Convenience Yields of Collectibles*

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Abstract

We propose a novel method to estimate convenience yields of collectibles based on factor mimicking portfolios. Using up to 110 years of collectibles returns for 13 distinct asset classes, we apply machine learning techniques to address challenges from non-synchronous trading. We use these estimates to study how convenience yields affect equilibrium pricing. Convenience yield estimates for 24 of our 30 collectibles return series are positive, with an annualized mean (median) of 2.64% (2.53%). Despite various forms of underestimation, these results provide evidence that assets with positive emotional returns have lower equilibrium financial returns. This finding has important implications for ESG investing.

Keywords: Collectibles, convenience yields, emotional dividends, sustainable investing, non-pecuniary returns, machine learning
JEL classification: C14, C38, C55, G11, G14

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1 Introduction

Researchers have argued that investors receive emotional dividends from sustainable investing and so earn lower financial returns in equilibrium. This is plausible, but little work has been done on whether these non-pecuniary benefits, themselves, affect equilibrium pricing. Pastor, Stambaugh & Taylor (2020) present a model that suggests, in equilibrium, lower financial returns are tolerated because non-financial (emotional) dividends compensate for the lower financial returns. However, this story is empirically difficult to disentangle from changing tastes for sustainable investment and demand for hedging sustainability risk factors.

Recent studies such as Riedl & Smeets (2017) and Bauer, Ruof & Smeets (2020) conduct surveys of individual investors and find that they receive large non-financial benefits from sustainable investing. Even so, the preferences of these small individual investors may not have a meaningful impact on prices. This seems to be true in the market for green bonds, which trade at only a slight premium of 2 bps in Zerbib (2019) and 5-19 bps in Baker et al. (2018). Studying the effect of emotional dividends on equilibrium pricing is challenging not only because of the confounding effects of changing tastes and hedging demand, but also because widespread interest in sustainable investing is a recent phenomenon, leading to a short time horizon for price investigation.

To study the role of emotional dividends in equilibrium pricing, researchers need an instrument that is largely insulated from changing tastes and hedging demands and has a sufficiently long time series. We seek to overcome these obstacles by using returns data for 13 distinct types of collectibles spanning 110 years. We leverage this rich database to answer two primary questions. First, how should emotional returns be estimated? Second, do emotional returns influence prices in equilibrium?

The market for collectibles has a long history. Assets such as art, wine, and stamps have been popular investments for centuries. Importantly, and in part due to the relative illiquidity of their markets, collectibles are more insulated from changing tastes and hedging demands. Instead, demand for collectibles originates with the emotional dividends associated with either viewing the object (Lovo & Spaenjers 2018; Goetzmann, Mamonova, & Spaenjers 2015) or signaling one's wealth (Mandel 2009). These features of collectibles and collectibles markets provide a natural setting for studying emotional dividends.

We construct a comprehensive database of collectibles, 30 distinct return series covering 13 categories: paintings, prints, photographs, drawings, sculptures, stamps, coins, furniture, rugs, jewelry, wine, classic cars, and violins. For some categories, we have multiple measures of the returns, which vary both in terms of the underlying (eg: English coins vs. US coins) and the time horizon (eg: annual 1901-2007 vs. quarterly 1997 - 2018).

Our measure of convenience yields is grounded in a factor mimicking portfolio paradigm. Since common pervasive factors are the main drivers of returns for well-diversified portfolios, we consider investors who, at each point in time, choose between a diversified collectibles portfolio and its factor mimicking portfolio counterpart. Assuming investors are risk-neutral, then in equilibrium, the conditional expected returns of the collectibles portfolio and the factor mimicking portfolio will be equal. While the factor mimicking portfolio of liquid securities has only a financial return component, the collectibles portfolio has both financial and non-financial return components. Explicitly measuring the financial returns of the collectibles and the factor mimicking portfolio, we can impute the non-financial return, which is the convenience yield.

We construct collectibles factor mimicking portfolios in the spirit of Roll & Srivastava (2018). The basic multiple-factor paradigm stipulates that the return on any asset, for example collectibles portfolio j, can be written as a linear function of pervasive factors f:

$$R_{j,t} = \alpha_j + \beta_{j,1} f_{1,t} + \beta_{j,2} f_{2,t} + \cdots + \beta_{j,K} f_{K,t} + \epsilon_{j,t} \tag{1}$$

The β's are the factor sensitivities. The factor mimicking portfolio of liquid securities matches the factor sensitivities (β's) of the collectibles portfolio while also minimizing the residual variance (ie: idiosyncratic risk).

Our implementation extends beyond the Roll & Srivastava (2018) approach to address several empirical challenges. First, collectibles returns are highly autocorrelated from non-synchronous trading and so standard coefficient estimators for the β's are unreliable (eg: Scholes & Williams 1977, Dimson 1979). We use the Dimson (1979) "aggregated coefficients" method to estimate autocorrelation-consistent loadings and guard against overfitting with machine learning methods (eg: lasso, ridge, partial least squares). Second, we generalize the factor mimicking portfolio procedure to relax the assumption that the basis assets of our factor mimicking portfolios have orthogonal residuals in equation (1). Last, we adapt the procedure to consider practical implementation, adding a short-sales constraint for the mimicking portfolio's constituents and formalizing the tradeoff between better matching factor exposures and minimizing the mimicking portfolio's idiosyncratic risk.

In this study, our pervasive factors are principal components (PCs) estimated from 18 countries' stock and bond return indices. The first ten PCs explain 90% of the total variation. Our mimicking portfolio basis assets are drawn from 57 stock and bond return indices from across these 18 countries. We use stock and bond indices from around the world to construct our PCs and form mimicking portfolios because collectibles are traded globally. We consider a multitude of implementation variations, and use measures of factor mimicking portfolio quality to standardize the process for choosing the best implementation. These variations consider, for example, whether to use the first five or ten PCs as factors, and whether the basis assets should include both stocks and bonds or only stocks.

Since variation in collectors' tastes are difficult to model economically but may have first-order effects on valuation (eg: Goetzman et al. 2021), we do not try to form factor mimicking portfolios period-by-period. This would require estimating time-varying loadings on the emotional returns. Instead, we form factor mimicking portfolios for the entire return period, which requires the much weaker assumption that tastes have been approximately stable over long periods of time. Our convenience yield estimates are thus unconditional expectations as opposed to conditional [time-varying] expectations.

Our results show that most collectibles carry a positive average convenience yield. 24 of the 30 return series have positive point estimates, and 14 of these are statistically significant. Moreover, the mean and median annualized convenience yield estimates are large, 2.64% and 2.53% respectively. Notably, the power of our tests are unusually limited because the convenience yields inherit the autocorrelation of the collectibles returns – correcting for the autocorrelation reduces our effective sample size.

These large effects appear despite the fact that our convenience yields are underestimated for at least four important reasons. First, our mimicking portfolios reduce the collectible portfolio's residual volatility by between 1 and 30 percentage points. While we treat investors as risk neutral for the estimation, more realistic risk-averse investors would assign value to this reduction in residual volatility, making the mimicking portfolio more attractive and increasing the estimated convenience yield. Second, we underestimate the emotional return by ignoring the average annualized transaction cost, which shows up explicitly in our convenience yield formula as a positive additive term. Collectibles transaction costs are material but challenging to estimate. Third, we do not adjust for the greater liquidity of the factor mimicking portfolio relative to the collectibles. As a result, we understate the attractiveness of the mimicking portfolio and so underestimate the convenience yield. Last, there is a well-known upward bias of repeat-sales price indices, leading the collectibles financial return to be overestimated and so the convenience yield is further underestimated. Given that our estimated convenience yields are underestimated but still generally positive and material, it seems that convenience yields are priced in equilibrium.

Our study makes several primary contributions. First, we show that emotional dividends are priced in equilibrium and are associated with lower financial returns. This contributes to the debate on whether and how investors can "do well by doing good." The Pastor, Stambaugh, & Taylor (2020) theory proposes that, in equilibrium, sustainable investments underperform because of compensatory emotional dividends, although a variety of other factors can lead to transitory outperformance. Our results provide empirical evidence that emotional dividends are priced in equilibrium, lowering the financial return quite meaningfully compared to investments with commensurate systematic risk and no emotional dividends. This is important because asset managers often market sustainable investments as offering superior risk-adjusted returns,[1] which our evidence suggests is not the case.

Second, we devise a new method for estimating non-financial dividends. While many papers consider non-financial dividends for collectibles theoretically,[2] few attempt to estimate them. Those that do focus on rental yields (Atukeren & Seckin 2007), factor model alphas (Hodgson & Vorkink 2004), and assumptions about how the level of financial returns relates across asset classes (Stein 1977). Our approach aims to be more general, with fewer assumptions, and more widely applicable. Estimating convenience yields has also gained recent attention in other markets like Eurozone debt (Jiang et al. 2021), US Treasuries (van Binsbergen, Diamond, & Grotteria 2021), green bonds (Baker et al. 2018; Zerbib 2019; Pastor, Stambaugh, & Taylor 2021), and explicitly sustainable venture capital funds (Barber, Morse & Yasuda 2021). Estimating convenience yields for collectibles entails additional complexity but has similar intuition.

Third, we create a factor mimicking portfolio framework that can be applied to a variety of private value assets. Goetzmann, Spaenjers, & van Nieuwerburgh (2021) find that the value of these assets is significant, with collectibles in the US comprising at least \$5.5 trillion. Their estimates are based only on jewelry, fine art, antique furniture, and classic cars, and

[1]For example, State Street Global Advisors (2018) claim "ESG [is] a source of alpha that could lead to positive portfolio performance over time." Allianz Global Investors (2019) argues that ESG is "a 'plus' for sustainability [and] may also result in a 'plus' for performance." Capital Group (2021) claims that "improvements in ESG performance can ultimately translate into superior returns." JP Morgan (2020) claims that the "systematic inclusion of financially material ESG factors...[supports their] goal of enhancing long-term risk-adjusted financial returns."

