2 \cdot t^3 + \epsilon_t$ ; and iv)  $\log(24 - month\ Moving\ average\ Wine\_Index_t)$ . The LR-stat is the likelihood ratio statistic calculated as twice the difference between the log-likelihood of the dynamic and the static model. We indicate the significance at the 10%, 5%, and 1% level by \*, \*\*, and \*\*\*, respectively.

**Figure 1. *Liv-ex Fine Wine Investables Index* and its fundamental value from January 1988 to October 2016**



Note: The figure displays the evolution of the Liv-ex Investables index as well as its fundamental value over the entire sample period.

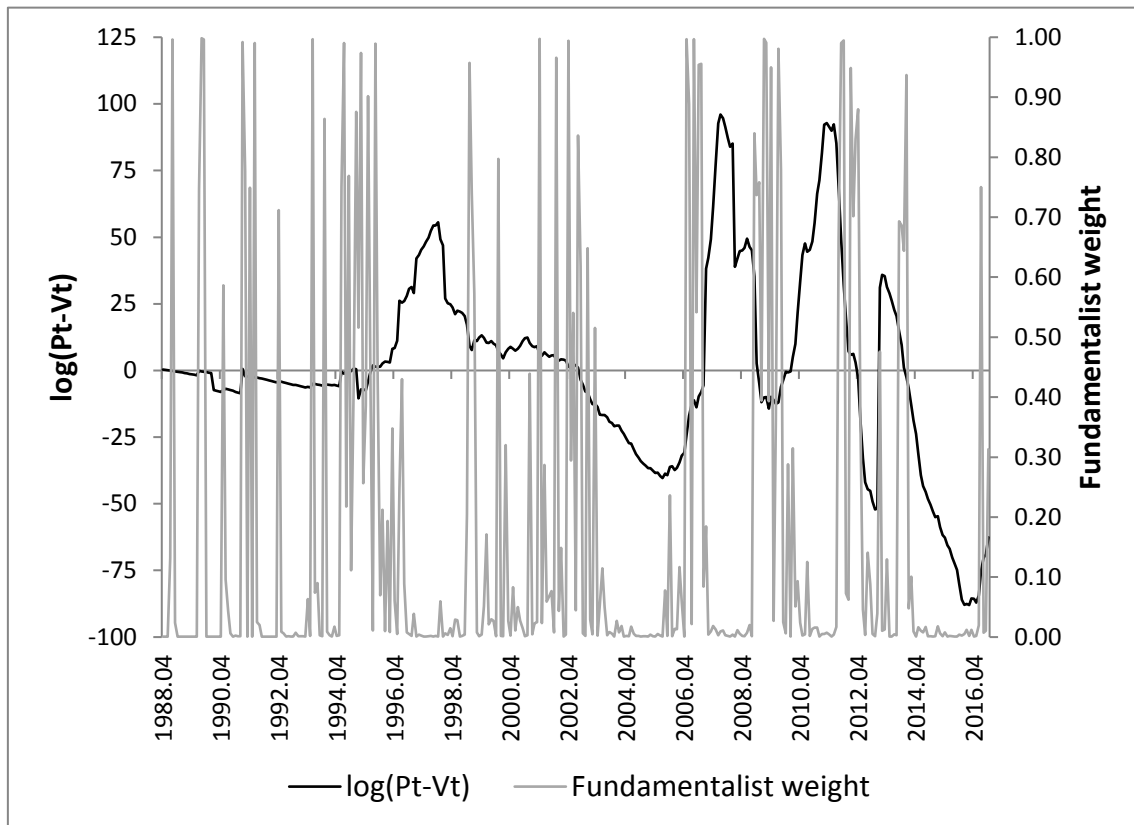
**Figure 2. Fundamentalist weight versus forecast performance**



Note: This figure plots the weights allocated to the fundamentalist strategy against the relative forecasting performance of fundamentalist strategy versus the chartist strategy, i.e.,

