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THE EFFECT OF AN ELECTRONIC EXCHANGE ON PRICES AND RETURN VOLATILITY IN THE FINE WINE MARKET

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Abstract

Fine wine has become an attractive alternative asset class in recent decades. In our study, we take the market microstructural perspective and verify how innovations in trading infrastructure affect the fine wine market. More specifically, we examine the average prices and the return volatility of fine wines traded on three different trading systems: automated electronic exchange, auctions and over-the-counter agreements (the OTC market). Our findings confirm an important role of a fully automated, cost-effective wine exchange in improving pricing efficiency and reducing market risk. This may constitute useful information for professional wine traders and institutional investors, who might consider shifting from less transparent trading systems into an automated on-book venue. This may also be a valuable indication for the future development of trading infrastructure in wine and other agricultural commodity markets.

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Introduction

Fine wine has become an attractive alternative asset class in recent decades. It is sought after in both primary and secondary markets by sophisticated consumers, collectors and, more frequently, by institutional investors (e.g. investment funds) wishing to provide a broad asset allocation to their clients. The wine industry has undergone digital transformation and advancements in trading technology facilitate trade execution and make the market function in a similar manner to traditional financial markets. The traditional methods of wine trading, conducted in the form of face-to-face interactions between traders or executed on auctions organized by specialized auction houses, have faced growing competition from online trading platforms and exchanges offering greater market transparency, cost reduction and, most importantly, a significant increase in the scope, scale and speed of business operations. The development of the fine wine market has led to several platforms becoming the leading marketplaces (or marketspaces) in a globally dispersed fine wine market, one example of which being the Liv-ex exchange.

This online electronic exchange, established in 2000 in London, offers services and regulations to its more than 400 members (wine business entities and institutional investors) which are typical of traditional stock exchanges, i.e. a trading system based on a continuous double auction mechanism, automated order matching, membership requirements, standard trading rules, secure transaction settlement, contract standardization, information disclosure and dissemination, including a set of market indices. Additionally, due to the physical delivery of wines being subject to trade, it provides comprehensive storage and distribution services that allow traders to track and manage current or due stock and its costs throughout the entire logistics process.

In our study, we verify how innovations in trading infrastructure influence the fine wine market. More specifically, we examine the impact of an electronic exchange on prices and the return volatility of fine wines, as compared to traditional trading venues such as auctions and the OTC market. The analysis is aimed at providing some detailed information on differences between major trading systems in the fine wine market, which may be of particular importance for institutional investors operating in this market.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of the related literature and presents formulated hypotheses. Section 3 shows detailed information concerning the dataset and its structure. Section 4 provides a methodology description and the empirical results. Section 5 is the conclusion.

Related literature and hypotheses development

The question as to how technological innovations in trading infrastructure influence market organization and asset price behavior has attracted the attention of considerable research activity in market microstructure literature. Most studies on financial markets generally confirm positive (as for investors) outcomes associated with shifts from traditional voice-based trading systems toward automated trade execution in continuous electronic systems, which are reflected e.g. in greater cumulative abnormal returns (Muscarella & Piwowar, 2001), liquidity enhancement and reduction in the cost of equity (Jain, 2005), superior information and operational efficiency (Chung et al., 2010), to name a few. However, although the spread of trade automation may presently seem inexorable, there are several indications that an electronic system is not always the optimal environment for trading (Weaver & Zhou, 2010; Hendershott & Madhavan, 2015). As revealed in numerous studies, the increased trading activity and transaction speed resulting from trading automation is usually accompanied by an observed increase in return volatility (Hendershott & Moulton, 2008; Tucker & Laipply, 2013). However, the problem of market risk in particular trading systems is more complex and multifaceted, and evidence indicating an inverse relationship, namely, greater volatility in off-book versus on-book systems, has also been provided in the literature. For example, the empirical study of Hauser and Levy (1998) on dual listed stocks reveals higher pricing errors and increased price volatility in the OTC market.

In the case of agricultural markets, where prices and price volatilities transmit along the entire supply chain (Assefa et al., 2015), initiation of electronic trading platforms shifts trading into effective competition by reducing uncertainty, lowering transaction costs and improving information distribution (Schrader, 1984). For instance, in examining the coffee market in India, Banker et al. (2011) show that grades with higher price volatility and from the premium segment obtain lower prices on a digital platform as compared to physical auctions or farm-gate trades.