[2] For example, Goetzmann & Spiegel (1995), Mandel (2009), Goetzmann, Mamonova, & Spaenjers (2015), and Lovo & Spaenjers (2018) assign an important theoretical role to collectibles' emotional dividends for valuation. Notably, Jovanovic (2013) and Dimson, Rousseau & Spaenjers (2015) examine whether wines that are associated with high emotional dividends generate lower financial returns.

there are many other types of collectibles that have garnered great interest. Our framework is also relevant for some types of real assets. For example, Andonov, Kraussl, & Rauh (2021) find that public institutional investors' unusually large commitment to underperforming infrastructure projects is driven by ESG considerations. In addition to using factor mimicking portfolios for estimating convenience yields, they also have more immediate practical applications. Investors can use apply our technique to obtain investment exposure to a portfolio of real and private value assets while owning only liquid securities and diversifying away idiosyncratic risk.

Our paper is organized as follows. Section 2 reviews the related literature. Section 3 describes our data. Section 4 presents our empirical strategy for estimating convenience yields for collectibles. Section 5 discusses our empirical results and Section 6 concludes. Additional empirical results and estimation details are located in the Online Appendix, which is available on the authors' websites.

2 Related Literature[3]

To provide additional context, we briefly review the literature on collectibles and the relation between sustainable investment and non-pecuniary benefits.

Concentrated academic interest in collectibles spans art (Goetzmann, Renneboog & Spaenjers 2010; Renneboog & Spaenjers 2013), cars (Laurs & Renneboog 2018), wine (Dimson, Rousseau, & Spaenjers 2013), stamps (Dimson & Spaenjers 2011), fine pens (Tomkovick & Dobie 1995), violins (Graddy & Margolis 2013), coins (Obaid, Pukthuanthong, & Maslar 2020), and rare books (Ursprung 2020). Many studies have focused on return measurement, which is not an easy task when each individual work is fundamentally unique and infrequently traded. Collectibles price indices are generally constructed using either repeat-sales regression, which exploits multiple sales of the same work, or hedonic regression, which exploits similar characteristics across works. In characterizing the returns to collectibles, many studies find that collectibles have higher average returns than bonds and bills but lower average returns than stocks. Separate from their average returns and high volatilities, some investors find them attractive for their portfolio diversification benefits (Vorsatz 2020).

Collectibles are also unusual for their very high transaction costs (Campbell 2008; Dimson & Spaenjers 2011; Kraussl & Nasser Eddine 2018). Round-trip transaction costs are often on the order of 20-30% of the sales price. Likely a consequence, collectibles are infrequently traded, with average holding periods believed to be between 28 years (Mei & Moses 2002) and 40 years (Reitlinger 1961).

We relate collectibles to sustainable investing since emotional dividends are important for both. Empirically, investors' preference for ESG has been well documented. Bialkowski & Stark (2016) find that inflows to socially responsible investment (SRI) funds are higher than inflows to comparable non-SRI funds and the SRI flow is less sensitive to performance. Hartzmark & Sussman (2019) provide related evidence that mutual funds with the highest Morningstar sustainability rating receive abnormally large flows. Bollen (2007), Renneboog,

[3]We will keep updating the literature review to incorporate more recent papers. The last update was in April 2021.

ter Horst, & Zhang (2011), and Glossner et al. (2020) show that flows to sustainable funds are more resilient in the face of systematic shocks and negative performance. Some studies corroborate these results with surveys. Riedl & Smeets (2017) find investors in SRI funds expect lower returns and are willing to pay higher management fees, with the forgone financial performance driven by social preferences and social signaling. Bauer, Ruof, & Smeets (2020) find that a majority of Dutch pension participants vote in favor of redirecting pension investments towards more sustainable goals, even if it leads to lower financial performance.

Pastor, Stambaugh, & Taylor (2020) provide a framework for thinking about how preferences for ESG investing relate to expected returns in equilibrium. Their model predicts that agents with stronger ESG preferences earn lower expected returns because they derive utility from their holdings. Importantly, they sacrifice less financial return than they are willing to, which suggests our convenience yield estimates serve as a lower bound. While emotional dividends are associated with lower equilibrium financial returns, they show theoretically that green assets can temporarily outperform if: (1) tastes unexpectedly become greener; or (2) a green-related risk emerges (eg: climate change worsens unexpectedly).

The Pastor, Stambaugh, & Taylor (2020) theory provides a framework for organizing the empirical results on ESG and returns. The aggregate evidence is mixed, which their framework emphasizes is because multiple factors are at play. For example, Friede, Bush, & Bassen (2015) review more than 2,000 published empirical studies and show roughly 90% of studies find a nonnegative relation between sustainability and stock performance. However, their setting does not address reverse causality and other studies like Gillian, Koch, & Starks (2020) have found mixed evidence. Earning non-financial utility should lower *equilibrium* financial returns as proposed theoretically by Pastor, Stambaugh, & Taylor (2020) and empirically supported by our results. However, temporarily higher financial returns can be driven by other factors like changing tastes (Fama & French 2007), unexpected risk realizations (Pastor, Stambaugh, & Taylor 2021), unrecognized employee loyalty or good governance mechanisms (Edmans 2011), or an unappreciated link between high sustainability and higher future profits (Albuquerque, Koskinen, & Zhang 2019; Pedersen, Fitzgibbons, & Pomorski 2020). A related point is that more sustainable firms have lower systematic risk and so lower cost of capital (Chava 2014; El Ghoul et al. 2011; Albuquerque et al. 2018).

Several additional studies are consistent with our results but find a meaningfully smaller effect. Focusing on the market for green bonds, the "greenium", or lower annual yield on green bonds relative to their non-green counterparts, is typically small, estimated at 5-19 bps in Baker et al. (2018), 2 bps in Zerbib (2019), and 0-4 bps in Pastor, Stambaugh, & Taylor (2021). Our results are an order of magnitude larger, with a median of 253 bps per year. These differences may be driven by clientele effects as well as hedging considerations.

3 Data

We construct a comprehensive database of collectibles returns as well as multi-country stock returns and bond yields spanning 110 years at different frequencies. This enables us to study convenience yields for a variety of collectibles assets.

Our collectibles data is from a variety of academic studies and private organizations. Our 30 distinct data series span 13 categories: paintings, prints, photographs, drawings, sculptures, jewelry, stamps, coins, wine, classic cars, violins, furniture, and rugs. The basket of collectibles underlying each price index is fundamentally unique. For example, 5 series focus on distinct categories of paintings, namely British paintings, blue-chip paintings, global paintings, paintings by popular artists, and paintings by the average artist. 6 of the 30 price indices are denominated in GBP and the rest are denominated in USD. For consistency, we convert all indices into a common currency (USD).[4]

To summarize our results, we sort our collectibles into three categories: public-domain collectibles, specialist-domain collectibles, and private-domain collectibles. These categories reflect which types of individuals are able to appreciate the collectible's value, which is important for signaling and enjoyment within social networks. Public-domain collectibles include fine art (paintings, sculptures, prints, photographs, and drawings) and jewelry, which are featured and showcased in many public venues. These items can be personally enjoyed and also used for signaling with a general audience. Specialist-domain collectibles include violins, stamps, coins, wine, and classic cars, which are often enjoyed by close-knit collector communities or specialists. These items can be personally enjoyed, but only serve a signaling purpose for a limited audience who will appreciate, for example, the 1794 Flowing Hair Silver Dollar.[5] Last, private-domain collectibles include antique furniture and fine rugs & carpets, which are generally admired in one's home and so derive most of their value from personal enjoyment and not signaling. We equal-weight the assets in each of these three categories to form summary statistics for groupings of similar collectibles, making slight adjustments to avoid over-weighting assets with multiple price indices.[6]

We collect data from academic studies including Goetzmann, Renneboog, & Spaenjers (2011) for British paintings & drawings, Dimson & Spaenjers (2011) for blue-chip British stamps, Dimson, Rousseau, & Spaenjers (2015) for blue-chip wine, Graddy & Margolis (2013) for violins, and Maslar, Obaid, & Pukthuanthong (2020) for US coins. We also collect data from private organizations including Sotheby's for blue-chip paintings, Artprice.com for global fine art price indices, Art Market Research for price indices across many asset categories, Liv-ex for their market price-based wine index, and Greysheet for coin data.

Table 1 provides descriptions of the 30 collectibles price indices. Notably, they suffer from a variety of estimation biases. First, the 21 repeat-sales price indices suffer from selection bias, as collectibles with greater price appreciation are more likely to trade (Goetzmann 1993; Korteweg et al. 2015). In particular, repeat-sales price indices are biased upward because they do not include works that fail to sell at auction (Anderson et al. 2016). At the same time, the 9 average-sales price indices fail to control for quality.[7] Second, many

[4] The annual wine & British art price indices are denominated in deflated GBP, so prior to currency conversion, we "reflate" the returns using realized UK CPI inflation from Global Financial Data (GFD).

[5] This is America's first minted silver dollar. Of 1,748 Flowing Hair dollars issued by the US Mint in 1794, only 140-150 survive today. A well-preserved specimen sold at auction for $10.0 million in 2013.

[6] For annual data, we simply equal-weight the return series within each category as there is no duplicity. For quarterly data, we equal-weight the specialist-domain return series and the private-domain return series. In contrast, the public-domain series feature great multiplicity. We first compute three equal-weighted sub-indices of global fine art (paintings, prints, sculptures, photographs, and drawings), popular fine art (popular artist paintings and popular Euro-American sculptures), and jewelry (jewelry and diamonds) and then compute the public-domain series as the equal-weighted average. The monthly series are treated identically to the quarterly series.

[7] To mitigate the effect of the tails on the average, Art Market Research includes only the central 80%

of the indices suffer from varying degrees of look-ahead bias. For example, the Sotheby's Mei-Moses index is based on paintings that sold at Sotheby's or Christie's post-1950, and for which a prior public auction could be identified from the artwork's provenance. As Sotheby's & Christie's are the premier art auction houses, these paintings are selected on the basis of being "blue chip" in the post-1950 time period, which almost surely inflates the estimated returns. Similarly, the Art Market Research popular artist paintings index is backdated using artists that were later determined to be popular. Selection biases affect many of our indices to differing degrees, and also play a role in determining the types of collectibles price indices available to us for analysis.

