A Regime Switching Analysis of Contagion from the U.S. Subprime Mortgage-Backed Securities Market

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Abstract

This paper analyses contagion from the ABX.HE indexes, which serve to proxy for the U.S. subprime mortgage-backed securities market, to other major financial markets during the crisis of 2007-2009. The seminal work analysing contagion from the ABX.HE indexes is that presented by Longstaff (2010) and so a time-varying transition probability Markov-switching vector autoregressive (TVTP MS-VAR) framework is employed in an effort to generalize the framework presented in that study. We find that the watershed of regimes occurs in mid-2007, with the crisis regime dominating thereafter. This suggests that exogenously imposing a crisis regime to break in January 2007, as in Longstaff (2010), is not appropriate. Tentative evidence of contagion is found to emanate from the ABX.HE indexes, but certainly not as widespread as that presented by Longstaff (2010) This indicates that correctly dating the crisis is crucial to the analysis, as in the original application the crisis period is an amalgamation of the tranquil start to 2007 followed by a turbulent second half.

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I. Introduction

In 2007 the United States' financial system suffered its worst crisis in almost a century, one that led the global economy into what has been dubbed by many the "Great Recession". Between October 2007 and March 2009 the S&P 500 lost approximately 56% of its value, in November 2008 the Chicago Board Options Exchange Volatility Index (VIX) increased steadily to an historical high of 80.86 percentage points, and it has been estimated that global losses due to the crisis will amount to over $12 trillion, (Better Markets Report, September 2012).

As the crisis unfolded many attributed U.S. subprime mortgage-backed securities as the underlying source of the problem, including Gorton (2009), Brunnermeier (2008) and Lim (2008). The fledgling market for these structured finance products had experienced rapid growth in the years prior to the crisis, trading not only in the United States but by investors worldwide. The tranche and ratings features of these asset-backed securities appealed to investors as a means of spreading risk, and soon suppliers of subprime mortgage-backed products were struggling to meet the increasing demand for them, leading to lax loan standards and feeding market growth even more (Mian & Sufi, 2009). The share of subprime mortgages increased from approximately 9% of new mortgages in the early 2000s to over 40% in 2006 (Hellwig, 2009) and subprime mortgage-backed security issuance grew from $195 billion to $362.5 billion during the same

period, (Park, 2010).
The growth of this market led to the creation of the ABX.HE indexes, which reference subprime mortgage-backed collateralized debt obligations (CDOs). With the decline of the real estate market in early 2007 things began to unravel rapidly as the threat of vast defaults in the subprime mortgage market led investors to reassess the risk of these asset-backed securities (Fender & Scheicher, 2008). Soon it became clear that in most cases there had been a gross underestimation of this risk, resulting in vast mispricing of these products (Whetten, 2006). This created widespread panic for the large number of investors trading them and in most cases the originating financial institutions were forced to take them back onto their books, resulting in warehousing risk and substantial losses, (Purnanandam, 2011). This financial market distress fuelled a lack of trust between financial institutions, as many were unsure of even their own exposure to these now "toxic" products, and so could not be confident of other institutions exposures. This led to a widespread credit crunch in 2008, with September of that year seen by many as a turning point in the crisis (Longstaff, 2010). Events such as the collapse of Lehman Brothers and the acquisition of Merrill Lynch by Bank of America caused further distress in already unstable markets as stock prices plummeted and liquidity came to a halt.

Contagion in financial markets during a crisis such as that experienced in 2007-2009 is important to both investors and financial institutions keen to halt the spread of crises. Therefore, this paper tests for contagion from the U.S. subprime mortgage-backed securities sector to other asset markets during the crisis, employing the ABX indexes to represent the distressed mortgage-backed market. The seminal work on testing for contagion from the ABX indexes, Longstaff (2010), is treated as a basis for this paper and we address some of the methodological limitations of that work to test for contagion from the U.S. subprime mortgage-backed securities market to government, corporate, volatility and equity markets during the 2007-2009 financial crisis. This paper therefore follows the definition of contagion used by Longstaff (2010), which is that presented by Forbes & Rigobon (2002,) as "an episode in which there is a significant increase in cross-market linkages after a shock occurs in one market".