Wine economists usually investigate different factors affecting fine wine prices (Ashenfelter, 2008; Outreville, 2011; Cardebat et al., 2014; Dimson et al., 2015) and examine price behaviour in the context of investment performance (Sanning et al., 2008, Masset et al., 2016, Masset & Weisskopf, 2018), price anomalies (Ashenfelter, 1989; McAfee, 1993; Ashta, 2006; Czupryna & Oleksy, 2015) or relationships among regional wine markets or their links to other financial markets (Faye et al., 2015). Variations in wine prices and their possible implications for risk management have been documented in Kourtis et al. (2010). The advent of electronic trading has raised the need for further in-depth analysis on fine wine market microstructure and for examining price behaviour and return volatility in a multimarket setting.

Based on the market observations and experiences from other financial or agricultural markets we postulate that:

Hypothesis 1: *Mean wine prices observed on an electronic exchange (Liv-ex) are lower than the respective mean prices in traditional trading venues (auctions and the OTC market)*

Hypothesis 2: *Return volatility observed on an electronic exchange (Liv-ex) is lower than the respective return volatility in traditional trading venues (auctions and OTC market)*

In the first hypothesis (H1) we postulate that the auction prices exceed the Liv-ex prices for several reasons. Firstly, the Liv-ex exchange is a more centralized trading system with strong interdealer competition and a continuous double auction mechanism. The auction market is more fragmented and transaction prices are formed through a one-sided auction mechanism where the bargaining power of buyers is limited due to constraints on the supply side (e.g. a reserve price). Secondly, trades on Liv-ex are performed exclusively between wine professionals, who may be classified as informed traders. On the auction market there is a significant proportion of private investors (collectors, consumers), whose trades are mostly emotionally-driven and who may likely behave as uninformed traders. This conjecture partially corresponds to findings revealed in some financial market segments, where the probability of informed trading tends to increase with the shift from open outcry to an automated trading system (e.g. Perry, 2011). Thirdly, transaction costs for traders involved in continuous trading on Liv-ex are (above a certain break-even point) relatively lower than at auctions, which incentivizes them to select this automated trading venue. Fourthly, the volume (number of bottles) traded in a single transaction on Liv-ex exceeds the volume transacted at auctions. The volume migration from floor trading to electronic trading, coupled with transaction cost reduction, has also been observed in agricultural futures markets (Martinez et al., 2011). In this hypothesis, we also postulate that mean Liv-ex prices are lower than mean prices from the OTC market. According to Muck (2006), prices on the OTC market are relatively higher than on exchange-driven trading systems because of reduced competition and arbitrage constraints. Additionally, in such types of markets the observed price is higher in order to compensate for the greater direct execution costs of search and negotiation efforts. Consequently, the probability of successful transaction execution at a higher (expected) price level is greater on the OTC market than on a downstairs market (Madhavan, 2000).

In our second hypothesis (H2), we assume that due to higher market transparency and price information availability, as well as due to the sole participation of professional traders, the noise factor (defined as the difference between asset market price and its fundamental value) should be lower on the electronic exchange under consideration (Liv-ex). This absence of noise traders on Liv-ex may be the primary explanation for decreased price volatility on the automated exchange, as they are commonly associated with price distortions and excessive volatility in traditional financial markets (Daiglar & Wiley, 1999). In this case, our H2 hypothesis is something more akin to an intuitive conjecture than an unambiguous conclusion drawn from observations on financial markets, where the transition from open outcry into electronic trading entails a generally simultaneous increase in asset price volatility (Liao et al., 2008). Additionally, Liv-ex is a more centralized trading system as compared to auctions and is characterized by continuous trading, while auctions are only held periodically.

In relation to the OTC market, our H2 hypothesis is motivated by analogous arguments. Namely, we postulate that greater market efficiency and the exclusion of non-professional traders on Liv-ex leads to a reduced daily return volatility on the electronic platform as compared to the OTC market, where both inter-dealer trades and transactions between dealers and private clients are executed. This may enhance the impact of emotional factors on wine prices and contribute to further deviations from the fundamental value, which subsequently translates into an increase in return volatility. Moreover, the relatively lower transaction costs on Liv-ex attract professional traders to shift trading onto the electronic platform which improves liquidity and depresses wine prices in this trading venue. Therefore, the volatility at an auction venue, with the potential noise trading component, may exceed the price volatility on the automated Liv-ex exchange.