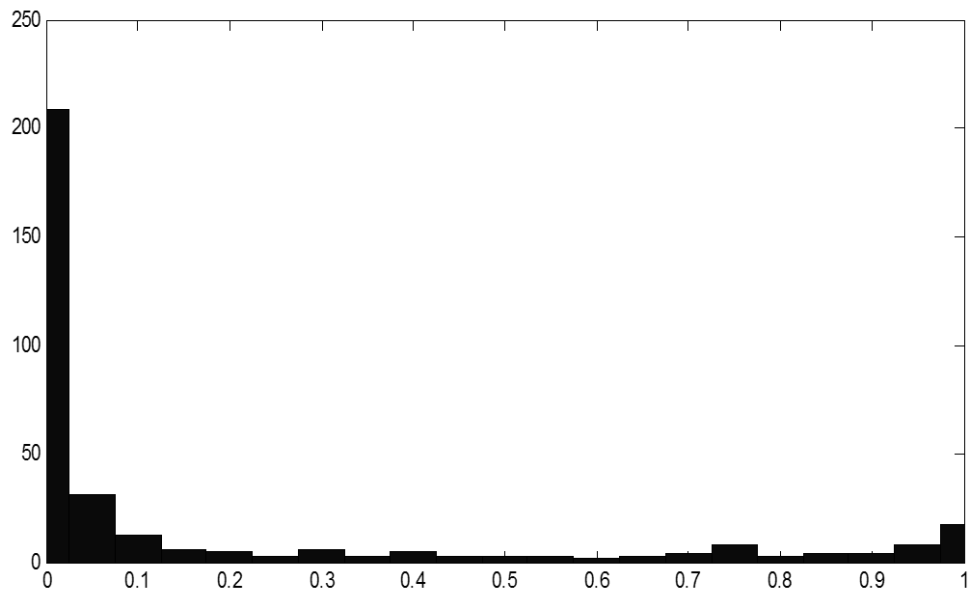
$$Z_t = \frac{Z_t^F - Z_t^C}{Z_t^F + Z_t^C}.$$

**Figure 3. Fundamentalist weights and deviations from fundamentals.**



Note: This figure shows the log price deviation between the wine index and the fundamental value,  $\log(P_t - V_t)$  (left axis), the weights on the fundamentalist strategy (right axis).

**Figure 4. Histogram of the fundamentalist weights.**



Note: This figure shows the histogram of the weights on the fundamentalist strategy from January 1988 to October 2016.

