

Volatility Exchange-Traded Notes: Curse or Cure?

ABSTRACT

This is the first comprehensive study of VIX futures ETNs. Our empirical research into their statistical characteristics motivates the development of a sub-class of these notes based on static and dynamic differential roll-yield trades. Results show that such notes provide very attractive risk and return characteristics, plus a new source of diversification for non-speculative investors. Moreover, scenario analysis demonstrates that banks may control ETN issues so that profits are virtually guaranteed net of hedging costs. However, there is a dark side of ETNs currently in issue, which stems from a few sub-optimal terms and conditions concerning early redemption values. These conditions underpin the speculative front-running of hedging activity of these products.

JEL classification: G11; G15; G21

Keywords: VIX futures; ETN; hedging; roll yield

1. Introduction

Futures contracts on the Standard and Poor's (S&P) 500 volatility index (VIX) began trading on the Chicago Board Options Exchange (CBOE) futures exchange (CFE) in March 2004. Because the VIX index is not tradable there is no unique closed-form, arbitrage free, cost-of-carry relationship connecting the VIX index with the price of a VIX futures. In fact, there is often a sizeable difference between the index and its futures price.¹ Still, the futures price represents the risk-neutral expectation of VIX at maturity, and as such VIX futures offer a volatility exposure that is very highly correlated with the VIX index and with the rates for over-the-counter (OTC) S&P 500 variance swaps brokered by investment banks. Moreover, unlike variance swaps, the futures have no credit risk. Hence, the investment side of a commercial bank no longer needs to rely solely on OTC trades to gain exposure to volatility.

Sophisticated market players now trade VIX futures for speculation, directional exposure, arbitrage, diversification and vega hedging. And now any type of investor – e.g., a pension fund or an individual – has easy access to volatility trades on the New York stock exchange (NYSE) through the exchange-traded notes (ETNs) that track constant-maturity VIX futures. The first two ETNs were issued in January 2009 but the majority were issued in November 2010 or September 2011. Now there are about 30 of them, with a market cap of about \$3 billion, and trading volume on some of these products can reach \$5 billion per day. Volatility exchanges and issuers of ETNs alike are marketing these products to non-speculative investors as innovative and highly effective instruments for diversification. See CBOE (2009) and Jhunjhunwala (2010) for instance. They are particularly welcome now that traditional asset classes have become more highly correlated. Yet securities regulators should be concerned that many non-speculative participants in volatility markets lack sufficient understanding of the risks they are taking.

Speculative trading on volatility ETNs is another issue which clearly should concern both securities and banking regulators. For instance, following many adverse press reports about TVIX – a relatively recent innovation in the volatility ETN market and an instrument specifically designed for speculating on volatility – Bloomberg reported that the U.S. Securities and Exchange Commission (SEC) investigators will review the product.² Of course, regulatory policy should consider the whole spectrum of volatility-related traded products. The study by Sussman and Morgan (2012) explains how the sophisticated tools available today can enhance the efficiency of risk management within large institutions with clear benefits for both market players and regulators.

During most market regimes the term structure of VIX futures is in contango. For instance, volatility is at a relatively low level at the time of writing but the fears held by investors that it will soon increase have induced a particularly strong contango. During this low point of the volatility cycle the returns on VIX futures and their ETNs are heavily eroded by the roll cost, which is particularly high at the short end of the term structure. Indeed, the ETNs that track short-term

¹Another (minor) difference is that VIX futures are settled on the special opening quotation price, which is based on traded prices of S&P 500 options fed in the VIX formula, whereas the VIX itself is based on the options mid price.

²See: “SEC Said to Review Credit Suisse VIX Note”. Bloomberg, March 29, 2012.

constant-maturity VIX futures offer a zero return in the long run. Volatility ETNs also have some adverse features not shared by futures, e.g.: they retain the credit risk of the issuer, which has been relatively high since the banking crisis; a small investor may be trapped into an illiquid investment because the issuer will only redeem the shares early in large lots, and; many ETNs have a callable feature whereby the issuer can retrieve the shares in issue at short notice.

The terms and conditions for early redemption initiated by the investor present problems for both ETN issuers and regulators. ETN issuers can hedge their exposure to early redemption perfectly only when they trade VIX futures at the daily closing price. Given this price, we explain how issuers could guarantee profits, net of hedging costs, by issuing a controlled portfolio of ETNs. However, the recent large-scale front-running of issuers' hedging activity has made such profits difficult to secure. In February 2012, Credit Suisse stopped the issue of TVIX (sending its traded price to a 90% premium over indicative value at one point, such is the speculative demand on this product) and re-opened it only on the condition that the hedging risk be passed on to the market makers. Still, such large positions must be taken on VIX futures for hedging certain ETNs that the ETN market now leads the VIX futures that they are supposed to track, and this is just one of several concerns stated by investors.³

Our paper provides the first detailed academic investigation of the volatility ETN market. We ask whether these products can indeed provide a much-needed source of diversification for non-speculative investors. In fact they can, but not in the way that they are marketed by issuers and exchanges. We also take a close look at the dark side of volatility ETNs, addressing the question of front-running posed above. We also recommend that ETNs have their terms and conditions for early redemption changed, so that large scale front-running is no longer precipitated.

We proceed as follows: Section 2 provides a concise taxonomy of VIX futures ETNs and summarizes their early redemption features; Section 3 constructs indices for the S&P investable, constant-maturity VIX futures which determine the indicative value of VIX futures ETNs over an eight-year period starting in March 2004. Then we explain the roll cost and convexity effects that drive the returns on VIX futures ETNs; Section 4 analyses the implications of a correlation analysis on the S&P indices for constructing ETN portfolios that trade on differential roll costs along the term structure of VIX futures. We assess the performance of the most popular ETNs, and that of certain ETN portfolios which should be attractive to long-term investors; Section 5 explains how the issuers of ETNs can structure their issue to make virtually guaranteed profits provided the hedge on VIX futures is transacted at the closing price on the CFE; Section 6 addresses various concerns that volatility ETNs may precipitate for regulators; Section 7 concludes and summarizes our recommendations for investors, issuers and regulators.

³See Reuters, February 23, 2012: "Analysis: Out of control? Volatility ETN triggers risk concerns."

2. Market Description

2.1. A Brief Taxonomy of VIX Futures ETNs

Barclays Bank PLC issued VXX and VXZ, their 1-month and 5-month constant-maturity VIX futures trackers in January 2009. Their performance is directly linked to that of the S&P 500 VIX Short-Term Futures Index and the S&P 500 VIX Mid-Term Futures Index respectively.⁴ More brokers, notably ETRACS of UBS AG and VelocityShares of Credit Suisse, quickly followed suit with other index tracker ETNs, $2 \times$ leveraged products and inverse exposures to the S&P VIX futures indices. By December 2011 about 30 VIX-linked ETNs, including four ProShares volatility-based products that trade as exchange-traded funds, were trading in very high volumes on secondary markets as well as on the primary market, the NYSE Arca. About \$875 million was traded per day, on average, during the first two months of 2012 – not a particularly volatile period – on just two of these ETNs (VXX, the Barclays iPath 1-month constant maturity tracker and TVIX, its supra-speculative, twice leveraged extension issued by Credit Suisse in November 2010).

Table 1 gives details of the ETNs issued by Barclays (in red), Credit Suisse (in blue) and UBS (in black). The first two columns state the maturity of the respective indicative S&P index,⁵ and the maturity of the notes. The third column gives the leverage, i.e. 1 for a direct tracker, -1 for an inverse tracker, and 2 for a direct leveraged tracker. Then follows: the annual fee, higher for the inverse products because the issuer charges a significant fee for hedging costs; the market cap of each note on February 29, 2012 and the average volume traded on each note between January 2 and February 29, 2012.

At the time of writing the market cap on VXX is still almost double that of TVIX. Together their cap is currently 64% of the total cap of all ETNs. Having been issued later, the UBS products have the lowest market cap (5% of the total) and the Barclays products constitute 56% of the total market cap. The average daily trading volume during the first two months of 2012 was 44.59 million shares over all ETNs, with 36.81 million shares traded on VXX and TVIX alone (amounting to about \$875 million dollars per day) and 23.87 million shares traded on average, per day, on just the Barclays products. On August 8, 2011 a total of \$4,973,659,365 was traded on the VXX on the NYSE Arca alone. Clearly, Barclays still dominates the market although shares on the TVIX and XIV products of Credit Suisse are being traded in increasingly high volumes.

2.2. Early Redemption Features

VIX futures exchange-traded notes are products with fixed maturity. However, they do not guarantee any return of principal at maturity nor do they pay any interest during their term. The investor may liquidate his investment in the secondary market during trading hours or otherwise he expects to receive a cash payment equal to the indicative value of the note in any of the four following situations: (a) at maturity, (b) in case of an automatic termination, (c) due to early

⁴See Standard & Poor's (2011b) for details of the methodology underpinning their calculation.

⁵And for the two ETN², XVIX and XVZ, which attempt to exploit differential roll yields, the maturities of the two indices they allocate between.

Table 1
ETN taxonomy.