Data structure and trade characteristics

Our unique dataset consists of 99,769 prices of Premier Cru fine wines of vintages 1992-2008 from the Bordeaux region (Haut Brion, Lafite Rothschild, Latour, Margaux, Mouton Rothschild) and covers a 10 year time span of trading (2005-2014). All prices have been provided by the Liv-ex exchange. Parallel to the wine prices coming from transactions executed on the exchange, the Liv-ex trading platform also provides every exchange member with transaction prices generated in the major auction houses and on the OTC market.

There are certain issues particular to the wine transaction database that make it different from a database containing information on typical financial asset transactions. Firstly, there are additional factors that may potentially influence the price, for instance: wine packaging (the original case of 6 and 12 bottles, assorted lots or single bottles), the bottle size (although bottles of 750 ml are the standard for the wine market, other bottle sizes can also be traded), differing contract standards or bottle conditions. Secondly, the data is sparse and unevenly spaced, with periods of different lengths between the transactions.

Therefore, we will first analyze the transactional data, particularly those factors which may influence price levels at each trading venue. Then, due to data exclusions, we seek to make the transactional data from different venues more comparable. In the final step, we analyze and compare the absolute price levels and return parameters (mean return and standard deviation). The proportion of transactions for different bottle volumes are presented in Table 1.

Since the bottle volume may influence the results, we limit our analysis to transactions with a standard bottle size of 750 ml. The total number of transactions in our dataset that is subject to the empirical analysis, amounts to 15899 (Liv-ex), 52729 (OTC market), 31141 (Auctions) transactions.

We consequently treat wines from different chateaux and of different vintages as being separate products, since both factors may influence the price behavior and in some sense render the wine unique. The distribution of wines among different chateaux is presented in Table 2. We can observe that Lafite Rothschild wines have the relatively highest share in turnover on all markets, while the smallest – Haut Brion wines.

The distribution of transactions among the years under consideration is shown in Table 3. The results indicate that in all trading venues younger vintages are

Table 1: Percentage of transactions for different bottle volumes

Bottle size	LIV-EX	OTC MARKET	AUCTIONS
38	0.11%	0.24%	1.12%
75	97.13%	94.64%	82.83%
150	1.93%	3.64%	6.85%
300	0.33%	0.61%	3.30%
500	0.14%	0.17%	1.00%
600	0.36%	0.70%	4.89%
900			0.02%
1500			0.00%
	(17125 transactions =) 100%	(55946 transactions =) 100%	(38000 transactions =) 100%

Source: Own calculations

Table 2: Distribution of transactions per Chateau

Wine brand	LIV-EX	OTC MARKET	AUCTIONS
Haut Brion	13.76%	12.01%	15.48%
Lafite Rothschild	30.52%	27.98%	27.53%
Latour	15.98%	17.93%	17.61%
Margaux	14.47%	16.33%	17.04%
Mouton Rothschild	25.27%	25.75%	22.33%
	(15899 transactions =) 100%	(52729 transactions =) 100%	(31141 transactions =) 100%

Source: Own calculations

Table 3: Distribution of transactions per trade year

Vintage	LIV-EX	OTC MARKET	AUCTIONS
2005	1.31%	2.09%	0.28%
2006	3.27%	2.42%	0.68%
2007	4.38%	4.68%	5.94%
2008	7.60%	2.75%	10.63%
2009	9.03%	10.81%	9.72%
2010	15.00%	22.53%	15.73%
2011	13.30%	16.54%	20.25%
2012	14.82%	12.49%	11.82%
2013	15.74%	14.82%	12.04%
2014	15.53%	10.87%	12.90%
	(15899 transactions =) 100%	(52729 transactions =) 100%	(31141 transactions =) 100%

Source: Own calculations

Table 4: Distribution of transactions per calendar month traded

Calendar month	LIV-EX	OTC MARKET	AUCTIONS
1	7.84%	5.56%	7.26%
2	8.28%	5.62%	4.50%
3	8.41%	7.34%	9.24%
4	7.09%	12.54%	8.80%
5	8.30%	11.75%	10.96%
6	9.26%	9.91%	7.96%
7	9.12%	16.75%	2.23%
8	7.76%	5.65%	0.88%
9	9.38%	5.81%	16.61%
10	8.59%	6.73%	12.11%
11	8.69%	7.37%	10.38%
12	7.28%	4.96%	9.07%
	(15899 transactions =) 100%	(52729 transactions =) 100%	(31141 transactions =) 100%