**Appendix A.** Component fine wines and vintages of *Liv-ex Fine Wine Investables* Index dated on 2015.

Wine name	Vintage	Wine name	Vintage	Wine name	Vintage	Wine name	Vintage	Wine name	Vintage	Wine name	Vintage		
Angelus	1990	Margaux	1996	Pavie	2000	Ausone	2005	Conseillante	2008	Petrus	2009	Haut Brion	2011
Cheval Blanc	1990	Montrose	1996	Petrus	2000	Cheval Blanc	2005	Ducru Beaucaillou	2008	Pichon Baron	2009	Mission Haut Brion	2011
Conseillante	1990	Mouton Rothschild	1996	Pichon Baron	2000	Conseillante	2005	Haut Brion	2008	Pichon Lalande	2009	Palmer	2011
Grand Puy Lacoste	1990	Pichon Lalande	1996	Pichon Lalande	2000	Cos d'Estournel	2005	Lafite Rothschild	2008	Pontet Canet	2009	Pavie	2011
Haut Brion	1990	Haut Brion	1998	Ausone	2001	Ducru Beaucaillou	2005	Latour	2008	Angelus	2010	Petrus	2011
Lafite Rothschild	1990	Lafite Rothschild	1998	Latour	2001	Grand Puy Lacoste	2005	Mission Haut Brion	2008	Ausone	2010	Angelus	2012
Latour	1990	Mouton Rothschild	1998	Pavie	2001	Haut Brion	2005	Montrose	2008	Cheval Blanc	2010	Ausone	2012
Leoville Las Cases	1990	Pavie	1998	Petrus	2001	Lafite Rothschild	2005	Pavie	2008	Conseillante	2010	Conseillante	2012
Leoville Poyferre	1990	Petrus	1998	Ausone	2002	Latour	2005	Petrus	2008	Cos d'Estournel	2010	Haut Brion	2012
Lynch Bages	1990	Ausone	1999	Latour	2002	Leoville Las Cases	2005	Pichon Baron	2008	Ducru Beaucaillou	2010	Margaux	2012
Margaux	1990	Lafite Rothschild	1999	Leoville Las Cases	2002	Margaux	2005	Pontet Canet	2008	Grand Puy Lacoste	2010	Mission Haut Brion	2012
Mission Haut Brion	1990	Palmer	1999	Angelus	2003	Mission Haut Brion	2005	Angelus	2009	Haut Brion	2010	Mouton Rothschild	2012
Montrose	1990	Pavie	1999	Ausone	2003	Montrose	2005	Ausone	2009	Lafite Rothschild	2010	Palmer	2012
Petrus	1990	Angelus	2000	Cos d'Estournel	2003	Mouton Rothschild	2005	Cheval Blanc	2009	Latour	2010	Pavie	2012
Pichon Baron	1990	Ausone	2000	Haut Brion	2003	Palmer	2005	Conseillante	2009	Leoville Barton	2010	Petrus	2012
Angelus	1995	Cheval Blanc	2000	Lafite Rothschild	2003	Pavie	2005	Cos d'Estournel	2009	Leoville Las Cases	2010		
Cos d'Estournel	1995	Conseillante	2000	Latour	2003	Petrus	2005	Ducru Beaucaillou	2009	Leoville Poyferre	2010		
Grand Puy Lacoste	1995	Ducru Beaucaillou	2000	Leoville Barton	2003	Pontet Canet	2005	Grand Puy Lacoste	2009	Lynch Bages	2010		
Haut Brion	1995	Haut Brion	2000	Leoville Las Cases	2003	Angelus	2006	Haut Brion	2009	Margaux	2010		
Lafite Rothschild	1995	Lafite Rothschild	2000	Leoville Poyferre	2003	Ausone	2006	Lafite Rothschild	2009	Mission Haut Brion	2010		
Latour	1995	Latour	2000	Margaux	2003	Cheval Blanc	2006	Latour	2009	Montrose	2010		
Leoville Las Cases	1995	Leoville Barton	2000	Montrose	2003	Haut Brion	2006	Leoville Las Cases	2009	Mouton Rothschild	2010		
Margaux	1995	Leoville Las Cases	2000	Pavie	2003	Lafite Rothschild	2006	Leoville Poyferre	2009	Palmer	2010		
Mouton Rothschild	1995	Leoville Poyferre	2000	Pichon Lalande	2003	Latour	2006	Lynch Bages	2009	Pavie	2010		
Petrus	1995	Lynch Bages	2000	Pontet Canet	2003	Leoville Las Cases	2006	Margaux	2009	Petrus	2010		
Pichon Lalande	1995	Margaux	2000	Angelus	2004	Mouton Rothschild	2006	Mission Haut Brion	2009	Pichon Baron	2010		
Ducru Beaucaillou	1996	Mission Haut Brion	2000	Lafite Rothschild	2004	Pavie	2006	Montrose	2009	Pichon Lalande	2010		
Lafite Rothschild	1996	Montrose	2000	Latour	2004	Pichon Lalande	2006	Mouton Rothschild	2009	Pontet Canet	2010		
Latour	1996	Mouton Rothschild	2000	Pavie	2004	Pontet Canet	2006	Palmer	2009	Ausone	2011		
Leoville Las Cases	1996	Palmer	2000	Angelus	2005	Ausone	2008	Pavie	2009	Cheval Blanc	2011		