Ticker ^{*§}	Inception	Maturity		Leverage [†]	Service fee [‡]	Market Cap. (million \$) [*]	Average Volume [*]
		VIX futures (m)	Note (y)				
VXX ^{a,b}	Jan-2009	1	10	1	0.89%	1,218.36	23,499,211
VXZ ^a	Jan-2009	5	10	1	0.89%	233.26	329,478
VIIX ^a	Nov-2010	1	20	1	0.89%	15.82	32,605
VIIZ	Nov-2010	5	20	1	0.89%	7.63	829
XVIX	Nov-2010	1 vs. 5	30	1	0.85%	23.04	7,539
XVZ	Aug-2011	1 vs. 5	10	1	0.95%	187.33	25,816
VXAA	Sep-2011	1	30	1	0.85%	5.94	1,210
VXBB	Sep-2011	2	30	1	0.85%	7.19	370
VXCC	Sep-2011	3	30	1	0.85%	8.14	660
VXDD	Sep-2011	4	30	1	0.85%	8.37	192
VXEE	Sep-2011	5	30	1	0.85%	8.58	371
VXFF	Sep-2011	6	30	1	0.85%	9.20	182
XXV	Jul-2010	1	10	-1	0.89%	15.66	13,586
XIV ^b	Nov-2010	1	20	-1	1.35%	427.55	7,321,582
ZIV ^b	Nov-2010	5	20	-1	1.35%	9.09	15,229
AAVX	Sep-2011	1	30	-1	5.35%	11.79	3,484
BBVX	Sep-2011	2	30	-1	5.35%	11.43	1,623
CCVX	Sep-2011	3	30	-1	5.35%	10.82	765
DDVX	Sep-2011	4	30	-1	5.35%	10.96	132
EEVX	Sep-2011	5	30	-1	5.35%	10.50	891
FFVX	Sep-2011	6	30	-1	5.35%	10.59	100
IVOP	Sep-2011	1	10	-1	0.89%	6.95	4,602
VZZB	Nov-2010	5	10	2	1.78% ^c	2.79	12,049
TVIX	Nov-2010	1	20	2	1.65%	676.04	13,315,361
TVIZ	Nov-2010	5	20	2	1.65%	7.32	4,464

* We colour ETNs according to their issuer: Barclays Bank PLC (red), Credit Suisse AG (blue) and UBS AG (black).

§ Except VXX, VXZ and XVZ, all other products have automatic termination clauses and all products except Barclays' are callable at any time by the issuer.

† For products with leverage other than 1, actual leverage depends on day and time of transaction.

‡ All ETNs carry an extra redemption fee: 0.05% (red and blue) and 0.125% (black).

* Market cap as of February 29, 2012; average daily volume computed between January 2, 2012 and February 29, 2012.

^a Options on these ETNs are available to trade on CBOE.

^b Split executed by the issuer: 1 for 4 (VXX), 10 for 1 (XIV), 8 for 1 (ZIV).

^c The 3m LIBOR is added on top of the service fee.

Details on the different ETNs were retrieved from the issuers' websites and market data was downloaded from Bloomberg.

redemption caused by the call right of the issuer or (d) upon early redemption at the investor's discretion (in which case the indicative value is reduced by an early redemption charge).⁶ The indicative value represents the performance of the underlying S&P constant-maturity VIX futures index less a service fee. In contrast, funds invested in the four ProShares VIX-based ETFs are directly allocated to the relevant contracts in the VIX futures market. Thus, investors expect to receive, upon redemption, the net asset value of the fund (that reflects the market value of the underlying investment minus the fund's fees and expenses) but without assuming the credit risk of the issuer.

⁶Cases (b) and (c) are not applicable to three Barclays' VIX ETNs: VXX, VXZ and XVZ.

Below, we present the early redemption features currently imposed by the issuers of the notes, in the case of an optional redemption on behalf of the investor. They are important since upon a decision to exit a VIX ETN investment prior to maturity, an investor has two alternatives: close the position in the secondary market at the prevailing market price, given the current liquidity constraints; or redeem the notes by directly contacting the issuer of the note.

There are two conditions that issuers of VIX ETNs require to be met: (i) the investor needs to redeem at least a certain minimum number of ETN shares; and (ii) the investor needs to deliver a notice of redemption prior to a specific time on the day prior to which the actual redemption of ETN shares will take place. More specifically, condition (i) requires the ETN holder to redeem at least 25,000 shares of a particular ETN. This applies to all but four products, for which a minimum of 50,000 shares is necessary: XXV, VXZ and IVOP (on behalf of Barclays), and XVIX (on behalf of UBS). For condition (ii), the investor needs to notify Barclays or Credit Suisse (UBS) of his desire to redeem early, no later than 4:00 pm (12:00 noon) New York City time immediately preceding the day of redemption. Given that condition (i) is met, if the investor receives confirmation of redemption by 5:00 pm, then the ETNs will be redeemed on the indicative value of the next trading day (less the early redemption charge). The implications of these two conditions are important for both the issuers hedging activity and the regulators of the VIX-based ETN market. We thoroughly discuss those in Sections 5 and 6 respectively.

Since ETN shares can be issued by the bank and redeemed by the investors (at a small cost) on any trading day, the number of shares outstanding varies considerably over time. Therefore, during market turmoil periods, such as during the Greek crisis in May 2010, and again during the August 2011 Eurozone crisis when the VXX ETN price jumped upward after a long period of decline, investors redeem their ETN shares. Contrary, during relatively less volatile periods investors build up positions in the VXX and thus the number of shares outstanding for the ETN rises.

3. Indicative Values, Roll Cost and Convexity

For the period March 26, 2004 to March 31, 2012 we obtained Bloomberg data on the daily close (last traded price or index value) for: (i) all VIX futures contracts; (ii) VIX and VXV, i.e. the 30-day and 93-day implied volatility indices calculated by CBOE; (iii) the S&P constant-maturity VIX futures indices; (iv) the two most well-established volatility ETNs, i.e. the VXX and VXZ, Barclays' 1-month and 5-month constant-maturity VIX futures trackers; (v) XVIX and XVZ, the two recently-launched ETNs that trade on a differential roll yield.⁷ From these data we construct two sets of synthetic constant-maturity time series, each set representing maturities of $m = 30, 60, \dots, 180$ days. The first set is a non-investable futures price time series which illustrates the general level of VIX futures, and the contango and backwardation features of their term structure. The second set of time series is the S&P indices of investable VIX futures returns.

⁷(i) are only available from the inception of VIX futures on March 26, 2004; (iii) start only in December 2005 and prior to this we construct the indices by applying the S&P methodology to traded VIX futures; (iv) are available only since their launch in January 2009, but we replicate their indicative values using actual and reconstructed S&P indices; (v) have very few traded prices, starting only in November 2010 and August 2011 respectively, but again we replicate their indicative values as for (iv).

3.1. Constant-Maturity Prices

The constant-maturity futures price on day t is derived as:

$$p_t^m = \alpha_t p_t^s + (1 - \alpha_t) p_t^l, \quad \alpha_t = \frac{l - m}{l - s} \tag{1}$$

where p^m is the synthetic futures price for a specific maturity m , p^s and p^l are the prices of the shorter and longer maturity exchange-traded futures contracts that straddle the maturity m , with $s < m < l$, and each maturity is measured in calendar days to expiry.

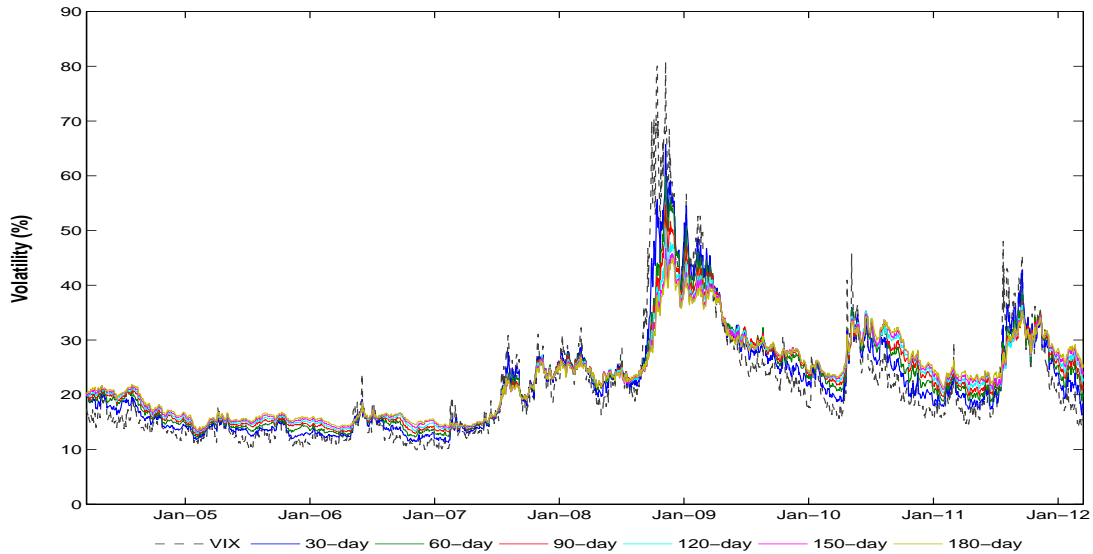


Fig. 1 Term structure evolution of the six constant-maturity VIX futures series, and the VIX 30-day implied volatility index. March 2004 – March 2012.