To make our returns data more comparable, we standardize the time horizons: annual data is 1901 - 2007 and quarterly data is Q1 1998 - Q3 2018. The only exceptions are US coins (1968-2007), blue-chip classic cars (1981-2007), and diamonds (Q3 2004 - Q4 2017). The monthly data is compounded to a quarterly frequency for our main analysis, although we consider the monthly frequency for robustness in the Online Appendix.

Table 2 provides summary statistics for the return series. A common feature of the returns data is autocorrelation, which is sometimes quite strong. This is because collectibles are infrequently traded, leading the returns to be autocorrelated and appear smoothed. In particular, this leads standard estimators to underestimate the true variance (Andersen et al. 2017) and misestimate the covariance (Scholes & Williams 1977, Dimson 1979).

In Table 3, we provide autocorrelation-adjusted and unadjusted estimates of the geometric average return, standard deviation, and total return. Our autocorrelation adjustment procedure for these summary statistics follows Vorsatz (2020) and is summarized in the Online Appendix. Underestimating the standard deviation has a dramatic effect on the reported geometric average return. For example, the unadjusted annual geometric average return for US coins is 10.1%, but after adjusting the standard deviation from 22.2% to 32.0%, the geometric average return falls to 7.4%.

Figures 1 & 2 plot the cumulative log returns for our collectibles for the annual and quarterly time horizons. Figure 1 shows the cumulative log returns of Public collectibles is much higher than that of Specialist collectibles. Blue-chip paintings have the highest returns and drive the returns of Public collectibles. We observe a sharp drop in returns around 1950 and in the early-to-mid 1990's. Figure 2 shows the returns of Specialist collectibles are higher than Public collectibles, and these are both much higher than Private collectibles. The relation between Public and Specialist collectibles is the opposite of the pattern presented in Figure 1. Notably, there is a systematic drop in returns in the late 2000's during the Subprime Mortgage Crisis. The English coins and classic cars generate the highest returns and drive the returns of Specialist Collectibles.

Despite these salient observations, we cannot read too much into the results in Figures 1 & 2. The previous discussion implies that the cumulative log returns in these figures are overestimates (sometimes substantially) of the true cumulative log returns that could have been obtained through a diversified buy-and-hold strategy in these asset classes. In addition, heterogeneity in the severity of autocorrelation (Table 3) means that different corrections need to be applied to the different indices, making comparisons across asset classes on the basis of the total return plots challenging.

We supplement our collectibles returns with international stock index returns for 18 coun-

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of sales prices for each month, meaning the top 10% and bottom 10% of monthly prices are omitted.

tries: Australia, New Zealand, US, Denmark, Canada, South Africa, Ireland, Germany, UK, India, France, Belgium, Sweden, Japan, Netherlands, Finland, Switzerland, and Italy. We also use corporate & government bond yields from these countries whenever available; there are as many as 39 distinct yield series for the most recent time periods. All of these series are from Global Financial Data (GFD) and reported in the Online Appendix.

We construct principal components (PCs) of stock and bond returns and retain the first 5 or 10 principal components as pervasive factors. The ten PCs are the eigenvectors that explain about 90 percent of eigenvalues.

4 Empirical Strategy

Our empirical strategy proceeds in three steps. First, we theoretically motivate a measure of convenience yields in a factor mimicking portfolio (FMP) paradigm. Second, we generalize the traditional FMP estimation framework of Roll & Srivastava (2018) to allow for residual correlation and to formalize the tradeoff between minimizing residual variance and minimizing factor exposure matching error. We also introduce a short-sales constraint on the mimicking portfolio weights to better reflect the typical investor's portfolio problem. Last, we adapt the factor estimation procedure to account for unique features of collectibles returns, namely their autocorrelation from non-synchronous trading.

4.1 Estimating Convenience Yields

We decompose total realized collectibles returns as:

$$\underbrace{R^C_{t+1}}_{\text{Total Collectible Return}} = \underbrace{R^F_{t+1}}_{\text{Financial Return}} + \underbrace{R^E_{t+1}}_{\text{Emotional Return}} - \underbrace{R^T_{t+1}}_{\text{Transaction/Holding Costs (\%)}} \tag{2}$$

$$\implies \mathbb{E}_t[R^C_{t+1}] = \mathbb{E}_t[R^F_{t+1}] + \mathbb{E}_t[R^E_{t+1}] - \mathbb{E}_t[R^T_{t+1}] \tag{3}$$

In equilibrium, investors trade each period t so that expected total collectible returns are equal to the expected return on the factor mimicking portfolio:

$$\mathbb{E}_t[R^C_{t+1}] = \mathbb{E}_t[R^{FMP}_{t+1}] \tag{4}$$

The challenge in forming this FMP is in setting $\beta^k_{C,t} = \beta^k_{FMP,t}\ \forall k$ because the total collectible return is unobservable. One might be tempted to instead set $\beta^k_{F,t} = \beta^k_{FMP,t}\ \forall k$, that is, replace the total collectible return with the collectible's financial return. However, an important implicit assumption in doing so is that the betas for E and T are zero at each date t, which is unlikely to hold. For example, Mandel (2009) proposes that art provides a constant utility dividend and so functions as insurance, which implies that $\beta_{E,t} < 0$ during recessions. Instead, we note that:

$$\overset{\text{by Eq (3)}}{\implies} \mathbb{E}_t[R^E_{t+1}] = \mathbb{E}_t[R^C_{t+1}] - \mathbb{E}_t[R^F_{t+1}] + \mathbb{E}_t[R^T_{t+1}] \tag{5}$$

$$\overset{\text{by Eq (4)}}{\implies} \mathbb{E}_t[R^E_{t+1}] = \mathbb{E}_t[R^{FMP}_{t+1}] - \mathbb{E}_t[R^F_{t+1}] + \mathbb{E}_t[R^T_{t+1}] \tag{6}$$

$$\overset{\text{by LIE}}{\implies} \mathbb{E}[R^E_{t+1}] = \mathbb{E}[\mathbb{E}_t[R^E_{t+1}]] = \mathbb{E}[R^{FMP}_{t+1}] - \mathbb{E}[R^F_{t+1}] + \mathbb{E}[R^T_{t+1}] \tag{7}$$

If we assume that the betas for C and F are very similar over long periods of time, then while we can't estimate the conditional expectations in Equation (6), we *can* estimate the unconditional expectations in Equation (7). This is because we can't form the conditional FMPs without strong assumptions, but can form the unconditional FMP with only the weak assumption that the long-horizon betas for C and F are similar.

4.2 Factor Mimicking Portfolio Framework

Factor mimicking portfolios use liquid securities ("basis assets") to match the factor structure of a target asset in a way that minimizes residual volatility, which in the multi-factor paradigm is uncompensated risk.

The basic multiple-factor paradigm stipulates that the return on any asset, say stock j observed over an interval ending at time t, can be written as a linear function

$$R_{j,t} = \alpha_j + \beta_{j,1} f_{1,t} + \beta_{j,2} f_{2,t} + \cdots + \beta_{j,K} f_{K,t} + \epsilon_{j,t} \tag{8}$$

where the f's denote the pervasive risk factors while the β's are factor sensitivities. We use $k = 1, \ldots, K$ to index the global factors.

Roll and Srivastava's (2018) mimicking portfolio is a portfolio that minimizes idiosyncratic risk while retaining the same loadings on the global factors for target asset j. In our applications, j will be the index for the collectibles.

The mimicking portfolio is composed of basis assets $i = 1, \ldots, N$. For each basis asset i, we estimate the asset's global factor exposures

$$R_{i,t} = \alpha_i + \beta_{i,1} f_{1,t} + \beta_{i,2} f_{2,t} + \cdots + \beta_{i,K} f_{K,t} + \epsilon_{i,t} \tag{9}$$

The portfolio problem Roll & Srivastava (2018) solve can be formulated as

$$\begin{aligned}
&\min_{\boldsymbol{\omega}} \sum_{i=1}^{N} \sum_{m=1}^{N} \omega_i \omega_m \widehat{\sigma}_{i,m} \\
&\text{s.t.} \quad \sum_{i=1}^{N} \omega_i \widehat{\beta}_{i,k} = \widehat{\beta}_{j,k} \quad \forall k \\
&\qquad\;\; \sum_{i=1}^{N} \omega_i = 1
\end{aligned}$$

where the $\widehat{\beta}_{j,k}$ are estimated from Equation (8) for target asset j, the $\widehat{\beta}_{i,k}$ are estimated from Equation (9) for basis assets $i = 1, \ldots, N$, and $\widehat{\sigma}_{i,m}$ denotes the residual covariance of basis assets i and m from equation (9). In words, the objective is to construct the portfolio of liquid securities with the minimum idiosyncratic risk that matches the factor sensitivities of the target asset. In our application, this is the portfolio of stocks and bonds with the minimum idiosyncratic risk that matches the factor sensitivities of the collectibles portfolio.

To be precise, $\widehat{\Sigma} = \mathrm{Cov}(\widehat{\epsilon}_{1,t}, \ldots, \widehat{\epsilon}_{N,t})$ is the $N \times N$ covariance matrix where the $\widehat{\epsilon}_{i,t}$ are the residuals estimated for the basis assets in equation (9). A key assumption Roll and Srivastava (2018) make for purposes of tractability is that the residuals are orthogonal, that is, $\text{Cov}(\widehat{\epsilon}_{it}, \widehat{\epsilon}_{mt}) = \widehat{\sigma}_{i,m} = 0\ \forall i \neq m$. To avoid assuming residual orthogonality, we solve the portfolio problem numerically.