Source: Own calculations

Table 5: Distribution of transactions according to different vintages

Year	LIV-EX	OTC MARKET	AUCTIONS
1992	0.12%	0.90%	0.84%
1993	0.53%	1.61%	2.42%
1994	0.83%	1.79%	3.33%
1995	4.47%	4.80%	12.98%
1996	9.15%	9.02%	14.90%
1997	0.86%	1.05%	2.57%
1998	5.98%	4.27%	8.96%
1999	2.55%	2.52%	5.29%
2000	5.51%	4.39%	14.21%
2001	3.94%	2.71%	4.05%
2002	4.41%	2.88%	5.25%
2003	8.24%	5.97%	9.51%
2004	9.16%	5.25%	3.93%
2005	8.20%	5.33%	4.98%
2006	10.48%	7.25%	2.48%
2007	4.84%	1.86%	1.38%
2008	10.29%	9.32%	1.82%
2009	5.01%	9.06%	0.73%
2010	3.33%	7.64%	0.30%
2011	1.20%	3.51%	0.06%
2012	0.79%	5.56%	
2013	0.09%	3.30%	
	(15899 transactions =) 100%	(52729 transactions =) 100%	(31141 transactions =) 100%

Source: Own calculations

traded more frequently than older vintages.

The distribution of transactions per trade month is presented in Table 4. The results reveal a limited number of transactions occurring on auctions during the summer months and an increased trading activity on OTC market between April and July. In contrast, trading at Liv-ex does not show any significant seasonal patterns in transaction distribution. The respective correlation coefficient between Liv-ex and the OTC market is 0.20, between the OTC market and Auctions it is -0.23.

The distributions of transactions according to the vintage traded is presented in Table 5.

As the distribution of vintages is highly influenced by the total number of transactions traded per year and the number of vintages available for trading in a particular year, we limit our analysis to the years from 2010 until 2014 and analyze for each year the percentage distribution of transactions for each wine age (defined as transaction year minus vintage) but only for wines which are at most 18 years old (in order to assure that all of the vintages were available for trade in each of the years 2010-2014). The results are presented in Table 6. We can observe that almost no wines younger than three years old are being traded on auctions, whereas the one year old wines represent 33,79% of OTC market transactions. The mean wine age (in years) is as follows: 8,06 in the case Liv-ex trades, 6,68 in the case of OTC market trades and 11.62 in the case of auction trades. All of these differences are statistically significant.

To analyze the wine age distribution with regard to contract type we only take into account the data from the Liv-ex venue, as it allows for differentiation between Standard In Bond (SIB - for wines in good condition, held in bond and delivered to Liv-ex within two weeks of the trade taking place), Standard En Primeur (SEP - for wines

Table 6: Distribution of transactions per wine age

Wine age (in years)	LIV-EX	OTC MARKET	AUCTIONS
1	4.33%	33.79%	0.02%
2	2.82%	3.10%	0.02%
3	9.11%	3.61%	0.87%
4	10.03%	4.69%	2.25%
5	9.41%	4.78%	3.79%
6	8.45%	4.20%	4.62%
7	7.97%	4.52%	5.88%
8	7.81%	5.14%	6.54%
9	6.28%	4.28%	6.06%
10	5.78%	4.09%	8.37%
11	5.33%	3.65%	8.08%
12	3.63%	3.12%	8.72%
13	2.93%	2.82%	6.90%
14	4.10%	3.79%	8.63%
15	3.68%	3.18%	8.74%
16	3.46%	4.04%	7.45%
17	2.37%	3.38%	6.62%
18	2.51%	3.83%	6.45%
	(15899 transactions =) 100%	(52729 transactions =) 100%	(31141 transactions =) 100%

Source: Own calculations

Table 7: Distribution of transactions per auction house and auction location

Trades per auction house			Trades per auction location		
House	number	share	location	number	share
Sotheby's	7356	23,62%	New York	8060	25,88%
Christie's	7038	22,60%	Hong Kong	7854	25,22%
Acker	4717	15,15%	London	6736	21,63%
HDH	4447	14,28%	Chicago	4600	14,77%
Zachys	4031	12,94%	Online	1573	5,05%
WineBid	1443	4,63%	Geneva	429	1,38%
Bonham's	1148	3,69%	Amsterdam	396	1,27%
Morrell	344	1,10%	Paris	387	1,24%
Historic Archive	267	0,86%	San Francisco	298	0,96%
Heritage	164	0,53%	UK	267	0,86%
Edward Roberts	137	0,44%	Los Angeles	218	0,70%
Bloomsbury	47	0,15%	Beverly Hills	203	0,65%
Spink	2	0,01%	United States	65	0,21%
			Las Vegas	53	0,17%
			Singapore	2	0,01%