These price series, displayed in Fig. 1, provide a visualization of the futures term structure based on market traded prices but returns based on these synthetic prices are not realizable. Fig. 1 shows that volatility has not returned to its previous stable behaviour since the great financial crisis started in mid 2007. In September 2008, precipitated by the Lehman Brothers collapse, VIX futures were trading at around 50% and volatility was especially high during the Greek crisis of May 2010 and the wider Eurozone debt crisis beginning in August 2011. Another feature that is evident from Fig. 1 is that the term structure is typically in contango, with brief periods of backwardation only during excessively volatile periods.⁸

Fig. 2 depicts how the typical shift and slope of the VIX futures term structure varies according to whether the market is in contango or backwardation. In March 2012 the term structure exhibited contango, slightly steeper at the short-end than at the longer maturities, and weekly shifts in the term-structure are relatively small. By contrast, during November 2008 the market was in distinct

⁸For our later analysis (in section 4) it is interesting to note that, over the entire sample, the 30-day futures price was greater than (less than) the 150-day futures price about 25% (75%) of the time.

backwardation where the negative slope of the term structure is very much steeper at the short-end and the shifts are of greater magnitude. For instance, the term structure shifted upward by 17 volatility points at the short-end during a single week, and then returned almost to the previous level by the end of the next week.

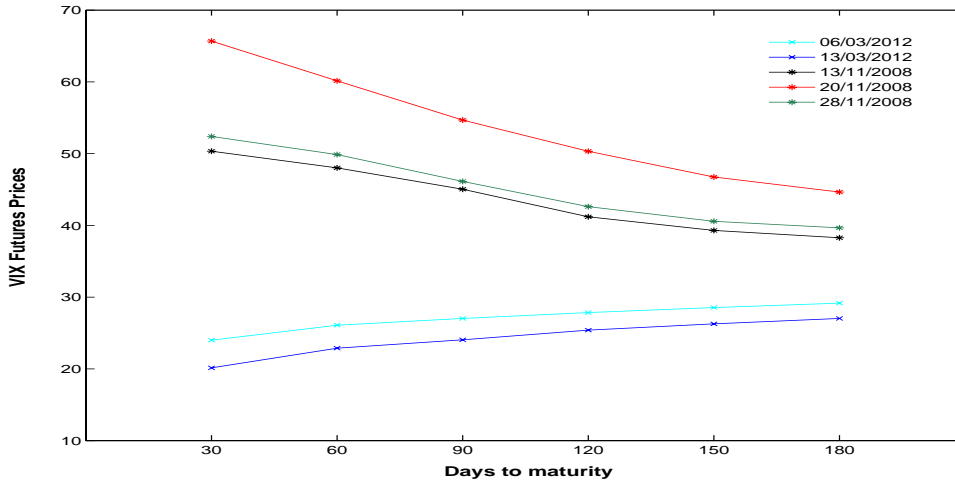


Fig. 2 Term structure of VIX futures while in contango (2012) and backwardation (2008).

3.2. Investable Returns and the S&P Indices

The indicative values of VIX futures ETNs are based on the S&P indices of investable constant-maturity VIX futures derived from their daily closing prices. As explained by Galai (1979), an investable discretely compounded return on VIX futures may be obtained via linear interpolation between the returns on the two futures with maturity dates either side of the constant maturity. To construct such a series we set

$$r_{t+1}^m = \beta_t r_{t+1}^s + (1 - \beta_t) r_{t+1}^l, \quad \beta_t = \alpha_t p_t^s / p_t^m, \quad r_{t+1}^i = \frac{p_{t+1}^i - p_t^i}{p_t^i}, \quad (2)$$

where r_{t+1}^i are the individual discretely-compounded returns on the tradable futures contracts with maturities $i = s$ (short) and $i = l$ (long).⁹ The ETN issuer can replicate the product using the exchange-listed VIX futures because at any point in time there is a unique interpolation constant β_t for each index return, which is used via Eq. (2) to distribute into weights on traded VIX futures.¹⁰

Fig. 3 depicts the theoretical value of \$100 invested in each of the S&P indices on March 26, 2004. To attain the constant-maturity index return one must rebalance the portfolio of the two straddling VIX futures daily. Since the VIX futures term structure is typically in contango, at

⁹Whenever there are not two contracts that straddle the desired maturity, linear extrapolation rather than linear interpolation is performed using the two closest contracts to that maturity. In that case a short position in one of the two contracts used in the calculation is necessary.

¹⁰Note that returns on VIX futures, as for any other futures contract, directly represent an excess over the current risk-free rate return – see Bodie and Rosansky (1980) and Fortenbery and Hauser (1990) for further explanation.

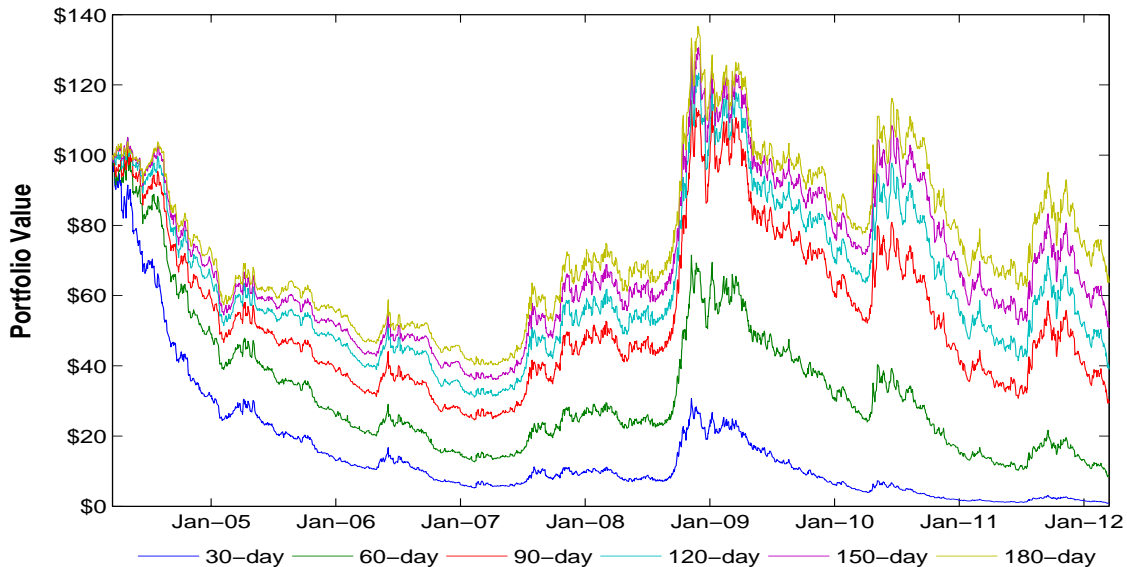


Fig. 3 Evolution of the value of \$100 invested in the VIX futures with constant-maturity returns net of costs, constructed using Eq. (2), on March 26, 2004. These represent the S&P indices of maturity T , with $T = 30, 60, \dots, 180$ days.

each rebalancing there is a small but almost always positive roll cost created by selling the lower price shorter-term futures and buying the higher price longer-term futures. This small daily roll cost is greater for short-term tracker ETNs than for long-term trackers, because of the convexity in the VIX futures term structure. That is, the size of the roll cost depends on the slope of the term structure, which is steepest at the short end. This is the main reason why the 1-month tracker VXX has performed so much worse than the 5-month tracker VXZ. For instance, \$100 invested in the VXZ on January 29, 2010 was worth a little over \$60 by December 30, 2011, but the same invested in VXX was worth less than \$9. The issuers now make it very clear on the prospectus that the long-term value of their short-term tracker ETNs is zero, and Barclays even quotes recommended holding periods: e.g. less than a week for VXX and up to a month for VXZ.¹¹

Panel A of Table 2 reports summary statistics on the six S&P index returns computed using Eq. (2) with maturities, 30, 60, \dots , 180 calendar days.¹² The returns on the longer maturities represent longer-term expectations of volatility and are consequently less variable over time, consistent with the Samuelson effect (Samuelson, 1965). However, the decrease in volatility as we move along the term structure of VIX futures is much more pronounced than it is in most other financial and commodity futures. Also, due to their differential roll costs, the negative returns at the short end of the term structure are of greater magnitude than those at the long end. Panel B presents the correlation matrix of these returns over the entire sample.

¹¹See www.ipathetn.com/static/pdf/volatility_etns.pdf.

¹²We present figures for excess kurtosis, not kurtosis, here and throughout the paper.

Table 2

Descriptive statistics for S&P indices of investable, constant-maturity VIX futures.

<i>Panel A: Summary statistics</i>						
Contract	Annualized Mean	Volatility	Sharpe Ratio	Skewness	Kurtosis	Total Return
30-day	-42.49%	56.69%	-0.7495	1.05	4.82	-99.10%
60-day	-21.03%	43.47%	-0.4837	0.74	3.94	-91.40%
90-day	-8.60%	36.40%	-0.2364	0.74	4.11	-70.60%
120-day	-6.42%	32.47%	-0.1977	0.70	4.31	-60.96%
150-day	-3.95%	30.01%	-0.1315	0.70	4.48	-49.31%
180-day	-1.68%	28.10%	-0.0599	0.71	4.74	-36.36%
<i>Panel B: Correlations</i>						
	30-day	60-day	90-day	120-day	150-day	180-day
30-day	1.00					
60-day	0.95	1.00				
90-day	0.93	0.96	1.00			
120-day	0.91	0.94	0.98	1.00		
150-day	0.89	0.92	0.96	0.99	1.00	
180-day	0.87	0.90	0.94	0.96	0.99	1.00

Panel A reports sample means, standard deviations annualized based on 250 trading days per year, corresponding Sharpe ratios, skewness, excess kurtosis and total return from March 26, 2004 and March 31, 2012. Panel B is the correlation matrix for the returns under consideration. All figures are significant at the 1% level.