To extend the VAR framework of Longstaff (2010), a time-varying transition probability Markov-switching VAR (TVTP MS-VAR) model, developed by Filardo (1994), is employed. In the model both variances and coefficients are allowed to switch discretely between two regimes; a non-crisis regime characterized by low volatility and a crisis regime classified by high volatility. This framework allows regimes to be determined endogenously by the data, a feature not present in the original application employed by Longstaff (2010), in which regimes are imposed exogenously. It also enables the switch in regime to be driven by an ABX asset, another aspect not present in the original methodology. We treat the ABX indexes as our possible source of contagion and are interested in analysing asset market interactions in low- and high-volatility regimes triggered by the subprime mortgage-backed securities market.

Analyses are performed on both the spliced ABX index employed by Longstaff (2010) and a traded ABX index. We characterize two regimes, a non-crisis regime classified by low volatility and a crisis regime classified by high volatility. The watershed of regimes occurs in mid-2007, with the crisis regime dominating thereafter until the end of the sample, suggesting that imposing a crisis regime to begin in January 2007, as in Longstaff (2010), is not appropriate. Although we observe an increase in the correlation between the ABX asset and the majority of financial variables analysed when the regime switches from a non-crisis to a crisis state we do not observe any evidence of price discovery in the VAR coefficients and so we fail to reject the null hypothesis of no contagion from the ABX indexes analysed to the financial market variables during the crisis regime, a result in direct contrast to that presented by Longstaff (2010). This may be due to the timing of market events and the transmission of shocks through other channels, such as real estate and asset-backed commercial paper (ABCP) markets. The results also highlight differences between the spliced ABX index and the traded indexes, suggesting that analysis of the spliced ABX index alone may not provide an accurate depiction of what was happening in this market and splicing the data may influence the results.

A number of robustness checks are performed, including trivariate TVTP MS-VAR analyses. The results suggest some evidence of contagion from the ABX market to the other financial markets, although contagion is not as widespread as that reported in Longstaff (2010). This indicates that accurately timing the onset of the crisis is crucial, and the original application may have induced persistence due to employing four lags and ignoring the structural break that occurred in mid-2007.

The remainder of the paper is organised as follows. Section 2 outlines some related literature while Section 3 describes the data analysed. Section 4 presents preliminary analysis of the data and Section 5 discusses the results of a rolling VAR analysis. Section 6 describes the time-varying transition probability Markov-switching VAR framework and specifies the model employed. Section 7 presents the results of a number of robustness checks. A final section then concludes.

II. Related Literature

The first two ABX indexes began trading in 2006 and soon became key measures of subprime mortgage market conditions for investors and financial institutions. As the crisis of 2007 unfolded many turned to this proxy for the subprime mortgage-backed securities market in order to shed light upon what had led the financial system to such a collapse. Gorton (2009) states that the ABX lay at the very heart of the crisis and suggests that trades in the indexes caused information regarding the decline of house prices to be exposed, revealing how interlinked the housing market and the market for these securities had become. The creation of this “common knowledge" fuelled the widespread panic that led to the liquidity crisis of 2008, causing the ABX to become the central point of the crisis.

Stanton & Wallace (2011) investigate whether ABX prices efficiently aggregate information regarding the credit performance of referenced subprime mortgage obligations and conclude that the indexes are in fact an imperfect benchmark for marking-to-market mortgage portfolios. Caruana & Kodres (2008) highlight that the over-the-counter (OTC) characteristics of ABX trading contributed to the opaque nature of the market. They suggest that price behaviour of the ABX implies that these products were used in place of actual liquid securities to absorb new information. Whetten (2006) highlights the differences between corporate credit default swaps and asset-backed credit default swaps and describes how the ABX enabled investors to convey their view of the subprime mortgage-backed security sector by taking a position in a credit default swap.

Although there is a large body of work analysing contagion in financial markets literature utilizing the ABX indexes to test for its presence during the crisis of 2007-2009 is not as extensive. Longstaff (2010) utilizes the ABX indexes to represent the U.S. subprime mortgage-backed securities market and tests for contagion from this market to several fixed income, equity and volatility markets using a vector autoregressive (VAR) framework. Strong evidence of contagion in the financial markets examined is found during the 2007 “subprime crisis” , along with significant price discovery of up to three weeks ahead during the turbulent period. This then dissipates during the 2008 “global-crisis” period, as liquidity dried up in markets, causing trades in the subprime securities sector to come to almost a complete halt.