Source: Own calculations

that have been released for sale but are not physically available on the market) and Special (X - for wines not compliant with SIB or SEP) agreements. Trading based on SIB settlements plays the dominant role in this market segment, representing 84,34% of all trades on the Liv-ex exchange, followed by SEP contracts with an 8,87% market share and then X-contracts, responsible for 6,78% of all trades. However, it should be mentioned here that SEP contracts have been designed for use in trading young wines, which is reflected and corroborated in our analysis, where they account for 85,58% transactions of one-year wines and 86,39% trades of two-year wines.

The distribution of transactions in the Auctions category, by auction house and location, is presented in Table 7. We may see that the five largest auction houses are responsible for around 90% of transactions. Most of the transactions taking place on auctions are concentrated in four cities, namely in New York, Chicago, Hong Kong and London.

We also analyze the transaction volume. We define volume here as the number of bottles being traded which is the number of bottles in a single transaction multiplied by the trade quantity. Statistics for the volume distribution are presented below in Table 8. The trade venue Liv-ex commands the highest volume, which is on average more than twice the volume seen in the Auctions category.

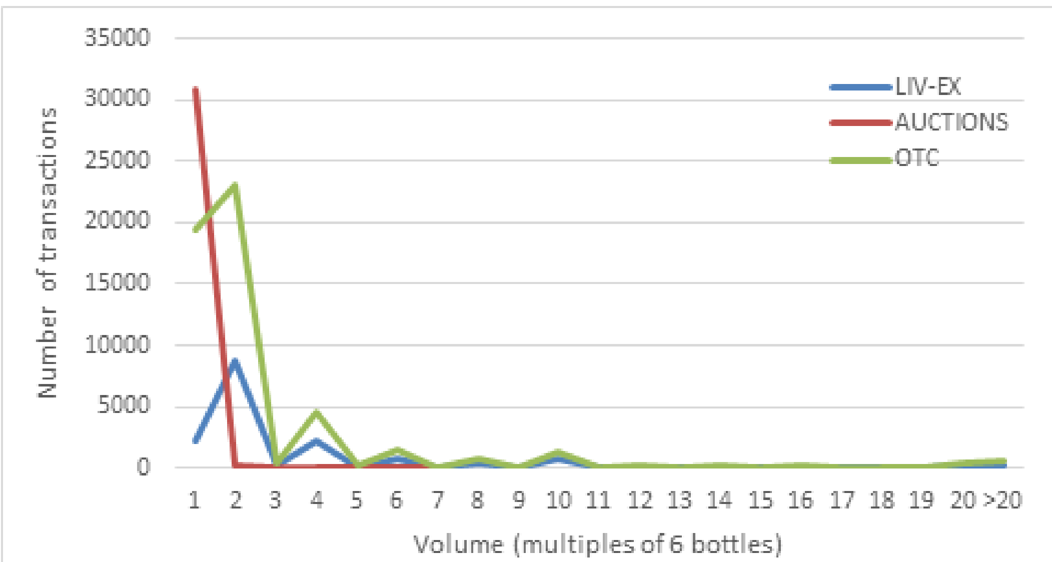
The differences in mean volume being traded are significant. Volume distribution is presented in Figure 1. The volume is expressed in multiples of 6, except for the number '1', which includes trades up to 5 bottles (e.g. 1 means that 1-5 bottles are represented by the transaction, '2' means 6-11 bottles and so forth).

Table 8: Volume distribution (number of bottles per transaction) – statistics

	LIV-EX	OTC MARKET	AUCTIONS
Mean	21.79	17.26	10.07
Median	12	12	12
Standard deviation	32.13	34.26	4.83
Skewness	9.96	15.56	19.94
Kurtosis	203.24	600.62	1311.24
Maximum	1200	2400	360

Source: Own calculations

Figure 1: Volume distribution



Source: Own work

Research methodology and empirical results

Fine wine prices

In this section we present the results of the analysis as to whether and how different factors – transaction volume, case size, auction house – influence the observed price level. Although we have a relatively rich longitudinal dataset, we decided to consider each time series separately. An alternative method of parameter estimation would be a panel regression model. This would potentially provide more efficient estimates of the parameters. However, this would require initial assumptions on the model to be used, in particular a decision on common characteristics shared among time series for different producers and vintages. An additional limitation is the lack of synchronization between particular time series due to the sparse and unevenly spaced data.