3.3. Roll Cost and Convexity Effects

The discretely-compounded daily return derived from the price index p_t^m is not realisable, and the difference between this and r_t^m is called the roll yield of maturity m . Its negative, the roll cost c_t^m captures the cost of rolling a futures position from a shorter maturity contract to one of a longer maturity on day t . A little algebra gives:¹³

$$c_{t+1}^m = r_{t+1}^m - [(p_{t+1}^m - p_t^m)/p_t^m] = \frac{p_{t+1}^s - p_{t+1}^l}{p_t^m} (\alpha_{t+1} - \alpha_t). \quad (3)$$

Note that $\alpha_t > \alpha_{t+1}$ unless a new contract is rolled into and the longer maturity contract becomes the shorter maturity one. For instance, when rebalancing inter-week rather than over a weekend, $\alpha_t - \alpha_{t+1} = (l - s)^{-1}$.¹⁴ When the market is in contango, $p_t^l > p_t^s$ so the roll cost (3) is positive. The roll cost is only negative (i.e. roll yield positive) when the term structure is in backwardation. The VIX futures term structure is very often in contango, as we have seen from Fig. 1, so a consistently negative roll yield has substantially eroded the returns realised on all the standard tracker ETNs products since their launch, as we have seen in Fig. 3.

Convexity of the term structure induces a different sensitivity of ETNs returns during periods of contango and backwardation. To see this, note that the short end of the VIX futures term structure is much more volatile, i.e. r_t^s is usually of much greater magnitude than r_t^l . The sensitivity of r_t^m to r_t^s and r_t^l depends on whether term structure is in backwardation or contango. For instance, set $\alpha_t = 0.5$, so that $\beta_t = (2p_t^m)^{-1}p_t^s$ and $1 - \beta_t = (2p_t^m)^{-1}p_t^l$. In contango, $\beta_t < 1 - \beta_t$ and the constant-maturity return r_{t+1}^m given by (2) has a relatively low sensitivity to r_{t+1}^s . But in backwardation,

¹³The S&P uses another definition but without apparent justification, e.g. Standard & Poor's (2011a).

¹⁴The value of $l - s$ depends on the distance between the two contracts used in the constant-maturity calculation, which is most often either 28 or 35 days.

where returns typically have much greater magnitude (cf. Fig. 2) we have $\beta_t > 1 - \beta_t$ so r_{t+1}^m has a higher sensitivity to r_{t+1}^s . This convexity effect means that, as the market swings from contango into steep backwardation at the beginning of a crisis, very rapid gains are made on the synthetic short-term VIX futures; but thereafter equally rapid losses are made, as the backwardation declines and the term structure returns to contango.

The convexity effect induces a heightened sensitivity to the short-term return during a period of strong backwardation. Thus, as the market swings from contango to backwardation the direct tracker indices jump up. For instance, during the two months following the collapse of Lehman Brothers on September 17, 2008 the direct 30-day index (VXX) rose by more than 200% and the 150-day index (VXZ) rose by 73% – and the TVIX indicative value rose by 670%! Then, as the market swung back to contango, the direct indices lost the value they gained. And, as is evident from Fig. 3, the higher the gain the greater and more rapid the subsequent losses. The convexity effect is positive for purchasers of direct tracker ETNs, but leads to large negative drawdowns for holders of the inverse tracker products. For instance, the inverse 30-day index (XIV) lost about 50% of its value during the first few days of the Eurozone crisis in August 2011.

4. Roll-Yield Arbitrage Exchange-Traded Notes

The movements of the S&P indices may also be decomposed into changes arising from: (a) the roll cost c_t^m , representing a slide along the VIX term structure from a maturity of i days to maturity of $i - 1$ days,¹⁵ for each contract $i = s, l$ straddling the maturity m ; and (b) a movement of the entire VIX futures term structure from day $t - 1$ to day t . The roll cost is relatively small and highly predictable, compared with the large and unpredictable movements of type (b). A roll-yield ‘arbitrage’ seeks trades that are immunized against movements of type (b) so that their main exposure is purely to the roll cost.¹⁶

4.1. Correlation Analysis

The S&P index returns form a very highly correlated system, as is evident from the correlation matrix displayed in Panel B of Table 2. Hence, their returns are an ideal input to principal component analysis (PCA), a statistical methodology which identifies the key factors that drive a highly correlated system. A PCA on the S&P index returns allows greater insight to the historical movements of the VIX futures term structure.

To fix ideas, consider a given set of $T \times n$ return series \mathbf{X} with correlation matrix \mathbf{C} . Then the principal components of \mathbf{C} are the columns of the $T \times n$ matrix \mathbf{P} such that $\mathbf{P} = \mathbf{X}\mathbf{W}$, where \mathbf{W} is the $n \times n$ orthogonal matrix of eigenvectors of \mathbf{C} . Principal components are, by construction, mutually uncorrelated because \mathbf{W} is an orthogonal matrix. The total variation in system \mathbf{X} is the sum of the eigenvalues of \mathbf{C} , and we label these eigenvalues λ_i with $\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_n > 0$. The

¹⁵Or subtract more than 1 day over a weekend, when using business rather than calendar day counts. And here ‘typical’ excludes the effect when moving to a new pair of contracts.

¹⁶We use the term ‘arbitrage’ here because it has slipped into market usage. But, as mentioned in the introduction, it is not really an arbitrage because it is not riskless.

m th component is determined by the eigenvector belonging to the m^{th} largest eigenvalue, so that the proportion of total variation explained by the m^{th} principal component is $\lambda_m/(\lambda_1 + \dots + \lambda_n)$. This way we identify how many key factors explain most of the total risk in the system.

Table 3

Principal components analysis on the correlation matrix of VIX futures constant maturity returns.

Contract	PC1	PC2	PC3	PC4	PC5	PC6
<i>Panel A: Proportion of variation explained</i>						
	95.00%	3.23%	0.91%	0.61%	0.21%	0.04%
<i>Panel B: Eigenvectors</i>						
30-day	0.3981	-0.6099	-0.6264	-0.2768	0.0197	0.0102
60-day	0.4058	-0.4360	0.3848	0.6544	-0.2622	-0.0127
90-day	0.4141	-0.0617	0.4737	-0.2928	0.7123	-0.0852
120-day	0.4138	0.2113	0.2551	-0.4683	-0.5282	0.4698
150-day	0.4121	0.3865	-0.1170	-0.0397	-0.2379	-0.7803
180-day	0.4053	0.4899	-0.3953	0.4343	0.2965	0.4036

Panel A reports the proportion of total risk explained by each factor driving the term structure of the S&P index returns, based on the sample from March 2004 to March 2012. Panel B reports the eigenvectors (i.e. factor weights for the principal component representation) for each return series.

Table 3 reports the PCA of the correlation matrix of S&P index returns, estimated over the entire sample. Panel A presents the proportion of total variation in the system explained by each component. The first component alone explains 95% of the movements in the system and with three factors representing the system we are able to explain about 99% of the total variation. Panel B of Table 3 reports the eigenvectors, i.e. the factor weights for each S&P index return series. Reading across the first row in panel B and using only three components, we have with over 99% accuracy, the following representation of the standardized returns \tilde{r}_t^{30} on 30-day S&P index:

$$\tilde{r}_t^{30} \approx 0.3981PC_{1,t} - 0.6099PC_{2,t} - 0.6264PC_{3,t},$$

where \tilde{r}_t^{30} denotes the 30-day index return at time t minus its sample mean divided by its sample standard deviation. Similar three-factor representations for futures of other maturities show that the first component captures an almost exact parallel shift in the term structure, in that if PC₁ moves up by 1% and the other components remain fixed, then all standardized futures shift upwards by about 0.4%. The first eigenvalue tells us that 95% of the movements in standardized VIX futures over the sample consist of parallel shifts of the whole term structure. The second component represents an almost exact linear tilt in the standardized term structure, with shorter maturities increasing whilst longer maturities decrease. Only 3.23% of the variation in the standardized VIX futures term structure can be attributed to tilting of the term structure.

4.2. Constructing the Roll-Yield Arbitrage ETNs

Our PCA analysis has implications for constructing ETN portfolios that specifically trade on differential roll costs along the term structure. We know that 95% of the observed moves in standardized returns have been parallel shifts of the entire term structure. Hence, long-short trades in standardized returns of different maturities should hedge about 95% of the large and

unpredictable daily movements of the term structure. That is, the amount gained (lost) through the movement at the short end of the term structure would be almost exactly offset by an equal and opposite loss (gain) at the long end of the term structure. A long-short ETN portfolio with positions weighted by the inverse of their respective volatilities will capture this offsetting effect. For instance, since the 30-day futures have an average volatility approximately twice that of the 150-day futures (cf. Table 2) a short position on 30-day VIX futures (long position on XIV) offset by a long position of twice the size on 150-day futures (VXZ, VIIZ or VXEE) should immunize against 95% the risk arising from movements of type (b).

This type of reasoning may well have been used by UBS to derive the XVIX, a roll-yield arbitrage ETN having a static allocation to the inverse 30-day VIX futures tracker and twice this allocation to the direct 150-day VIX futures tracker. Based on our PCA analysis it is evident that this relationship hedges about 95% of the term structure movements so that it earns the differential roll yield across the two maturities, which is typically positive because the market is in contango.