Regime switching analyses were initially used primarily in business cycle research, as in Hamiliton (1989) and, in recent years, in currency crisis literature, such as in Mandilaras & Bird (2010). They argue the use of a regime switching methodology, highlighting such advantages as the fact that the endogenous choice of crisis and non-crisis periods eliminates the need to select regimes a priori. Analysing European exchange rates during the Exchange Rate Mechanism (ERM) they find that the Markov-switching VAR is an appropriate methodology as it successfully identifies the eleven realignments of the ERM. Using a multivariate version of the Forbes & Rigobon (2002) contagion test they find evidence of contagion in the European Monetary System (EMS). Billio et al. (2005) review Markov switching models in contagion analysis by examining the 1997 Hong Kong stock market crash, treating contagion as a structural break in the data generating process during a crisis. They also point out that one advantage of Markov-switching models is the endogenous identification of crisis periods from sample data, along with the fact that such models can sufficiently handle theoretical issues such as non linearity. Using a CDS index to represent the U.S. credit default market, Guo et al. (2011) test for cross-market contagions among this market, a U.S. stock market, real estate market, and energy market during the 2007 crisis using a Markov-switching vector autoregressive (MS-VAR) framework. They find that stock market and oil shocks are driving forces behind credit default and stock market variations, respectively.

Markov-switching models with time-varying transition probabilities have been applied mainly in currency crises literature, such as Peria (2002) and Brunetti et al. (2008).

III. Data

III.1 The ABX.HE Indexes

The exceptional growth of the subprime mortgage-backed securities sector during the early 2000s led to the creation of the ABX.HE indexes, standardized indexes that provided credibility, transparency and liquidity to this relatively new and innovative structured finance market. Produced by the Markit Group, trading on the ABX was launched on January 19, 2006, to enthusiastic investors. The indexes track twenty equally weighted, static U.S. portfolios of credit default swaps backed by subprime mortgages. Each index takes on a CDO structure, covering specifically rated reference obligations (AAA, AA, A, BBB, and BBB-). Ratings are the lower of those issued by Moody's and Standard and Poor's (S&P's).

Each index is based on twenty subprime mortgage-backed securities, issued over the previous six-month period and indexes are renewed or "rolled" every six months. To be included in the index each residential mortgage-backed security (RMBS) must meet stringent requirements, such as deal size must be at least $500 million, the weighted average Fair Isaac Corporation (FICO) score of the creditors backing the securities issued in the RMBS transaction may not be greater than 660 and at least four of the required tranches must be registered pursuant to the U.S. Securities Act of 1933.[1] Only four indexes were issued, with the fifth subject to several postponements and unlikely to go ahead.

Each index is a synthetic CDO in which the ratings do not differentiate borrowers according to how risky they are. Instead they simply distinguish the order in which investors bear losses and receive payments. The misconception that a AAA-rated ABX asset was equal to that of a corporate bond led to many mandate-driven bodies, such as pension funds and universities, to heavily invest in these securities. Figure 1 plots ABX raw prices for each index from its issuance date until December 31, 2009.[2]

[Insert Figure 1 about here]

[1] In the U.S. an individual's credit risk is commonly measured by a FICO score. These scores range from 300 to 850 and are based on analysis of the individual's credit history. A mortgage issued to a borrower with a FICO score of 620 or less is classified as a subprime mortgage.

[2] Note that as each index was issued six months subsequent to the previous vintage the data are unbalanced.

There is clearly a steep decline in prices in all four indexes over the sample period. As the subprime deals underlying the ABX 06-1 index were issued in the second half of 2005 the assets underlying this index would be of considerably better quality than those included in later issued indexes. It is clear that all assets in this index traded at or near par for all of 2006 before declining rapidly during 2007, a trend evident in the other three indexes. However, the AAA-rated asset in the ABX 06-1 index does not reach the lows of later issued AAA assets. The two later issued indexes were hardest hit.

III.2 Longstaff (2010) Spliced ABX Index

Longstaff (2010) constructs an on-the-run ABX index by splicing the series together at the date that each new index is issued. The series is therefore spliced together on 19 July 2006, 19 January 2007 and 19 July 2007, respectively. As each new series began trading at par it is necessary to re-base the series at each splicing date. This paper analyses the spliced ABX index employed by Longstaff (2010) and the traded ABX 06-1 index in order to ascertain if splicing the data could have had any influence upon the results.[3] ABX data have been obtained from the Markit Group Ltd. and weekly (Wednesday to Wednesday) returns are used in the analysis. The sample period ranges from January 19, 2006, to December 31, 2009.