Therefore, in the case of volume, we estimate the parameters of the linear regression model of the general form:

$$ln\left(\frac{P_1}{P_0}\right) = \alpha + \beta ln\left(\frac{V_1}{V_0}\right) + \varepsilon_t \quad (1)$$

where P_0 = the monthly average of transaction prices (per case) at time t_0

P_1 = the monthly average of transaction prices (per case) at time t_1

V_0 = the case quantities of each single transaction at time t_0

V_1 = the case quantities of each single transaction at time t_1

α = intercept

β = the price volume elasticity coefficient

ε_t = error term

We can see that with the exception of 12 bottle cases and the Liv-ex trading venue the parameter beta is not significant. Even in the exception case, although the beta parameter is significant its value is close to 0. Therefore, we observe no or almost no dependency between price and volume across all trade venues (see Table 9).

To analyze the influence of case size on the price level, we compare the monthly average of price levels (for each chateau and vintage) for single bottle trades against transactions having more bottles per case. First, we construct the differences between the monthly average price for cases containing multiple bottles minus monthly average price for single bottles for each standard, wine and auction house separately. We first attempted to construct the daily price differences among different trading venues. However, due to different trading time regimes (especially for auctions) and relatively sparse data, the number of such observations was very limited. An aggregation period of one month was used as a compromise between price comparisons for a relatively similar trading period in each of the trading venues and the number of such

Table 9: Liv-ex, OTC market and Auctions price volume elasticity

	Estimate	Std. Error	t value	Pr(>|t|)
Liv-ex: 6 bottles cases				
(Intercept)	-0.001693	0.002980	-0.568	0.570
Log of volume	0.004124	0.003108	1.327	0.185
Liv-ex: 12 bottles cases				
(Intercept)	-0.004484	0.001749	-2.564	0.01042 *
Log of volume	0.005438	0.001982	2.744	0.00612 **
OTC market: 6 bottles cases				
(Intercept)	-0.006327	0.005447	-1.161	0.246
Log of volume	0.000308	0.005773	0.053	0.957
OTC market: 12 bottles cases				
(Intercept)	-0.0038246	0.0023200	-1.648	0.0993
Log of volume	-0.0001858	0.0024556	-0.076	0.9397
Auctions: 1 bottle cases				
(Intercept)	-0.002185	0.010346	-0.211	0.833
Log of volume	0.003970	0.012054	0.329	0.742

Source: Own calculations

Table 10: Liv-ex, OTC market and Auctions single bottles and bottles in cases pairwise price transactions comparison for each venue

	Estimate	Std. Error	t value	Pr(>|t|)
Livex	12.824	5.709	2.246	0.0311 *
OTC market	3.788	3.050	1.242	0.214
Auctions	17.785	4.023	4.421	1.03e-05 ***

Source: Own calculations

Table 11: Mean, standard deviation of the differences of monthly average prices per auction house

Auction house	Christie's	HDH	Sotheby's	Zachys
	Mean of the differences			
Acker	-2.09	27.15	-3.85	27.57
Christie's		34.25	-0.94	36.96
HDH			-33.98	2.36
Sotheby's				20.37
	Standard deviation of the differences			
Acker	100.55	74.21	127.06	70.45
Christie's		333.88	131.39	296.01
HDH			139.23	118.65
Sotheby's				84.55
	Number of comparisons			
Acker	794	592	874	677
Christie's		584	867	724
HDH			727	533
Sotheby's				745

Source: Own calculations

Table 12: Pairwise comparisons of the average price levels (price differences between venue 1 and venue 2)

Venue 1	Venue 2	Mean value	Standard deviation	Observation number	T Value	P Value
Liv-ex	OTC	-19.52	33	3841	-36.6674	0
Liv-ex	Auctions	-4.29	69.59	2699	-3.2007	0.0014
OTC	Auctions	18.34	90.54	4645	13.8095	0

Source: Own calculations

comparisons available for further statistical evaluation. Next, we regress the differences on the intercept. We can observe that the bottle price is significantly higher when cases having more than 1 bottle are traded on Liv-ex and auctions trade venues, and insignificantly higher in the case of the OTC market. Results are presented in Table 10.