In addition, depending on the target asset and the set of basis assets, it may be undesirable (or impractical) to ensure that $\sum_{i=1}^{N} \omega_i \widehat{\beta}_{i,k} = \widehat{\beta}_{j,k}\ \forall k$. For example, the cost of satisfying this constraint may be an unreasonably high residual volatility. To account for this trade-off between better matching factor exposures and minimizing the mimicking portfolio's residual volatility, we formalize this trade-off by reframing the optimization problem:

$$\begin{aligned}
\min_{\boldsymbol{\omega}} \ & \sum_{i=1}^{N}\sum_{m=1}^{N}\left(\frac{\omega_i \omega_m \widehat{\sigma}_{i,m}}{\widehat{\sigma}_j^2}\right) + \kappa\left(\sum_{k=1}^{K}\left|\sum_{i=1}^{N}\omega_i \widehat{\beta}_{i,k} - \widehat{\beta}_{j,k}\right|\right) \\
\text{s.t.} \quad & \sum_{i=1}^{N}\omega_i = 1 \\
& \omega_i \geq 0\ \forall i
\end{aligned}$$

where $\widehat{\sigma}_j^2$ denotes the residual variance of the target asset estimated from equation (8). The first term is the ratio of the mimicking portfolio's residual variance to the target asset's residual variance and the second term is the sum of the absolute differences between the target asset's factor exposures and the mimicking portfolio's factor exposures. κ determines how the investor trades-off reducing the mimicking portfolio's residual variance and better matching the factor exposures of the target asset.

We include a non-negativity constraint for the mimicking portfolio weights for two key reasons. First, this contributes to greater stability in the estimated weights across specifications. Second, this is more broadly implementable for the typical investor (who can't get unlimited leverage), reflecting the spirit of Sharpe's (1992) style analysis.

4.3 Addressing Return Autocorrelation

It is well known that aesthetic assets are infrequently traded, leading to high return autocorrelation, which ultimately leads standard estimators to underestimate the true variance (Andersen et al. 2017) and misestimate the covariance (Scholes & Williams 1977, Dimson 1979). While Campbell (2008) and Dimson & Spaenjers (2011) apply the Geltner (1993) unsmoothing method for art and stamps respectively, we seek to avoid the method's strong assumptions. Instead, we rely on the model-free approach of Dimson's (1979) "aggregated coefficients" for estimating autocorrelation-consistent factor loadings.

Dimson's (1979) autocorrelation-consistent slopes are estimated from the following regression:

$$R_{j,t} = \alpha_j + \sum_{l=0}^{L}\beta_{j,1,l} f_{1,t-l} + \sum_{l=0}^{L}\beta_{j,2,l} f_{2,t-l} + \cdots + \sum_{l=0}^{L}\beta_{j,K,l} f_{K,t-l} + \epsilon_{j,t}$$

where L is the number of statistically significant autocorrelation lags for the dependent variable and a consistent estimate of the slope is obtained as the aggregated coefficients, for example, $\sum_{l=0}^{L}\beta_{j,1,l}$.[8]

[8] Note that lags address dependent variable autocorrelation while leads (which are not included here) address independent variable autocorrelation.

To address potential overfitting and to facilitate the relaxation of $T > (L+1)K$ when L gets large, we consider estimating the factor loadings using not only ordinary least squares, but also lasso, ridge, elastic net, and partial least squares (PLS) regression. PLS yields factor loading estimates that are the most robust to small perturbations in the specification, and so while we consider a variety of machine learning methods for the factor loading estimation, we ultimately choose to only use the loadings from PLS.

4.4 Assessing Mimicking Portfolio Performance

We consider several key measures to assess the performance of our mimicking portfolios:

1. **Residual Variance Ratio**: The ratio of the mimicking portfolio's residual variance to the target asset's residual variance: $\sum_{i=1}^{N}\sum_{m=1}^{N}\left(\frac{\omega_i\omega_m\widehat{\sigma}_{i,m}}{\widehat{\sigma}_j^2}\right)$. This ensures that the FMP has less idiosyncratic risk than the test asset. For interpretability, we compare the target asset's residual volatility with the FMP's residual volatility.

2. **Maximum Absolute Loading**: The maximum absolute target asset factor exposure: $\max|\widehat{\beta}_{j,k}|$. This ensures the factors are appropriate for the given test asset. For example, if the collectibles portfolio does not load on any of the pervasive factors, then the factors are not appropriate for the collectible and the FMP is unreliable.

3. **Mean Absolute Deviation (MAD)**: The average absolute difference between the mimicking portfolio's factor exposures and the target asset's factor exposures: $\frac{1}{K}\sum_{k=1}^{K}\left|\sum_{i=1}^{N}\omega_i\widehat{\beta}_{i,k} - \widehat{\beta}_{j,k}\right|$. This is a measure of how well the FMP matches the test asset's factor exposures. To understand how large or small this value is in each specification, we normalize it by: (1) the maximum absolute loading; and (2) the average absolute loading.

5 Empirical Results

Applying our convenience yield framework to the data, we estimate that collectibles convenience yields are positive and nontrivial in magnitude. Of particular importance, we reach this conclusion even before we consider the various sources of underestimation, many of which are of first-order importance.

5.1 Convenience Yield Estimates

Table 4 reports our baseline convenience yield estimates for the 30 collectibles price indices. We consider 6 specifications using: (1) either 5 or 10 PCs for the pervasive factors; (2) PCs estimated from only stock returns or both bond and stock returns; and (3) basis assets consisting of only stocks or both bonds and stocks.[9] The reported results are from the combination of factors and basis assets that yields the best performance in terms of

[9] If bonds and stocks are used for the PCs, we don't consider using only stocks for the basis assets.

residual volatility reduction, factor relevance, and factor matching. Importantly, we choose the best performing specification without regard for the convenience yield estimate. The Online Appendix reports the results from all 6 specifications for each collectible return series. The convenience yield estimates are generally quite stable across specifications, and the qualitative conclusions are unchanged when using other reasonable choices.

24 of the 30 collectibles price indices have positive convenience yield point estimates, although only 14 of the 24 are statistically significantly positive at the 5% significance level. The limited statistical significance is due to relatively large autocorrelation-adjusted standard errors for the convenience yield time series, which inherits the autocorrelation of the original collectibles return series. Nevertheless, given various forms of underestimation, it's surprising to see the *unadjusted* convenience yields so strongly priced in equilibrium. Focusing only on the annual and quarterly series,[10] the mean and median annualized convenience yield estimates are 2.64% and 2.53%.

Figures 3 & 4 plot the time series of the estimated convenience yields. Figure 3 shows the convenience yield of Public collectibles is lower than that of Specialist collectibles, which is consistent with the message from Figure 1 where the financial returns of Public collectibles are higher than that of Specialist collectibles. Figure 4 also supports the same message. The convenience yield of Specialist collectibles is lowest and investors seem to demand the highest returns as shown in Figure 2. Although the two figures support our argument, these are only of limited direct interest since we focus on estimating unconditional convenience yields instead of conditional convenience yields.

In addition, the factor mimicking portfolios achieve a substantive reduction in residual volatility relative to the collectibles themselves. The mean and median reductions in annualized residual volatility are 9.61 percentage points and 6.80 percentage points. The range is quite large, from as little as a 1.51 percentage point reduction to as much as a 29.95 percentage point reduction. In estimating the convenience yields, we treat investors are risk-neutral, and so ignore these large reductions in uncompensated risk that a risk-averse investor would highly value.

Two key observations come from our examination of these cross-sectional convenience yield estimates. First, Private collectibles carry the largest convenience yields by an order of magnitude. In the Q1 1998 - Q3 2018 data, the average is 9.55%, much larger than the 2.28% of Public collectibles or the 0.45% of Specialist collectibles. Second, despite great heterogeneity in the underlying baskets, our estimates for the convenience yields of Specialist and Public collectibles are remarkably similar across these two very different time horizons (ie: 1901-2007 and 1998-2018).

5.2 Sources of Convenience Yield Underestimation

There are four main sources of convenience yield underestimation: (1) we treat investors as risk-neutral and so ignore the benefits of large reductions in uncompensated risk; (2) no annualized transaction cost is added; (3) repeat-sales price indices suffer from selection bias; and (4) we ignore the liquidity benefits of the FMP relative to the collectibles.

First, we ignore the much lower residual volatility of the FMP, which would make the FMP

[10] This avoids double-counting the monthly series, as they are also converted to quarterly series.

more attractive than the collectible for a risk-averse investor. In our framework, the FMP is constructed to reduce the portfolio's residual volatility as much as possible while still matching the test asset's factor exposures. This objective function, which does not seek to maximize the portfolio's expected return, implies that the investor is risk-averse. However, in comparing the test asset with the FMP, we focus only on the difference in average returns, and ignore the fact that the FMP reduces the residual volatility by between 2 and 30 percentage points, which would accrue utility benefits to a risk-averse investor. As a result, we underestimate the incremental attractiveness of the FMP's financial return relative to the test asset's financial return, meaning we underestimate the convenience yield.

Second, we do not add the annualized transaction cost, a positive term, to our estimate of the convenience yield. Our motivating formula for the estimation of the unconditional emotional return is:

$$\underbrace{\mathbb{E}[R_t^E]}_{\text{Emotional Return}} = \underbrace{\mathbb{E}[R_t^{FMP}]}_{\text{FMP Return}} - \underbrace{\mathbb{E}[R_t^F]}_{\text{Collectible's Financial Return}} + \underbrace{\mathbb{E}[R_t^T]}_{\text{Transaction/Holding Costs (Annualized \%)}}$$

We do not try to account for transaction & holding costs because of substantial time variation within and across assets and difficulty in obtaining high quality estimates. For example, Dimson, Rousseau, & Spaenjers (2015) estimate wine storage & insurance costs at between 0.13% and 0.94% for each decade between 1940 and 2000, with the cost of insurance being a fixed fee (eg: 1.6 shilling or 0.075 GBP in March 1940) that is converted into a percent based on average prices during that time period. In contrast, custody costs for stamps are so low that they can be reasonably ignored (Dimson & Spaenjers 2011).

Transaction costs are also complicated, with auction house transaction costs being composed of a buyer's premium and a seller's commission. The buyer's premium, introduced during the mid-1970s, was initially flat at 10% of the hammer price and is currently as high as 25% for hammer prices below $200,000 (Kraussl & Nasser Edinne 2018). While the seller's commission is often estimated at 10% of the hammer price, it is not observed and is negotiable. Many papers assume that roundtrip transaction costs are 20-30% of the hammer price.[11] The annualized transaction cost then depends on the average holding period, often believed to be between 28 years (Mei & Moses 2002) and 40 years (Reitlinger 1961), which would yield an average annualized transaction cost of 0.5-1.1%, at least for recent years.