III.3 Financial Market Variables

Longstaff (2010) analyses weekly returns of the five assets comprising the spliced ABX index to proxy for returns in the distressed subprime mortgage-backed CDO market, testing for contagion from this market to several equity, volatility and fixed-income markets. As we are estimating a highly nonlinear model we include one proxy for each financial market mentioned in an effort to reduce the number of coefficients to be estimated and yield more accurate results. We therefore include the S&P 500 index, the VIX index and the Aaa-rated corporate spread. A Treasury bond spread is created by subtracting the short-term yield from the long-term yield. Weekly changes of this spread are included to account for changes in the Treasury market. Treasury yield and corporate yield data have been obtained from the Federal Reserve Board while S&P and VIX data have been obtained from the Bloomberg system. As with the ABX indexes the financial market variables data range from January 19, 2006, to December 31, 2009.

IV. Preliminary Analysis

Table 1 reports summary statistics for weekly returns of the ABX indexes under analysis over the sample period.

[Insert Table 1 about here]

Mean returns are negative in all asset tranches, and are monotonically related to credit rating in both indexes indicating these lower-rated securities were hit hardest over the sample period. Standard deviations are high in all cases, indicating the high volatility of returns. They do not appear to be inversely related to credit rating as, based on these, the AA-rated asset is most volatile in the spliced ABX index, while the BBB-rated asset is most volatile in the ABX 06-1 index. This highlights differences between the three indexes, suggesting that they are distinct assets in which ratings tranches behave differently. Unsurprisingly almost all returns are negatively skewed and it is clear that normality is rejected in all cases.

V. Rolling Vector Autoregressive Analysis

To test for contagion Longstaff (2010) divides the data into three distinct periods; a “pre-crisis" period for 2006, a “subprime-crisis"

[3] The ABX 06-1 is chosen as it provides the longest time series and also due to the known better quality of the underlying assets.

period for 2007 and a "global-crisis" period for 2008, therefore allowing the VAR coefficients to vary by year. This framework assumes that the system switches from a non-crisis to a "subprime-crisis" regime on January 1, 2007, and to a "global-crisis" regime on January 1, 2008. If this is a reasonable assumption we should therefore observe a change in coefficient behaviour at these times. Therefore, as a preliminary analysis of the stability of the coefficients in the VAR system, a rolling VAR is estimated with a window width of 24. This window width is chosen as there are relatively few observations in the data sets analysed.[4] The VAR specification estimated is as follows:

$$Y_t = \alpha + \sum_{k=1}^{4} (\beta_k Y_{t-k} + \gamma_k ABX_{t-k}) + \epsilon_t, \quad (1)$$

in which Y_t denotes the financial market measure included as the dependent variable. Thus, there are four dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX index included as an exogenous variable. As there are five ratings classes there are five ABX assets and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC).

Figure 2 present the rolling VAR coefficients and confidence bands over the entire sample period employing the spliced ABX index AAA rated asset as an explanatory variable and the four aforementioned dependent variables. In order to conserve space the spliced ABX index lag one coefficients only are presented.[5]

[Insert Figure 2 about here]

This figure indicates that the coefficients are not stable over the 2006-2009 period. We observe very little movement in the coefficients prior to mid-2007, after which all become relatively volatile. This suggests that imposing the crisis regime to begin in January 2007, as in Longstaff (2010), may not be appropriate and provides motivation for further analysis.

VI. TVTP MS-VAR Analysis

This paper aims to analyse the effect of shocks to the subprime mortgage-backed securities market on different financial markets during the crisis of 2007-2009 following the framework outlined in Longstaff (2010). To this end, a VAR framework is appropriate. However, the results of the rolling VAR analysis presented above suggest that imposing a crisis regime to begin in January 2007 may not be realistic as coefficient behaviour remains relatively stable during early 2007.