Barclays launched a dynamic VIX ETN (XVZ) in August 2011 which seeks to take advantage of positive and negative roll yields when the VIX futures term structure is in backwardation and contango. The XVZ is a relatively complex dynamic strategy that attempts to allocate between VXX and VXZ to gain full advantage of the roll-yield differences along the VIX futures term structure, by switching the positions in the short-term and long-term end of the term structure depending on whether the VIX term structure is in contango or backwardation. Full details are given in Barclays Bank PLC (2011).

4.3. Performance Analysis of ETNs and Simple ETN Portfolios

We replicate the values of the XVIX and XVZ back to March 2004 using all available data on VIX futures and S&P's constant-maturity indices.¹⁷ We deduct the annual service fee (which is 0.85% and 0.95% per annum, for XVIX and XVZ respectively) so that the results correspond to the actual excess return received by the investor. We find that the XVIX performs best when the market is in contango (when the XVZ returns are low or negative) and that the XVZ performs very well indeed when the VIX futures term structure swings into steep backwardation (when the XVIX loses money). Therefore, it should be possible to enhance returns by holding a portfolio of the XVIX and XVZ. To this end we consider one static and one dynamic allocation as follows:

- The CVIX allocates 75% of capital to XVIX and 25% to XVZ. This allocation is chosen because it corresponds almost exactly to the proportion of days in our sample that the relationship between the 30-day contract and 150-day contract was in contango (75%) and backwardation (25%), as previously noted;
- The CVZ, holds XVIX when the VIX term structure is in contango (i.e. $Y_t < 1$) and XVZ when VIX term structure is in backwardation ($Y_t \geq 1$).

¹⁷XVIX and XVZ are total return products, i.e. the 91-day U.S. T-bill is added to their underlying index return. However, here we present the excess returns on the products since, assuming they can borrow money at close to the T-bill rate, it is excess returns that are of interest to large investors.

There are numerous other ways the investor might allocate between the XVIX and the XVZ – the CVIX and CVZ are just the simplest possible static and dynamic rules based on our empirical observations. As benchmarks, we shall also examine the performance of the two longest-established ETNs (VXX and VXZ), again after accounting for their annual service fee of 0.89%.

Fig. 4 shows the daily returns to the VXX and VXZ (above), the XVIX and XVZ (middle) and CVIX and CVZ (below) plus some descriptive statistics: the annualized mean daily return, the volatility, Sharpe ratio and total return computed over the entire sample period, net of fees. The two VIX futures trackers VXX and VXZ are obviously high-risk ETNs with negative mean returns. As such they are undesirable as stand-alone long-term investments and should only be used for short-term speculation.¹⁸ By contrast, the differential roll-yield trades, XVIX and XVZ, have a much better risk-adjusted performance: the XVIX has a lower risk than the XVZ, and a higher total return over the period. However, its average daily return is lower, at only 16.45% in annual terms compared with 17.45% for the XVZ. The CVIX and CVZ, are highly correlated with the XVIX and XVZ: the static products (XVIX and CVIX) have a sample correlation of 92.10% and the dynamic products (XVZ and CVZ) have a sample correlation of 91.62%. The CVIX has a total return similar to the XVIX but the CVZ performs very much better than the XVZ. In fact, since 2004 CVZ has had an average Sharpe ratio of 1.32 and a total return of 870%!

Table 4 reports a variety of performance measures for the VXX, VXZ, XVIX, CVIX, XVZ and CVZ over the entire sample period and over three sub-periods: March 26, 2004 – October 31, 2006 (a period of stable trending equity markets); November 1, 2006 – May 31, 2009 (which covers the credit and banking crises); and June 1, 2009 – March 31, 2012 (a period that includes the Eurozone debt crisis). In addition to the Sharpe ratio we report the measure introduced by Sortino and Van Der Meer (1991), which adjusts only for downside risk as measured by the square root of semi-variance introduced by Markowitz (1959). The Omega ratio introduced by Keating and Shadwick (2002) is the ratio of the expectation of the positive excess returns to the expectation of the negative excess returns. A positive Omega ratio indicates that positive returns tend to outweigh the negative returns, on average. As another measure of downside risk we calculate the maximum daily drawdown over the entire sample from March 2004 to March 2012. Finally we compute the manipulation-proof performance measure Theta derived by Goetzmann, Ingersoll, Spiegel, and Welch (2007).¹⁹

Panel A results for the tracker ETNs confirm that long-term investments in these products are unwise. The tracker ETNs only performed reasonably well during the sub-sample that included the credit and banking crises, and over this period the long-term VIX futures tracker VXZ outperformed the short-term tracker VXX according to each criterion. Both XVIX and XVZ outperform the

¹⁸Twice-leveraged direct trackers (e.g. TVIX) are clearly supra-speculative instruments: their indicative values had a volatility of over 110% and an annualized mean return less than -70%, on average over the 8-year sample.

¹⁹Manipulation of a performance measure is due to the fund manager’s actions, like window dressing or closet indexing, which increase the value of a performance measure, but add no real value to the investor. The properties of such a manipulation-proof performance measure are similar to a power utility pay-off. In particular, the measure depends on the relative risk aversion of the investor, γ . We set $\gamma = 3$, but our empirical results are qualitatively robust to the choice of this parameter.

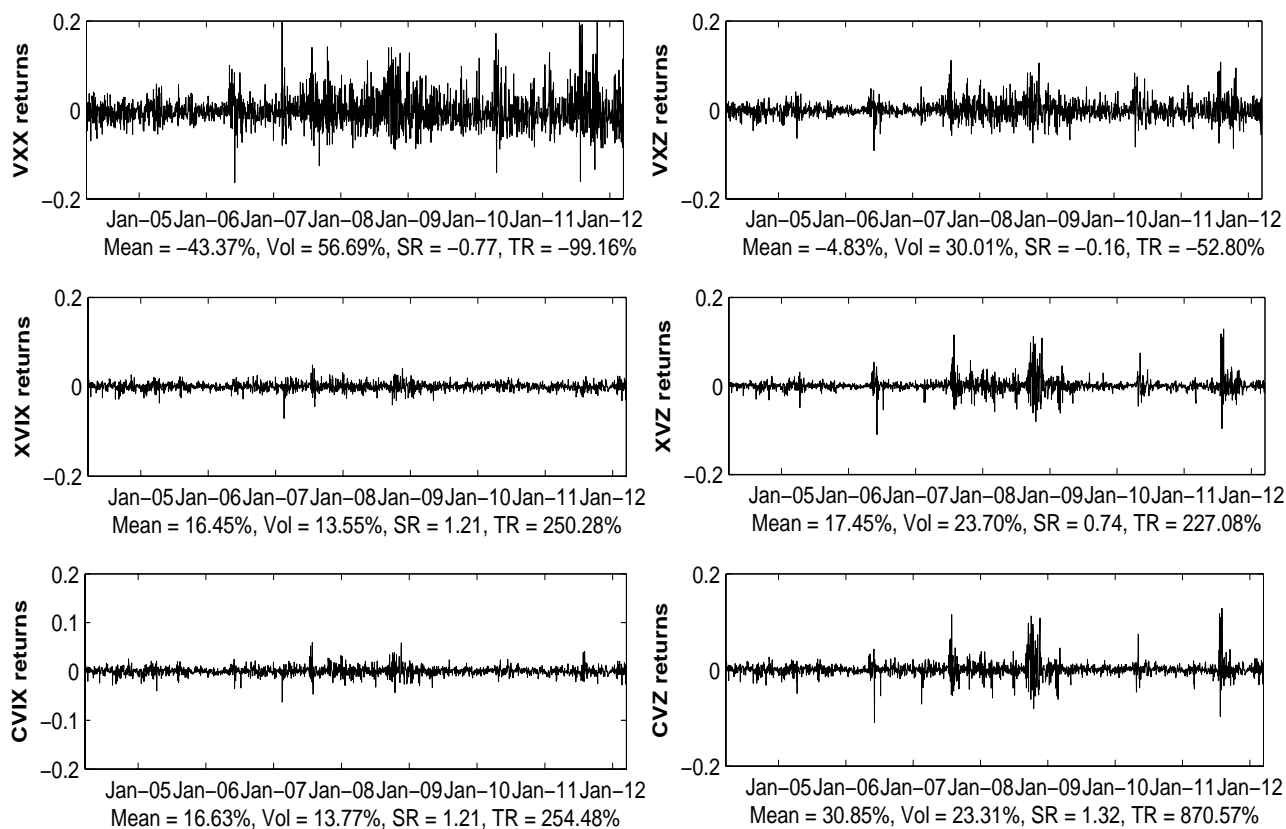


Fig. 4 Times series of daily returns on volatility ETNs (VXX, VXZ, XVIX, XVZ, CVIX and CVZ) and simple statistics: annualized mean daily return, volatility, Sharpe ratio and total return between March 26, 2004 and March 31, 2012.

tracker ETNs over the entire period, and over the first and last sub-samples in Panel B and Panel D (when the XVIX also outperforms the XVZ). This is according to each criterion, except for the large maximum daily loss observed for the XVZ. During the credit and banking crisis period (Panel C) their performance was comparable to that of the tracker ETNs, with the XVZ clearly a better investment than the XVIX. Still, the large daily drawdowns highlight that the VIX futures market can swing very quickly from contango into strong backwardation, with inverse contracts rapidly appreciating in value, especially the short-term ones. In this case the potential profits from differential roll-yield strategies can easily turn into large losses. The CVIX and CVZ have higher Sharpe ratios, Sortino ratios, Omega and Theta than any of the existing ETNs. However, the XVIX outperforms both during the first sub-sample and XVZ outperforms CVIX during the second sub-sample. CVZ experiences the same large drawdowns as the XVZ but they are still much smaller than those experienced on the VXX. According to Theta, the CVZ is the preferred amongst all the ETNs except during the first sub-sample, when the XVIX performed best. The static CVIX outperforms the dynamic CVZ only during the stable trending market of the first sub-sample.