Third, we do not directly account for the upward-bias of our repeat-sales price indices. Repeat-sales price indices are upward-biased because collectibles do not randomly trade at least twice. Korteweg, Kraussl, & Verwijmeren (2016) show that this selection bias leads a 1960-2013 repeat-sales painting price index to overstate average annual returns by 2.4%. As our repeat-sales price indices may overstate the collectible's average financial return, this is another source of convenience yield underestimation.

Last, we do not attempt to account for the liquidity mismatch between the collectibles and the FMP, which makes the FMP more attractive (all else equal). There is a large body of evidence documenting a positive relation between expected illiquidity and expected returns (eg: Amihud & Mendelson 1986; Amihud 2002; Pastor & Stambaugh 2003; and Dimson

[11] Penasse & Renneboog (2017) argue that total transaction costs are minimally 20% of the sales price while Campbell (2008) notes that total transaction costs can be as much as 30%. Kraussl & Nasser Eddine (2018) document the evolution of the buyer's premium over time, which when paired with the seller's commission, also gives estimates in this range. Dimson & Spaenjers (2011) use 25% for stamps, which they find is similar for either a roundtrip trade through an auction or a dealer (Stanley Gibbons).

& Hanke 2004). Collectibles are illiquid, evidenced by the high transaction costs and long average holding periods. While there are no studies estimating the illiquidity premium in collectibles markets, studies of the US stock market have estimated the annual illiquidity premium to be between 1.7% and 7.5%.[12] By comparing the financial return of the relatively-illiquid collectibles to the financial return of the relatively-liquid factor mimicking portfolio, we fail to adjust for return differences based on liquidity. As a result, we overestimate the collectible's financial return and thus underestimate the convenience yield.

6 Conclusion

We design a method for estimating convenience yields of collectibles and apply it to 30 collectibles return series spanning 13 distinct asset classes. The intuition behind our strategy is simple: investors choose between a well-diversified collectibles portfolio and a factor mimicking portfolio by comparing the expected returns, both financial and non-financial. The convenience yield is the difference in expected financial returns, which makes the investor indifferent between owning the collectibles and the factor mimicking portfolio.

We find that most collectibles carry a moderate and positive convenience yield on the order of 2.5% annually. This value can be viewed as a lower bound because of several simplifications that lead us to underestimate the convenience yield. We find that convenience yields appear fairly stable across different time periods, and that private-domain collectibles carry much larger convenience yields than public-domain or specialist-domain collectibles.

Our finding that convenience yields, or emotional dividends, are priced in equilibrium sheds light on the future of ESG investing. As theoretically predicted in Pastor, Stambaugh, & Taylor (2020), our results suggest that ESG investing, in equilibrium, will feature nontrivial non-pecuniary benefits and so lower financial returns.

Our results also have practical implications for a growing base of retail investors who are drawn to alternative assets (whether collectibles or non-fungible tokens). These emotional or aesthetic assets may underperform comparable portfolios of stocks and bonds, lending credit to the old adage that collectors should "buy what they love" and not buy aesthetic assets purely as financial investments.

Work on estimating emotional dividends, or non-pecuniary returns, is still in its infancy. Extending our framework to other long-term asset classes like residential real estate (or luxury residential real estate) could prove fruitful. One benefit of real estate is that close alternatives are more easily identifiable, and comparing the cost of renting and buying the same property (or similar properties of heterogeneous quality) may provide a means of constructing more precise estimates of convenience yields.

More generally, our findings of large convenience yields in mature collectibles markets hint that there may be large non-financial returns associated with sustainable investing. Future work may want to focus on studying the distribution of willingness to pay for sustainability across the population, not just among wealthy investors that affect equilibrium prices. To the extent that either the median investor or dollar-average investor is willing to pay a

[12] Pastor & Stambaugh (2003) estimate a 7.5% annual premium, Acharya & Pedersen (2005) estimate a 4.6% annual premium, and Hagstromer, Hansson, & Nilsson (2013) estimate a 1.7-2.1% annual premium.

premium for sustainability, government regulations requiring more sustainable corporate policies may have large welfare benefits.

Figures

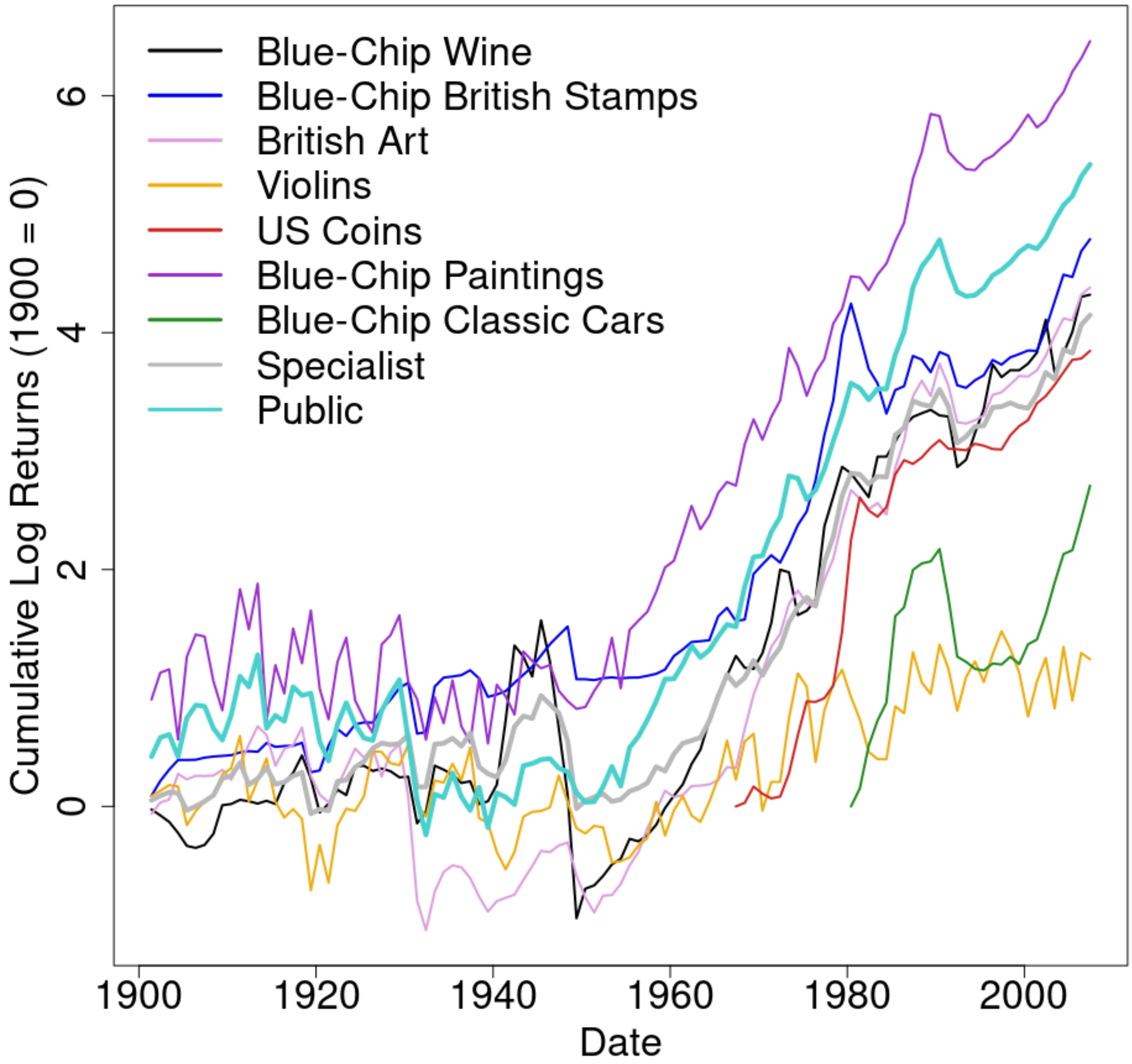

Figure 1: Cumulative Log Returns for Annual USD Series

This figure plots the cumulative log returns of the annual USD collectibles over the 1900-2007 time period. 1900 is scaled to have a cumulative log return of 0, although US coins and blue-chip classic cars are scaled to 0 for the first year of the series (in 1967 and 1980, respectively). The Specialist and Public series are cumulative equal-weighted averages of the non-missing log returns for groups of similar collectibles. Specialist-domain collectibles include blue-chip wine, blue-chip British stamps, violins, US coins, and blue-chip classic cars. Public-domain collectibles include British art and blue-chip paintings.