We then compare the monthly averages of bottle prices in different auction houses, although we limit our analysis to the largest five auction houses. The monthly average price level is analyzed per individual auction house and for single bottle trades and trades involving cases of wine (multiple bottles) separately. The results are shown in Table 11. It is evident that significant differences exist in prices across the various auction houses.

Based on the prior analysis, and in order to make the price levels among different trade venues more comparable, we make the following additional exclusions. We consider only wines that are at least 3 years old, we analyze only SIB (Standards in Bonds transactions at Liv-ex), only undamaged bottles in the case of the OTC market, and only those auction transactions taking place at the five largest auction houses. We first construct the monthly average price per bottle per wine (same chateau and vintage), trading venue and separately for single bottles and cases containing multiple bottles. Secondly, we make the pairwise comparisons by building appropriate differences, provided that both monthly averages are available. The results are presented in Table 12 below. It can be seen that the lowest average price levels occur at Liv-ex, followed by auctions and then the OTC market.

Return volatility analysis

In this section we analyze the returns according to trading venue. To deal with unevenly spaced data we follow the general approach taken by Lo and MacKinlay (1990), for instance, by assuming that the (hidden) daily returns follow the stochastic model:

$$R_{it} = \mu_i + \varepsilon_{it} \quad (2)$$

We assume that ε_{it} is independent and identically distributed with the parameters mean = 0 and standard deviation = σ_I being constant for each period. We also define the observed return as:

$$R_{it}^{o} = \sum_{k=o}^{\infty} X(k)_{it} R_{it-k} \quad (3)$$

where $X(k)_{it}$ = a binary variable, which is 1 when the wine is traded in day t and is not traded in the previous k days and 0 otherwise

R_{it-k} = k-period rate of return

As we do not have information on the time of the transaction, we first construct the daily average of prices for each I (where I stands for a particular wine at a particular trade venue). Parameter μ_i is estimated as:

$$\mu_i = \frac{ln\left(\frac{P_{ie}}{P_{is}}\right)}{T_{ie} - T_{is}} \quad (4)$$

where P_{ie} = the average daily price at the end of the observation period

P_{is} = the average daily price at the start of the observation period

T_{ie} = the end date of the observation period

T_{is} = the start date of the observation period

The parameter sigma is calculated in a standard way, taking into consideration that the variance of each observed rate of return is proportional to the number of days it consists of. Therefore, each squared demeaned observed rate of return is divided by the number of days,

Table 13: Volatilities of the daily average prices by trading venue

Venue	No. WIDs	Mean. No.Trans-actions	Mean. No.obs	Mean. Sd.Intraday	Mean. Avg. Time	Mean. Sd Time	Mean. Avg. Return	Mean. Time.Span	Mean. Sd.Return
Liv-ex	82	178.4	144.5	2.5	23.2	29	0.01%	2679.3	1.72%
OTC	103	348.4	243.7	6.5	16.3	26.4	0.01%	2824.7	5.45%
Auctions	82	370.5	145.2	16.3	24.2	31.6	0.02%	2854.5	8.03%

The columns have the following interpretation:

Venue – trading place; No. WIDs – number of wines (different Chateau and vintage traded at the particular venue);Mean number of transactions – mean number of transactions per wine and venue; Mean number of observations – mean number of trading days per wine and venue; Mean standard deviation of intraday – mean standard deviation of prices traded on the same day, provided that we could observe more than 1 transaction on that particular day); Mean average of transaction days' time difference – mean per wine and trading venue of the average of time differences between two consecutive trading days (firstly, for each wine and trading venue we calculate the average of the time differences between two consecutive days and then the average of the previously calculated mean values for each venue); Mean standard deviation of transaction days' time difference – mean per wine and trading venue of the standard deviation of time differences between two consecutive trading days (firstly, for each wine and trading venue we calculate the standard deviation of the time differences between two consecutive days and then the average of the previously calculated mean values for each venue); Mean average daily return – mean per venue of the average daily returns per wine; Mean time span – mean observation period (in days) per venue; Mean standard deviation of return - mean per venue of the standard deviation of daily returns per wine.

Source: Own calculations

before calculating the average.