Table 4

Performance measures for tracker ETNs, roll-yield arbitrage ETNs and simple portfolios of these.

	VXX	VXZ	XVIX	XVZ	CVIX	CVZ
<i>Panel A: Full Sample</i>						
Sharpe ratio	-0.7651	-0.1610	1.2146	0.7364	1.2079	1.3233
Sortino ratio	-1.1722	-0.2443	1.7719	1.2045	1.8145	2.1801
Omega ratio	0.8719	0.9710	1.2372	1.1848	1.2463	1.3435
Maximum daily loss	-16.35%	-9.16%	-7.09%	-10.96%	-6.25%	-10.96%
Theta	-89.96%	-18.15%	13.69%	9.24%	13.79%	22.88%
<i>Panel B: March 26, 2004 - October 31, 2006</i>						
Sharpe ratio	-2.6751	-1.5779	1.2081	-0.3174	0.8276	0.7343
Sortino ratio	-3.3698	-2.0236	1.7334	-0.4047	1.1418	0.9635
Omega ratio	0.6249	0.7537	1.2320	0.9341	1.1576	1.1563
Maximum daily loss	-16.35%	-9.16%	-3.65%	-10.96%	-3.96%	-10.96%
Theta	-112.47%	-37.89%	12.45%	-8.06%	7.66%	7.64%
<i>Panel C: November 1, 2006 - May 31, 2009</i>						
Sharpe ratio	0.7697	1.0588	0.7664	1.3681	1.1579	1.5526
Sortino ratio	1.2706	1.7141	1.1110	2.3175	1.7958	2.6325
Omega ratio	1.1416	1.2109	1.1451	1.3279	1.2368	1.3851
Maximum daily loss	-12.58%	-7.43%	-7.09%	-8.05%	-6.25%	-8.05%
Theta	-8.83%	19.04%	8.59%	28.79%	15.77%	34.08%
<i>Panel D: June 1, 2009 - March 31, 2012</i>						
Sharpe ratio	-1.2271	-0.5745	1.8658	0.6530	1.7341	1.5693
Sortino ratio	-1.8804	-0.8735	2.8100	1.1504	2.6755	2.8421
Omega ratio	0.8066	0.9037	1.3682	1.1735	1.3497	1.4484
Maximum daily loss	-16.12%	-8.64%	-3.10%	-9.65%	-2.76%	-9.65%
Theta	-142.33%	-33.63%	19.43%	7.42%	17.60%	26.71%

Table reports various performance measures for the excess returns, net of fees, on the two tracker ETNs (VXX and VXZ) the two differential roll-yield strategies (XVIX and XVZ) and their static and dynamic portfolios (CVIX and CVZ). Theta denotes the manipulation-proof performance measure of Goetzmann, Ingersoll, Spiegel, and Welch (2007).

5. Hedging ETNs: Concerns for Issuers and Regulators

The holder of an ETN has the right to redeem early (typically in lots of 25,000 shares) at the closing indicative value one business day after the holder gives notice (through his broker) of the redemption. During volatile periods early redemptions can be extremely large. For instance, during the first few days of the Euro crisis in August 2011 the number of VXX shares outstanding more or less halved, from 42 million to 21 million. The early redemption features of ETNs require the issuer to secure a profit through hedging his exposure daily, to earn at least the annual service fee after accounting for hedging costs. We first derive expressions for net assets and liabilities on the hedging account and illustrate the extent of profits or losses using some straightforward examples. Then we address risk management of the sell-side, using a scenario analysis based on the statistical block bootstrap.

5.1. Perfect Hedges Based on Indicative Values

Let x_t^m denote the net liability facing the issuer of a single constant-maturity tracker ETN, with maturity m , on day t . Let r_{t+1}^m denote the (excess) return on the m -maturity S&P index from day t to day $t+1$, which is given by Eq. (2). Let f^m denote the (daily equivalent) constant investment

fee and let \tilde{r} denote the daily return on the risk-free asset. Then from day t to day $t+1$ the liability x_t^m changes to

$$x_{t+1}^m = x_t^m(1 + r_{t+1}^m + \tilde{r} - f^m).$$

The assets held by the issuer in the risk-free asset are x_0^m on the day of issue and thereafter the assets y_t^m on day t grow at the risk-free rate \tilde{r} , plus the P&L from the hedge of his liabilities on day t . Suppose the issuer hedges his liabilities x_t^m at time t using the synthetic m -maturity futures. Ignoring any margin costs, taking an exposure of x_t^m in the futures with return r_{t+1}^m adds the P&L $x_t^m r_{t+1}^m$ to the issuer's assets, so that in the absence of transaction costs his total assets at time $t+1$ would be given by $y_t^m(1 + \tilde{r}) + x_t^m r_{t+1}^m$. However, there is a small daily transaction cost of

$$h_{t+1}^m = \frac{s_{t+1}^m}{2} |x_{t+1}^m - x_t^m(1 + r_{t+1}^m)|$$

arising from rebalancing the positions in the two futures that straddle the target maturity.²⁰ Here s_t^m represents the bid-ask spread for an m -maturity futures exposure on day t .²¹ Hence,

$$y_{t+1}^m = y_t^m(1 + \tilde{r}) + x_t^m r_{t+1}^m - h_{t+1}^m.$$

Thus, the net assets (i.e. assets – liabilities) at time $t+1$ are given by

$$z_{t+1}^m = y_{t+1}^m - x_{t+1}^m = (y_t^m - x_t^m)(1 + \tilde{r}) + x_t^m f^m - h_{t+1}^m. \quad (4)$$

5.2. Assets – Liabilities in the Hedging Account

Fig. 5 depicts three empirical examples showing, on the left, the daily average flow of fees and hedging costs, averaged over the previous month. The right-hand graphs depict the cumulative net assets accruing to the issuer of ETNs, as a proportion of the current liability. The examples are: (i) an initial issue of equal amounts in the 30-day tracker VXX and its inverse tracker, the AAVX; (ii) an initial issue of XVIX, plus two-thirds of this exposure in the inverse 150-day tracker and one-third in the direct 30-day tracker; and (iii) an initial issue of equal amounts on the XVIX, and the four direct and inverse trackers at 30-day and 150-day maturities, i.e. five ETNs in all. For simplicity, we suppose all shares in issue were sold on the primary market on March 30, 2004 and that the number of shares outstanding is constant, i.e. the number of shares issued equals the number of shares redeemed or called early on any day.

The net asset path (assets minus liabilities) is not shown, as it increases monotonically over the

²⁰Recall that during a weekday the amount $(l - s)^{-1}$, which is usually 1/28 or 1/32 of the exposure, is transferred from the shorter to the longer maturity futures. Over a weekend it is 3 times this amount.

²¹In the next section we report an empirical analysis of net assets accruing to the issuer of ETNs over time, reporting fees and hedging costs separately. Here we assume constant spreads of 25bps for the 30-day and 30bps for the 150-day trackers. It is true that spreads have decreased dramatically over time, but our purpose is to assess the profitability of a potential future issuance of ETNs, so it is appropriate to assume hedging costs are fixed at their current size.

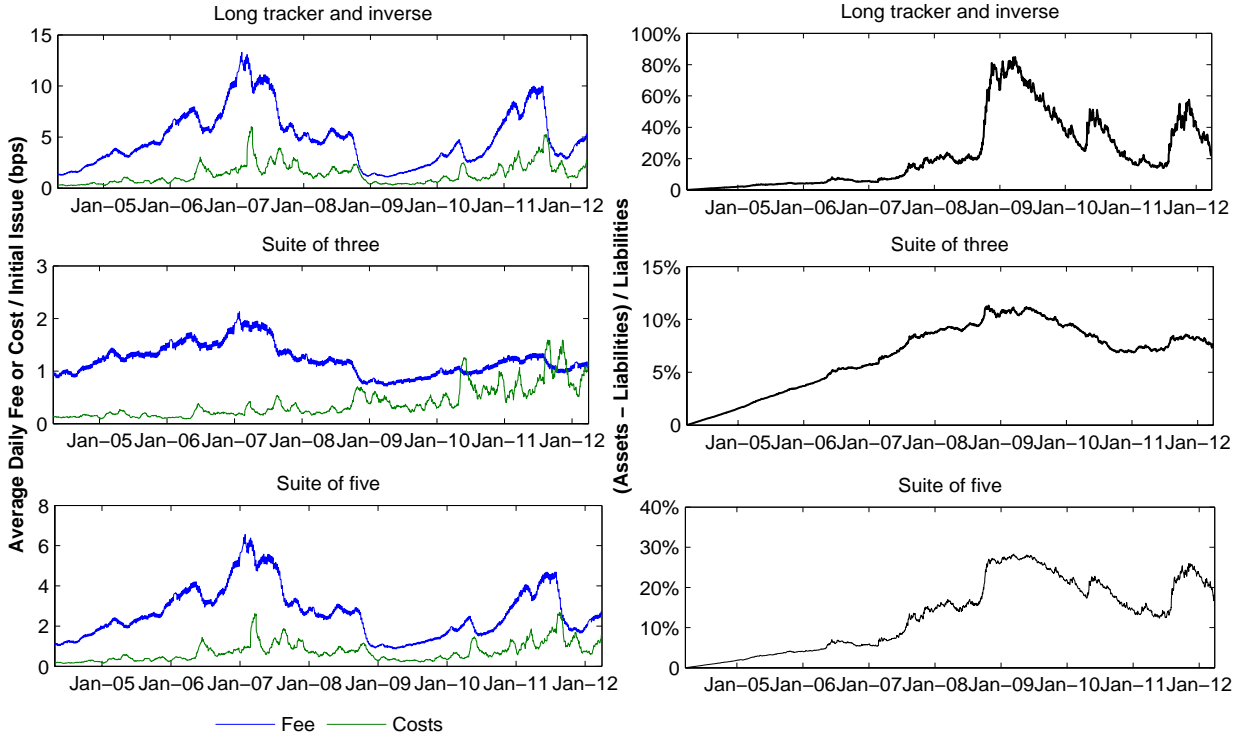


Fig. 5 Daily average fees and transaction costs, averaged over the previous month (on the left) and the cumulative net assets accruing to the issuer of ETNs, as a proportion of the current liability (on the right).