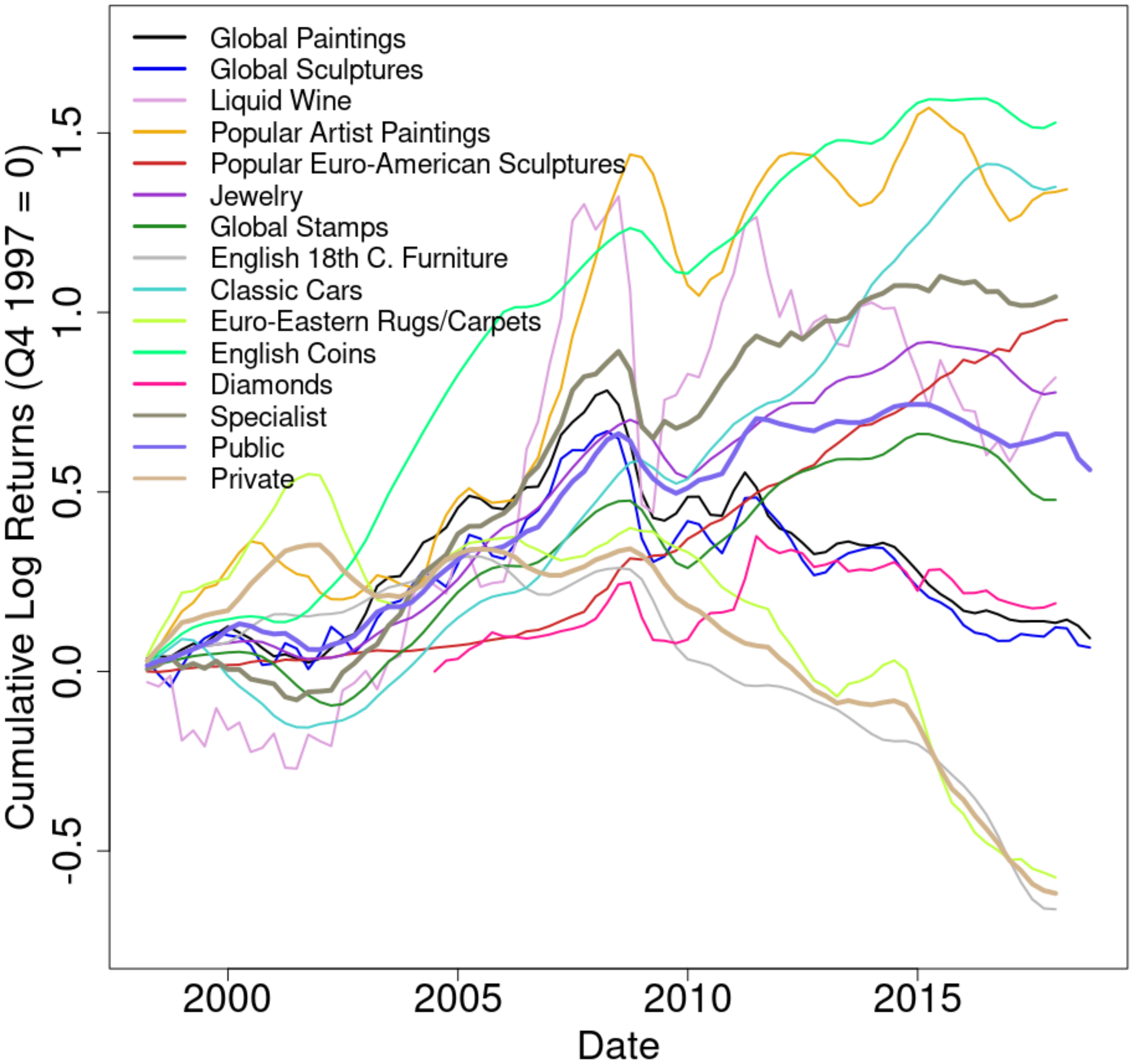

Figure 2: Cumulative Log Returns for Representative Quarterly USD Series

This figure plots the cumulative log returns of the quarterly USD collectibles over the Q1 1998 - Q3 2018 time period. Q4 1997 is scaled to have a cumulative log return of 0, although diamonds are scaled to 0 for the first quarter of the series (Q2 2004). The Specialist, Public, and Private series are cumulative equal-weighted averages of the non-missing log returns for groups of similar collectibles. Specialist-domain collectibles include liquid wine, global stamps, classic cars, and English coins. Public-domain collectibles include global paintings, global sculptures, global photographs, global drawings, global prints, popular artist paintings, popular artist European & North American sculptures, jewelry, and diamonds. Private-domain collectibles include English 18th century furniture and European & Eastern Rugs & Carpets.

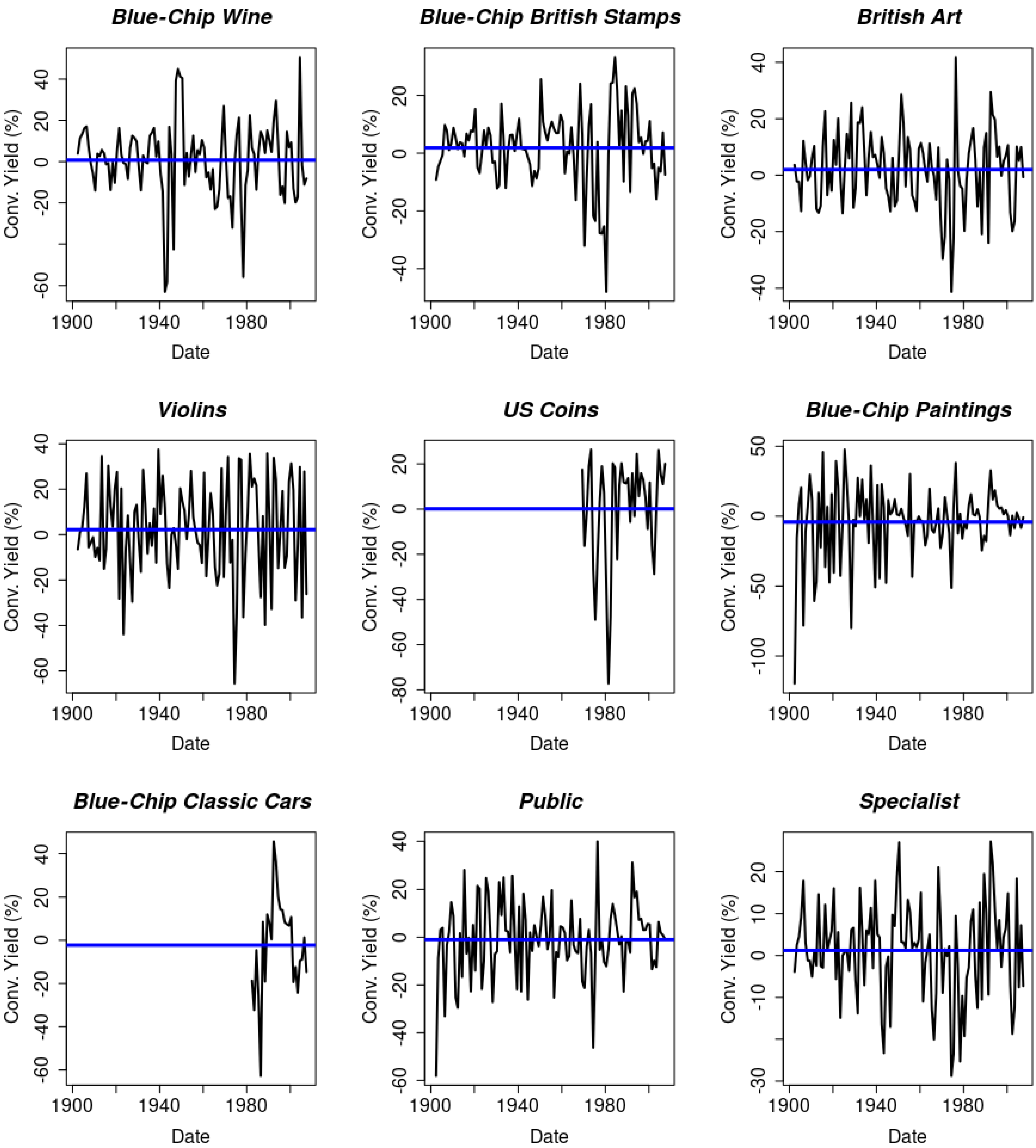

Figure 3: Exponentially-Smoothed Convenience Yields for Annual USD Returns

This figure plots the exponentially-smoothed convenience yields of the annual USD collectibles over the 1900-2007 time period. The exponential smoothing function takes the form $s_t = \alpha x_t + (1-\alpha)s_{t-1}$, where x_t is the estimated convenience yield for period t. We set $\alpha = 0.2$ to allow for a moderate degree of smoothing. The Specialist and Public series are equal-weighted averages of the non-missing convenience yields for groups of similar collectibles. Specialist-domain collectibles include blue-chip wine, blue-chip British stamps, violins, US coins, and blue-chip classic cars. Public-domain collectibles include British art and blue-chip paintings.

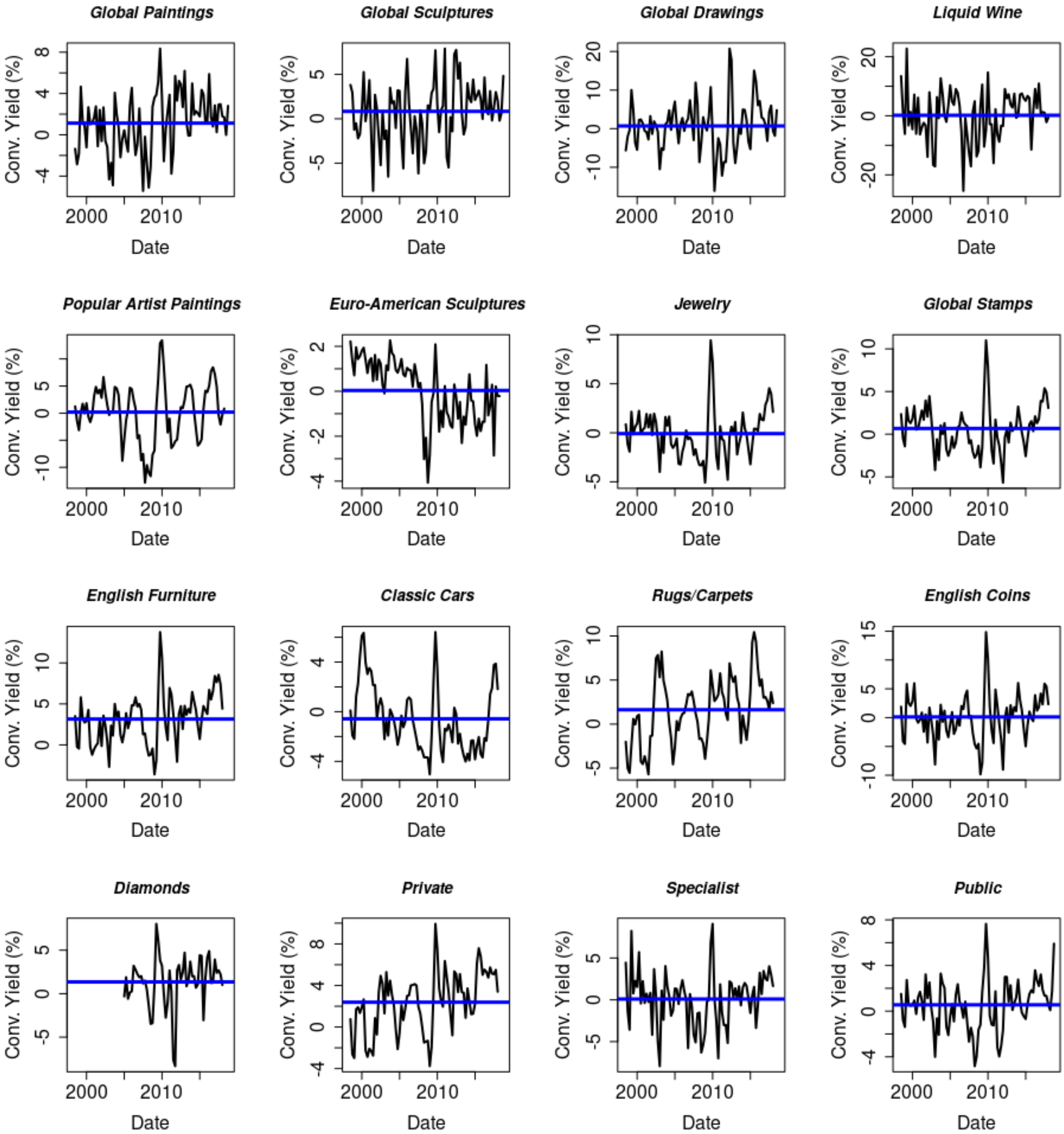

Figure 4: Exponentially-Smoothed Convenience Yields for Representative Quarterly USD Returns