Different approaches can be found, as in de Jong and Nijman (1997) or Hayashi and Yoshida (2005), for example. De Jong and Nijman propose the regression approach (squared returns being regressed on the observed period length). Their approach is more general and allows for estimating the autocorrelations of the time series. However, as we assume no autocorrelation (as is normally observed on the financial markets) we use a simplified approach. Hayashi and Yoshida analyze the continuous time process and their estimator (which is the sum of squared demeaned observed rate of returns divided by the time observation period) would have higher variance when applied to the discrete data.

For the analysis of variance we have made the same exclusions as in the analysis of the average price levels. Additionally, we have taken into consideration only those wines with more than 50 days of trading activity at a given trading venue. We have not distinguished between single bottles and cases. The results are presented in Tables 13 and 14. We can observe that the Liv-ex exchange is characterized by the lowest volatility of returns, followed by the OTC market and then the Auctions category of trading venue.

We also made the pairwise comparisons of the standard deviation of the daily unobserved returns for the same wine (same Chateau and same vintage) traded at different venues. The results of these comparisons are presented in Table 14.

Conclusions

Fine wine is a multi-attribute experience good (asset) that is traded in many marketplaces by an increasing number of utility- or profit-driven traders. The market is evolving, and technological innovations (e.g. electronic trading platforms) facilitate wine trading and affect price formation in this market.

In our study we conducted a multidimensional analysis of average prices and the return volatility of fine wines traded in three different trading systems, namely: (a) an automated electronic exchange (Liv-ex), (b) intermediated auctions (Auctions) and (c) bilateral over-the-counter agreements (OTC market).

Our research objectives were motivated by the search for some regularities in the fine wine market microstructure that may be important for wine traders and institutional investors investing in fine wines. Therefore, we have developed and positively verified two hypotheses, based on pairwise comparisons of wine prices between Liv-ex and auctions and the OTC market respectively. In our first hypothesis we postulated that mean wine prices observed on an electronic exchange (Liv-ex) are lower than the corresponding mean prices (μ) obtained at traditional trading venues (auctions and the OTC market). Our findings confirm the general relationship concerning price formation at these trading venues, which may be presented in the form of the following inequality:

$$\mu_{LIV-EX} < \mu_{AUCTIONS} < \mu_{OTC}$$

Furthermore, in our second hypothesis we assumed

Table 14: Volatilities of daily average prices by trading venue

Venue 1	Venue 2	Number of comparisons	Number of greater	Number of lower	Number of equal	Number of greater significant	Number of lower significant
Liv-ex	OTC	71	0	69	2	0	71
Liv-ex	Auctions	55	0	55	0	0	55
OTC	Auctions	71	3	49	19	3	56

The columns have the following interpretation:

Venue 1 – first trading venue in the pairwise comparison; Venue 2 – second trading venue in the pairwise comparison; Number of comparisons – number of wines traded at venue 1 and venue 2 with at least 50 transaction days at each venue; Number of greater – number of wines where the standard deviation of the daily unobserved returns at venue 1 is higher by at least 1.5% than at venue 2; Number of lower – number of wines where the standard deviation of the daily unobserved returns at venue 1 is lower by at least 1.5% than at venue 2; Number of equal - number of wines where the standard deviation of the daily unobserved returns at venue 1 differs by no more than 1.5% from that observed at venue 2; Number of greater (lower) significant – number of significant comparisons with F-Snedecor test

Source: Own calculations

that return volatility (σ) observed on the electronic exchange (Liv-ex) is lower than the respective return volatility in traditional fine wine markets – OTC and auctions (see Table 13 and 14). This conjecture has been empirically proved, revealing the following relationship:

$$\sigma_{ELIV-EX} < \sigma_{OTC} < \sigma_{AUCTIONS}$$

In summary, the results of our analysis indicate an important role for a fully automated, cost-effective wine exchange in increasing pricing efficiency, risk reduction and enhancing fine wine market transparency. In the case of professional wine traders and institutional investors, the shift from less transparent trading systems into an automated on-book venue would seem to be an economically sensible move. This may serve as a valuable indication for the future development of trading infrastructure in the fine wine market and other agricultural commodity markets.

Our further research will focus on the impact of digital transformation on the behavior of different agents in the fine wine market and examine price formation across specified trading venues. To overcome the problem of nonsynchronous data, which is characteristic for the fine wine market, advanced simulation methods based on the Bayesian approach will be applied.

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