entire period in all three cases. Instead, on the right we depict net assets as a proportion of the current liabilities. This remains positive over the entire period, even though the fees earned cover the hedging costs only in case (i) and (iii), but it does not increase monotonically. In case (ii) the excess of hedging costs over fees earned erodes the asset side of the balance sheet so that they are much less than in cases (i) and (iii).

Even when the number of shares outstanding is constant the direct and inverse exposures change over time. Indeed, the liabilities for direct and inverse trackers vary inversely, so that the liability to the inverse tracker grows when the liability to the direct tracker falls. This is why the net assets can fall, as a proportion of the liabilities. For instance, by March 20, 2009 the net assets in case (i) – i.e. an initial issue of equal dollar amounts in VXX and AAVX – had risen to nearly 85% of the current liability, net of fees and hedging costs. But one year later, by March 20, 2010 it had fallen steadily to less than 30% of the net liability because the liability to the inverse tracker was gradually rising during the long contango market following the banking crisis. The issuer of a suite of products may find it advantageous to issue further notes in direct tracker products at such times, if possible. This way, the basket of ETNs can be kept in balance so that net assets are not only always growing, they are always growing as a proportion of the current liability.

5.3. Sell-Side Risk Management: Scenario Analysis

The examples selected in Fig. 5 considered just one (historical) scenario for the evolution of the S&P indices that determine the indicative values of the ETNs. We now apply a statistical bootstrap methodology to simulate a distribution for net assets accruing to the issuer, as a proportion of liabilities, at different time horizons in the future. For each distribution we use the bootstrap to simulate 10,000 possible paths such as those shown in Fig. 5, each with a different, randomly-selected sequence of historical returns on the S&P indices.

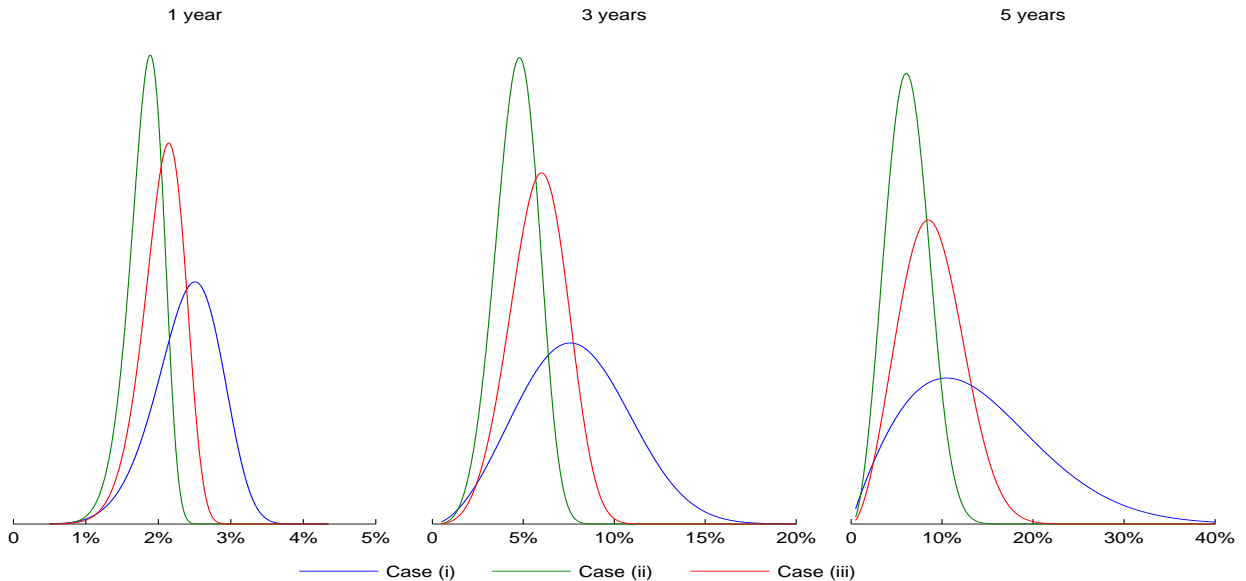


Fig. 6 Densities of current assets minus current liabilities of the ETN issuer as a proportion of current liabilities: one year after issue (left); three years after issue (middle); and five years after issue (right). Case (i) is equal initial dollar amounts in VXX and AAVX, shown in blue; case (ii) is XVIX with balanced exposures to inverse 150-day and direct 30-day shown in red; and case (iii) is XVIX with equal amounts in direct and inverse 30-day and 150-day trackers, shown in green. No re-issue or early redemptions included in the scenarios. Assets include accrual of the principal raised at the risk free rate, investment fees, profit and loss on the VIX futures positions and hedging costs. Densities are based on 10,000 block bootstraps of 1250 observations from the historical data between March 2004 and December 2011.

For the purpose of illustration we retain the assumption that issuance is equal to early redemptions plus calls. However, the scenarios have a straightforward extension to accommodate changes in the number of shares outstanding. We use the block bootstrap to simulate a distribution for net assets and liabilities at some future point in time, as follows: (1) Fix with an initial number of notes sold on the primary market in our three cases: (i) equal initial dollar amounts in VXX and AAVX; (ii) XVIX with balanced exposures to inverse 150-day and direct 30-day; and (iii) XVIX with equal amounts in direct and inverse 30-day and 150-day trackers; (2) re-sample with replacement 1250 observations from our historical data on m -maturity indices in such a way that the cross-correlation and autocorrelation properties are retained. So we select a date at random and then sample 10 consecutive daily returns on all the constant maturity indices, starting from this date. Repeating this process 125 times gives a bootstrapped multivariate time series with 1250 observations; (3)

From this simulated time series we compute the net assets as a proportion of liabilities, exactly as we did for the real historical data in Fig. 5, but we retain only five points viz. the net assets one year after the issue, as a proportion of the liabilities at that time, and the same again for n years after the issue, with $n = 2, \dots, 5$, assuming 250 trading days per year; (4) Repeat steps (1) – (3) 10,000 times to simulate a distribution of possible values for net assets as a proportion of liabilities, based on the block-bootstrap methodology.

Fig. 6 displays the entire density of net asset value as a proportion of liabilities for each issuance strategy and at one, three and five years after issue. The graph on the left depicts one-year densities for the three different issuance strategies; in the middle we compare the three-year densities and on the right we compare the five-year densities. In each case the near-normal one-year density with low mean and variance evolves over time into densities with progressively higher means and variances, positive skewness and [except in case (ii)] excess kurtosis. The most uncertain of the relative net asset values arises in case (i), where only the direct and inverse 30-day trackers are issued, and the most certain relative net asset values are for case (ii), the XVIX with balanced exposures to inverse 150-day and direct 30-day trackers. However, the expected relative net asset value is also largest in case (i) and lowest in case (ii).

Table 5
Bootstrapped Sample Statistics: (Assets – Liabilities)/Liabilities.

Year	1	2	3	4	5
<i>Case (i): 30-day direct and inverse trackers, VXX and AAVX</i>					
Mean	2.41%	5.07%	7.86%	10.73%	13.73%
Stdev	0.42%	1.33%	2.83%	4.95%	7.74%
Skew	-0.10	0.69	0.97	1.38	1.73
Kurt	1.16	1.67	2.23	4.84	6.34
Max	4.35%	14.02%	27.96%	70.50%	106.44%
Min	0.63%	1.19%	1.19%	1.79%	1.36%
<i>Case (ii): XVIX with 1/3rd in 30-day and 2/3rd in inverse 150-day trackers</i>					
Mean	1.81%	3.38%	4.63%	5.58%	6.24%
Stdev	0.23%	0.64%	1.14%	1.69%	2.27%
Skew	-0.38	-0.11	0.09	0.29	0.53
Kurt	0.35	0.01	-0.10	-0.04	0.60
Max	2.58%	6.02%	9.69%	13.52%	22.43%
Min	0.67%	1.06%	1.19%	0.98%	0.86%
<i>Case (iii): XVIX Suite of Five</i>					
Mean	2.06%	4.05%	5.85%	7.46%	8.88%
Stdev	0.28%	0.75%	1.40%	2.20%	3.19%
Skew	-0.31	0.31	0.68	1.03	1.57
Kurt	0.94	1.09	1.39	2.79	6.42
Max	3.12%	8.56%	14.10%	30.12%	45.54%
Min	0.75%	1.37%	1.47%	1.90%	1.45%

The mean, standard deviation, skewness and excess kurtosis of the distribution of 10,000 block-bootstrapped net asset values, as proportion of liabilities, after n years, with $n = 1, 2, \dots, 5$. We also report the minimum and maximum values obtained in all 10,000 simulations.