This figure plots the exponentially-smoothed convenience yields of the quarterly USD collectibles over the Q1 1998 - Q3 2018 time period. The exponential smoothing function takes the form $s_t = \alpha x_t + (1-\alpha)s_{t-1}$, where x_t is the estimated convenience yield for period t. We set $\alpha = 0.2$ to allow for a moderate degree of smoothing. The Specialist, Public, and Private series are equal-weighted averages of the non-missing convenience yields for groups of similar collectibles. Specialist-domain collectibles include liquid wine, global stamps, classic cars, and English coins. Public-domain collectibles include global paintings, global sculptures, global photographs, global drawings, global prints, popular artist paintings, popular artist European & North American sculptures, jewelry, and diamonds. Private-domain collectibles include English 18th century furniture and European & Eastern Rugs & Carpets.

Tables

Table 1: Details of Collectibles Price Indices

This table provides brief descriptions of the collectibles price indices. Panel A describes the longer-term (annual) raw series. Panel B describes the more recent (quarterly and monthly) raw series.

Index Name	Data Description
	Panel A. Longer Term
British Art	This annual repeat-sales price index spans 1766-2007 and is denominated in GBP. The index focuses on British paintings and drawings and is provided by Goetzmann, Renneboog, & Spaenjers (2011). The index is based on 1,336 repeated sales found by merging the Reitlinger (1961) and Renneboog & Spaenjers (2013) datasets.
Blue-Chip Paintings	This annual repeat-sales price index spans 1901-2016 and is denominated in USD. The index focuses exclusively on paintings sold by Sotheby's or Christies post-1950, with prior public transactions included whenever possible using the provenance. The index is provided by Sotheby's and is an expansion of the original 4,896 price pairs of Mei & Moses (2002) to over 80,000 repeat sales in its current form.
Blue-Chip British Stamps	This annual repeat-sales price index spans 1900-2008 and is denominated in GBP. The index begins with the 50 most valuable British stamps in the Stanley Gibbons catalogue in 1900 and adds the missing members of the top 50 most valuable stamps every 9 years, with the basket growing to 127 stamps by the end of the sample. This index is provided by Dimson & Spaenjers (2011).
Blue-Chip Wine	This annual repeat-sales price index spans 1900-2012 and is denominated in GBP. The index focuses on five red Bordeaux wines (the Premier Crus: Haut-Brion, Lafite-Rothschild, Latour, Margaux, and Mouton-Rothschild) and is provided by Dimson, Rousseau, & Spaenjers (2015).
Violins	This annual repeat-sales price index spans 1876-2012 and is denominated in GBP. The index focuses on 320 distinct violins and 1,328 repeat sales and is provided by Graddy & Margolis (2013).
US Coins	This annual repeat-sales price index spans 1968-2012 and is denominated in USD. The index focuses on US coins (pennies, nickels, dimes, quarters, half dollars, and dollars) and is provided by Maslar, Obaid, & Pukthuanthong (2020).
Blue-Chip Classic Cars	This annual capitalization-weighted price index spans 1980-2017 and is denominated in GBP. The index focuses on high-end cars, with the 50 models that are current index constituent having a minimum price of £100,000 and maximum number of survivors at 1,000 units. The index is provided by Historic Automobile Group Inc (HAGI).
	Panel B. More Recent
Global Art	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index focuses on all Fine Art auction results (paintings, sculptures, drawings, photographs, prints, watercolors, etc.) recorded by Artprice.com except for antiques and furniture, and compiles auction sales from over 6,300 auction houses globally. The price index is provided by Artprice.com.
US Art	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to US auction sales.

Global Paintings	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to paintings.
Popular Artist Paintings*	This monthly exponentially-smoothed moving average sales price index spans January 1976 - March 2018 and is denominated in USD. The index focuses on paintings (Old Masters, European Impressionists, Modern, and Contemporary) by 100 well-known artists including Basquiat and Canaletto, with public auction data sourced globally accounting for 90% of painting sales by value. The index is provided by Art Market Research.
Average Artist Paintings*	This monthly exponentially-smoothed moving average sales price index spans January 1976 - March 2018 and is denominated in USD. The index measures the average value of paintings sold by the average artist in each month and is provided by Art Market Research.
Global Prints	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to prints.
Global Photographs	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to photographs.
Global Drawings	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to drawings.
Global Sculptures	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to sculptures.
Popular Artist European & North American Sculptures*	This monthly exponentially-smoothed moving average sales price index spans January 1985 - March 2018 and is denominated in USD. The index focuses on European & North American sculptures by 100 well-known artists, covering 55,527 works. The index is provided by Art Market Research.
Liquid Wine	This monthly value-weighted price index spans January 1988 - December 2017 and is denominated in GBP. The index focuses on Bordeaux red wines from 24 leading chateaux, and the 100 highest-rated wines (in terms of Robert Parker Jr. scores) trading on the Liv-ex exchange are included in the scarcity-weighted basket. The index is provided by Liv-ex.
Global Stamps*	This monthly exponentially-smoothed moving average sales price index spans January 1976 - December 2017 and is denominated in USD. The index focuses on 25 distinct genres of stamps spanning more than 11 countries. The index is provided by Art Market Research.
English Coins*	This monthly exponentially-smoothed moving average sales price index spans January 1976 - December 2017 and is denominated in USD. The index focuses on hammered & milled English gold & silver coins. The index is provided by Art Market Research.
Classic Cars*	This monthly exponentially-smoothed moving average sales price index spans January 1981 - December 2017 and is denominated in USD. The index focuses on 15 brands of luxury classic cars. The index is provided by Art Market Research.

Jewelry*	This monthly exponentially-smoothed moving average sales price index spans January 1986 - December 2017 and is denominated in USD. The index focuses on four broad genres of jewelry and is provided by Art Market Research.
General Diamonds	This daily value-weighted price index spans January 1, 2004 to January 31, 2018 and is denominated in USD. The index focuses on 300 stone profiles that accounted for approximately 43% of the total market in dollar value at the time of the index composition. The index is provided by IDEX.
European & Eastern Rugs & Carpets*	This monthly exponentially-smoothed moving average sales price index spans January 1985 - December 2017 and is denominated in USD. The index focuses on European and Eastern Rugs & Carpets and is provided by Art Market Research.
English 18th Century Furniture*	This monthly exponentially-smoothed moving average sales price index spans January 1976 - December 2017 and is denominated in USD. The index focuses on 36 genres of English 18th Century furniture and is provided by Art Market Research.
Global Old Masters Art	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to Old Masters Art.
Global 19th Century Art	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to 19th Century Art.
Global Modern Art	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to Modern Art.
Global Post-War Art	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to Post-War Art.
Global Contemporary Art	This quarterly repeat-sales price index spans Q4 1997 - Q3 2018 and is denominated in USD. The index uses the same underlying sample as the Global Art index, but restricts consideration to Contemporary Art.

* In constructing the index, Art Market Research includes only the central 80% of sales prices for each month, meaning the top 10% and bottom 10% of monthly prices are omitted.

Table 2: Descriptive Statistics

This table presents descriptive statistics for the collectibles we use in our study in US dollars (USD). Start and end dates for the data series are in *yyyy* format for the annual data and *yyyymmdd* format for the quarterly data. The mean, maximum, minimum, and return standard deviation are all in percentage points. AC denotes the first-order autocorrelation coefficient.

	Mean	Max	Min	Std. Dev.	Obs	Start Date	End Date	AC
				Annual USD				
Blue-Chip Wine	6.78	88.28	-64.66	23.58	107	1901	2007	0.22**
Blue-Chip British Stamps	5.69	73.44	-35.93	15.61	107	1901	2007	0.32***
British Art	5.74	48.27	-58.52	17.24	107	1901	2007	0.31***
Violins	4.80	71.28	-47.79	27.42	107	1901	2007	-0.26***
US Coins	11.73	116.52	-10.32	22.22	40	1968	2007	0.51***
Blue-Chip Paintings	11.44	146.60	-68.70	34.69	107	1901	2007	-0.26***
Blue-Chip Classic Cars	13.41	107.27	-39.21	26.77	27	1981	2007	0.26***
				Quarterly USD				
Global Art	0.22	33.40	-20.68	10.77	83	19980331	20180930	-0.55***
Global Paintings	0.18	8.84	-13.09	3.68	83	19980331	20180930	0.64***
Global Prints	0.29	7.30	-13.25	3.86	83	19980331	20180930	0.67***
Global Sculptures	0.18	9.99	-15.64	4.44	83	19980331	20180930	0.48***
Global Photographs	0.25	24.10	-18.75	7.15	83	19980331	20180930	0.41***
Global Drawings	0.67	19.30	-17.68	6.91	83	19980331	20180930	0.52***
Global Old Masters Art	-0.42	22.27	-16.51	6.81	83	19980331	20180930	0.08***
Global 19th C. Art	-0.49	13.36	-13.90	4.94	83	19980331	20180930	0.50***
Global Modern Art	0.07	8.06	-12.98	3.63	83	19980331	20180930	0.60***
Global Post-War Art	0.73	15.15	-11.20	4.83	83	19980331	20180930	0.47***
Global Contemporary Art	0.70	16.91	-16.37	7.33	83	19980331	20180930	0.36***
US Art	0.49	11.57	-13.56	4.06	83	19980331	20180930	0.54***
Liquid Wine	1.71	36.88	-44.89	11.44	80	19980331	20171231	0.22***
Average Artist Paintings	2.39	10.04	-3.68	3.53	81	19980331	20180331	0.48***
Popular Artist Paintings	1.81	15.83	-11.77	5.38	81	19980331	20180331	0.79***
Popular Euro-American Sculptures	1.22	5.29	-0.90	1.26	81	19980331	20180331	0.33***
Jewelry	1.00	4.39	-4.92	2.02	80	19980331	20171231	0.86***
Global Stamps	0.62	3.99	-5.30	2.24	80	19980331	20171231	0.90***
English 18th C. Furniture	-0.80	2.45	-6.71	2.28	80	19980331	20171231	0.90***
Classic Cars	1.73	5.78	-3.98	2.45	80	19980331	20171231	0.90***
Euro-Eastern Rugs/Carpets	-0.64	6.37	-9.82	3.82	80	19980331	20171231	0.81***
English Coins	1.96	6.78	-4.23	2.43	80	19980331	20171231	0.90***
Diamonds	0.41	12.70	-9.29	3.40	54	20040930	20171231	0.30**

*, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 3: Effect of Autocorrelation Adjustment on Summary Statistics

The table presents additional summary statistics for the USD collectibles returns, focusing on the impact of autocorrelation-adjustment on the geometric average, standard deviation, and cumulative return. If the return series has no statistically significant autocorrelation, there is no adjustment needed for these values so the adjusted statistic is omitted. The averages and standard deviations are annualized and all values are reported in percentage points.

	Arithmetic Average	Geometric Average	Adj. Geometric Average	Standard Deviation	Adj. Standard Deviation	Cumulative Return	Adj. Cumulative Return	Significant Lags
Annual USD (1901 - 2007)								
Blue-Chip Wine	6.78	4.12	-	23.58	-	7421	-	0
Blue-Chip British Stamps	5.69	4.58	3.82	15.61	20.06	11925	5419	1
British Art	5.74	4.18	3.49	17.24	22.05	7890	3811	1
Violins	4.80	1.17	-	27.42	-	246.5	-	0
US Coins	11.73	10.09	7.35	22.22	32.00	4581	1606	1
Blue-Chip Paintings	11.44	6.22	-	34.69	-	63870	-	0
Blue-Chip Classic Cars	13.41	10.55	-	26.77	-	1401	-	0
Specialist	5.06	3.95	-	14.92	-	6232	-	0
Public	7.10	5.20	-	19.60	-	22509	-	0
Quarterly USD (Q1 1998 - Q3 2018)								
Global Art	0.89	-1.37	-	21.55	-	-24.72	-	0
Global Paintings	0.72	0.45	0.11	7.36	11.14	9.70	2.22	1
Global Prints	1.16	0.86	0.47	7.72	11.87	19.50	10.16	1
Global Sculptures	0.72	0.32	-0.05	8.89	12.50	6.89	-1.13	1
Global Photographs	1.02	0.01	-0.81	14.30	19.29	0.27	-15.51	1
Global Drawings	2.69	1.74	0.79	13.82	19.70	43.33	17.71	1
Global Old Masters Art	-1.67	-2.59	-	13.62	-	-41.64	-	0
Global 19th C. Art	-1.95	-2.43	-2.91	9.87	13.95	-39.75	-45.46	1
Global Modern Art	0.28	0.01	-0.30	7.25	10.78	0.27	-5.98	1
Global Post-War Art	2.91	2.46	2.03	9.67	13.45	66.25	52.11	1
Global Contemporary Art	2.79	1.73	0.96	14.66	19.31	43.20	22.06	1
US Art	1.97	1.65	1.29	8.12	11.77	40.60	30.75	1
Liquid Wine	6.82	4.11	-	22.87	-	126.8	-	0
Average Artist Paintings	9.56	9.33	8.88	7.06	11.91	546.9	492.2	2
Popular Artist Paintings	7.25	6.69	5.12	10.77	21.00	283.1	179.0	2
Popular Euro-American Sculptures	4.90	4.87	4.80	2.51	4.60	166.4	162.6	3
Jewelry	3.99	3.91	3.61	4.04	8.83	117.6	105.0	3
Global Stamps	2.50	2.40	1.99	4.47	10.17	61.28	48.70	3
English 18th C. Furniture	-3.19	-3.30	-3.80	4.56	11.08	-48.43	-53.43	4
Classic Cars	6.92	6.81	6.30	4.90	11.33	285.7	249.3	3
Euro-Eastern Rugs/Carpets	-2.57	-2.86	-3.88	7.64	16.25	-43.67	-54.13	3
English Coins	7.83	7.72	7.15	4.86	11.88	361.3	312.6	4
Diamonds	1.63	1.41	-	6.81	-	20.90	-	0
Specialist	5.48	5.25	5.06	6.73	9.31	184.0	173.3	1
Public	2.82	2.72	2.50	4.63	8.16	75.37	67.58	2
Private	-2.95	-3.08	-3.66	5.14	11.95	-46.10	-52.04	4

Table 4: Convenience Yield Estimates: USD Results

This table presents the collectibles convenience yield estimates from the best performing factor mimicking portfolios. We assess mimicking performance with three criteria: (1) the maximum absolute loading (ie: evidence we're using appropriate factors); (2) MAD/$\overline{|\beta|}$ (ie: evidence that the FMP reasonably captures the factor loadings); and (3) the FMP's reduction in residual volatility (ie: evidence we're eliminating uncompensated risk). The 6 considered specifications all use PLS to estimate the factor loadings and entail all combinations of sets of factors (5 or 10 stock-only PCs or stock & bond PCs) with sets of basis assets (stocks & bonds or stocks only).The Specialist, Public, and Private average convenience yield series are constructed ex-post as the equal-weighted average of the underlying collectibles' convenience yield time series, so there is no information provided beyond the average and autocorrelation-adjusted standard error.

	Conv Yield (%)	Adj. SE	Res Vol Reduct (pps)	$\max\lvert\beta_{test}\rvert$	$\frac{\text{MAD}}{\max\lvert\beta_{test}\rvert}$	$\frac{\text{MAD}}{\overline{\lvert\beta\rvert}}$	Spec
				Annual USD (1901-2007)			
Blue-Chip Wine	0.86	2.08	17.44	3.93	0.00	0.01	5 BS PC, BS Bas
Blue-Chip British Stamps	1.82	1.69	10.43	2.72	0.04	0.11	5 BS PC, BS Bas
British Art	2.01	1.55	9.41	5.06	0.02	0.08	5 S PC, BS Bas
Violins	2.26	2.65	24.33	1.87	0.14	0.27	5 S PC, BS Bas
US Coins	-0.02	4.94	16.06	3.88	0.15	0.18	5 S PC, S Bas
Blue-Chip Paintings	-4.44	3.33	29.95	3.02	0.02	0.05	5 S PC, BS Bas
Blue-Chip Classic Cars	-2.96	4.89	23.92	2.77	0.02	0.05	5 S PC, BS Bas
Specialist	1.21	1.33					
Public	-1.21	1.90					
				Quarterly USD (Q1 1998 - Q3 2018)			
Global Art	4.43	2.32	20.56	0.38	0.12	0.40	5 S PC, BS Bas
Global Paintings	4.62	0.83	3.88	1.99	0.21	0.47	5 S PC, BS Bas
Global Prints	3.51	0.86	4.37	1.00	0.03	0.14	5 BS PC, BS Bas
Global Sculptures	3.34	0.92	5.26	1.12	0.05	0.21	5 S PC, BS Bas
Global Photographs	4.08	1.84	11.50	1.11	0.05	0.19	5 BS PC, BS Bas
Global Drawings	3.10	2.01	11.35	1.05	0.15	0.37	5 BS PC, BS Bas
Global Old Masters Art	8.31	1.41	12.03	0.60	0.05	0.18	5 S PC, BS Bas
Global 19th C. Art	7.38	1.28	7.14	1.01	0.06	0.24	5 S PC, BS Bas
Global Modern Art	6.27	0.84	4.64	1.76	0.18	0.44	5 S PC, BS Bas
Global Post-War Art	4.85	1.92	6.00	2.54	0.22	0.45	5 S PC, S Bas
Global Contemporary Art	2.31	1.89	12.20	1.06	0.04	0.14	5 S PC, BS Bas
US Art	3.21	0.97	4.81	0.99	0.05	0.20	5 BS PC, BS Bas
Liquid Wine	0.77	2.32	15.79	3.53	0.18	0.35	5 S PC, S Bas
Average Artist Paintings	-2.65	3.14	4.45	2.61	0.24	0.83	10 S PC, S Bas
Popular Artist Paintings	0.74	2.30	7.68	3.43	0.21	0.93	10 BS PC, BS Bas
Popular Euro-American Sculptures	0.17	0.64	1.91	0.20	0.43	1.40	10 BS PC, BS Bas
Jewelry	-0.29	0.86	2.63	0.54	0.17	0.40	5 S PC, BS Bas
Global Stamps	2.75	0.98	3.03	0.62	0.06	0.24	5 S PC, BS Bas
English 18th C. Furniture	12.59	1.14	1.51	0.70	0.17	0.33	5 BS PC, BS Bas
Classic Cars	-2.25	1.25	1.93	1.36	0.33	0.87	10 BS PC, BS Bas
Euro-Eastern Rugs/Carpets	6.50	1.67	6.46	0.44	0.06	0.17	5 S PC, BS Bas
English Coins	0.52	1.10	1.62	1.13	0.16	0.34	5 BS PC, BS Bas
Diamonds	5.29	0.88	6.07	0.25	0.06	0.24	5 S PC, BS Bas
Specialist	0.45	0.88					
Public	2.28	0.78					
Private	9.55	1.21					

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