Table 5 reports the summary statistics associated with bootstrapped net asset densities at maturity 1, 2, ..., 5 years. For the three different issuance strategies we summarize the results as follows:

1. The means increase over time in all cases. Case (i) produces the greatest values on average, followed by case (iii) and finally case (ii). The uncertainty (as measured by the standard deviation) also increases over time and has similar ordering to the mean;
2. The ratio of mean to standard deviation decreases over time but still, the mean is significantly greater than zero even after five years; the mean-standard deviation ratio is at most 7.8 [case (ii) after one year] and at least 1.8 [case (i) after five years];
3. The distributions are near normal after one year, but thereafter skewness is positive and growing over time in all three cases. Excess kurtosis does not necessarily grow over time – see case (ii) for instance, which gives the lightest-tailed distributions of all;
4. The minimum value obtained over all 10,000 simulations is always positive. For instance, after five years net assets accruing from the XVIX suite of five would be at least 1.45% and at most 45.54% of liabilities; and net assets from the VXX – AAVX combination would be at least 1.36% and at most 106.44% of liabilities.

These results assume no change in the numbers of shares outstanding of each ETNs. In practice, the sell-side risk management should also employ scenarios where the number of shares outstanding changes in a correlated manner with the price changes of the ETNs. If the block bootstrap is employed for generating such scenarios one need only change the algorithm specified above to sample from a pair of historical time series (r_{it}, n_{it}) where r_{it} denotes the return and n_{it} denotes the change in the number of shares outstanding on the i th ETN at time t . Stress testing of the asset-liability account value could also be performed by limiting the historical sample used in the block bootstrap to stressful periods, e.g. when the ETN returns are large and negative/positive and the number of shares outstanding increases/decreases. Results are not reported for brevity but are available from the authors on request.

6. Potential Concerns for Regulators

A variety of issues surround the early redemption of ETNs. The large-scale hedging activities of ETN issuers on the CBOE market are likely to influence both the level and volatility of VIX futures prices. Moreover, there can be an indirect speculative activity surrounding this hedging that we now explain. Because the early redemption value of an ETN is determined by the closing prices of the two straddling VIX futures (one day after notice is given) the previous analysis of assets and liabilities in the issuer’s ETN account is based on closing prices of VIX futures. Of course, ETN issuers can put their VIX futures hedging trades to the CBOE at any time during the day, but any systematic changes in a VIX futures price after the trade and before market close will bias the hedging account. For this reason, the issuer may see an advantage in timing the rebalance of his hedge as near as possible to the CFE market close.

The number of shares outstanding on each ETN is public knowledge, although notices for early redemption are known only by the investor, the broker and the issuer and the placement of new shares on the primary market is known only by the issuer and broker. So, assuming there are

no very large changes in the number of shares outstanding, a speculator could compute the net exposure to VIX futures across the suite of ETNs offered by an issuer, just as we have done in Section 5.1. This way, speculative traders on the CBOE could predict how much the ETN issuers are required to trade on each VIX futures contract at the end of each day for rebalancing the hedge.

During volatile periods the issuer often needs to off-load a significant number of VIX futures which, due to large-scale early redemptions, are no longer required for hedging (as in the VXX example cited at the beginning of Section 5). Since it is relatively easy for a speculator to predict both the time that an issuer places his hedging trades, and the size and direction of these trades, he could front-run these trades to create an ‘arbitrage’ in the CFE market for his own benefit.

The scale of front-running of the hedging activities by Credit Suisse related to the TVIX led to such an increase in hedging costs that the bank suspended further issuance of the ETN, in February 2012. As a result of the excessive speculative demand for TVIX, over the next few days it traded at a significant premium (up to 90%) of its indicative value. Credit Suisse subsequently re-opened the issue only on the condition that the market makers on the NYSE and CFE agree to transact VIX futures in the required amount for hedging at the daily closing price, thus passing on the hedging risk to the market makers.

The ability of the ETN issuers to influence the prices of VIX futures via their large-scale hedging activities and the speculative activity surrounding these hedging trades, are causing great concerns for regulators because the ETN market on NYSE is now leading the VIX futures market on CFE, not the converse. If the ETN terms and conditions were changed so that the early redemption value was based on an average VIX futures price over a day, or even a longer period, the opportunity for speculators to influence the redemption value would be mitigated.

On the other hand, roll-yield arbitrage ETNs, and portfolios of these, appear to provide long-term investors with very attractive risk-return and diversification characteristics, as we have shown in Section 4.3. Notably, the best performing portfolios take positions in short-term inverse trackers and long-term direct trackers. But since short-term speculative traders would be happy to take opposite positions most of the time, the ETN issuer should be able to structure their issues of different ETNs to hold a natural partial hedge, thus reducing their demand for VIX futures. This structuring would appear to be a fruitful avenue for further discussion between issuers and regulators.

7. Summary and Conclusions

A chronology of VIX futures ETNs shows that more than half of them directly track a single constant-maturity VIX futures, including three $2 \times$ leveraged products recently issued by Credit Suisse and Barclays. During the first two months of 2012 about 37 million shares were traded on direct tracker ETNs every day. Their market cap on February 29, 2012 was nearly \$2.5 billion, i.e. 82% of the total market cap of all VIX futures ETNs at that time, the other ETNs being ten inverse trackers plus two differential roll-yield products, XVIX and XVZ. The combined trading volume on all ETNs can exceed \$5 billion per day.

Investment returns on direct tracker ETNs are eroded by negative roll-yield effects, except during the brief periods that the VIX futures term structure is in backwardation. However, it is possible to build portfolios of ETNs, which typically have a short exposure to short-term VIX futures trackers and a long exposure to longer-term trackers, which offer very attractive risk and return characteristics through trading the differential roll yield along the VIX futures term structure. To replicate the indicative returns on these portfolios we use the S&P constant-maturity indices from December 2005 and prior to this we replicate the S&P index values ourselves, by linearly interpolating between VIX futures returns. Such indices are investable because they retain a one-to-one correspondence between the synthetic and traded maturities of VIX futures.

According to a wide variety of risk-adjusted performance measures over an eight-year historical period the CVIX and CVZ, simple static and dynamic portfolios of the two existing roll-yield arbitrage ETNs, XVIX and XVZ, clearly outperform the volatility ETNs that have already been issued, with two exceptions: XVIX would have performed best during the period March 2004 – October 2006; and XVZ would have outperformed CVIX during the banking crisis. It would be difficult to construct allocations to the VIX term structure that have a lower volatility than the CVIX. For instance, the CVIX has displayed an average volatility of less than 14% since 2004. Yet, the total buy-and-hold returns from March 2004 to March 2012, net of investment fees, was 255% for the CVIX and 870% for the CVZ. The Sharpe ratios averaged at 1.21 for the CVIX and 1.32 for the CVZ, over the eight-year sample period.

However, there are many problems with VIX futures ETNs on the sell-side. Since early redemptions of direct and leveraged tracker ETNs are frequent during volatile periods, these can pose a significant risk to the issuer who needs to hedge against such redemptions using VIX futures. We have demonstrated, algebraically and empirically, how the issuer can hedge an exposure to a suite of ETNs almost exactly, provided their trades on VIX futures are at the daily closing price. Moreover, they may be able to control the issues of their various ETNs and hedge the whole portfolio in such a way that the net assets accruing after hedging costs are very substantial. To illustrate risk management techniques for the sell-side we have applied the statistical block bootstrap to build scenarios for the evolution of the issuers assets and liabilities over a five-year horizon. Such scenarios capture the cross-correlation and autocorrelation of the ETN returns, as well as accounting for the fees accruing to and the hedging costs paid by the issuer. We only exclude margin costs. Under every simulation the net asset value after hedging costs is always positive for the examples we have considered, even after deducting liabilities arising from the unlikely scenario of full early redemption (or entire issue called). The expected value of net assets relative to liabilities also grows over time, but so does its variance. Nevertheless, even five years after issue the expected net assets relative to liabilities is significantly greater than zero. But in this exercise we only examined three possible ETN issuance strategies and we bootstrapped scenarios using historical data. Although the period includes the credit and banking crisis, even more severe hypothetical stress tests with partial early redemption and/or new issuance scenarios should be performed. The aim should be to construct a diverse array of ETNs that makes considerable profits for the fully-hedged issuer

under all bootstrapped historical and hypothetically stressed scenarios.

A major concern is that the hedging activities of ETN issuers are a vehicle whereby ETN market trading now influences the prices of the futures contracts that they are supposed to track. We recommend that regulators perform a thorough investigation into the distortion effects of the early redemption conditions for VIX futures ETNs. As they are currently, the redemption conditions precipitate large-scale trades on VIX futures that are predictable in both timing and quantity. So there is great potential for speculators to front-run the daily hedges of ETN issuers, by trading VIX futures shortly before close on the CBOE. One possible remedy would be to change the terms and conditions of early redemption to be similar to those of standard passive ETFs, such as the SPDR, and furthermore pass on the hedging responsibility to the market makers. Another would be to set the redemption value to be the S&P index value averaged hourly over the day of redemption.

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