We therefore employ a two-state Markov-switching VAR with time-varying transition probabilities, thus allowing regimes to be selected endogenously by the data. Two states are chosen due to the relatively short length of our data and the fact that academic literature analysing the crisis suggests once the U.S. real estate bubble burst in early 2007 markets remained in contraction until June 2009, (National Bureau of Economic Research). Also, casual analysis of ABX index returns and the financial market variables suggest that two regression lines would better fit the data than one. This is also backed up by the results of the rolling VAR analysis presented above.

In order to test for "a significant increase in cross-market linkages following a shock in one market", we include an ABX asset as an endogenous variable in the VAR framework to examine the relationship between this market and the other financial markets analysed. We include the AAA-rated asset because this tranche would have been the largest in the CDO structure (approximately 80%) and would have been the most liquid, particularly when the crisis hit. Should we observe a significant difference in the relationships between the ABX asset and the financial market variables once the system enters a crisis regime we can then conclude evidence of contagion, following our definition and framework.

This approach also requires us to choose an "information variable", i.e. a variable that triggers

[4] Various alternative window widths were employed but the results did not change considerably.

[5] Full results are available on request.

the regime switch. As we are analysing contagion from the ABX market, this trigger should come from within the ABX assets. However, as we include the AAA-rated asset as an endogenous variable in the VAR we must select a variable outside of the system. We therefore choose the next highest rating, the AA-rated asset. Thus, our TVTP MS-VAR analysis includes the AAA-rated asset within the VAR model, with regime changes dependent upon the behaviour of the AA-rated asset returns.

VI.1 Model Specification

Our model takes the form:

$$y_{i,t} = \alpha(s_t) + \sum_{k=1}^{2} \beta_k(s_t) y_{i,t-k} + \epsilon_{i,t}^{st}, \quad (2)$$

$$s_t \in \{1, 2\},$$

$$\epsilon_{i,t}^{st} \sim i.i.d.N(0, \sigma_{st}^2),$$

in which $y_{i,t}$ is an n dimensional time series vector of dependent variables, α is a matrix of state dependent intercepts, $\beta_1 \; . \; . \; . \; \beta_k$ are matrices of the state dependent autoregressive coefficients, $\epsilon_{i,t}^{st}$ is a state dependent noise vector and s_t is an unobserved random variable that causes the system to change from regime to another. We assume s_t follows a first-order Markov process in which the current regime, s_t relies only on the regime one period in the past, s_{t-1}. We therefore examine two discrete states, denoted as s_1 and s_2. s_1 represents a low-volatility, "non-crisis' regime while s_2 represents a high-volatility, "crisis' regime. Four lags were initially employed but, due to the highly nonlinear nature of the model and the relatively large number of coefficients to estimate, led to imprecise estimates and difficulty in converging to a global maximum. Three lags also led to this problem. We therefore employ a two lag model which, as we will show later, is sufficient to capture any serial correlation in this system.

In order to allow the transition between regimes to depend upon the behaviour of the AA-rated ABX asset we employ the time-varying transition probability specification of Filardo (1994). In this case the regime follows a first order Markov-chain and is directly affected by the information variable z_t:

$$\begin{aligned} p[s_t = 1 | s_{t-1} = 1] &= p_{11}(z_t), \\ p[s_t = 2 | s_{t-1} = 2] &= p_{22}(z_t), \\ p[s_t = 2 | s_{t-1} = 1] &= p_{12}(z_t), \\ p[s_t = 1 | s_{t-1} = 2] &= p_{21}(z_t), \end{aligned} \quad (3)$$

in which p_{11} denotes the probability of the system remaining in state 1 at time t, given that the system was in state 1 at time t-1; p_{21} denotes the probability of the system switching to state 2 from state 1; p_{22} denotes the probability of the system remaining in state 2 at time t, given that the system was in state 2 at time t-1; p_{12} denotes the probability of the system switching to state 1 from state 2. We model the transition probabilities as a logistical functional form:

$$\begin{aligned} p(z_t) &= \frac{exp(\theta_{p0} + \sum_{k=1}^{K_1} \theta_{pk} z_{t-k})}{1 + exp(\theta_{p0} + \sum_{k=1}^{K_1} \theta_{pk} z_{t-k})}, \\ q(z_t) &= \frac{exp(\theta_{q0} + \sum_{k=1}^{K_2} \theta_{pk} z_{t-k})}{1 + exp(\theta_{p0} + \sum_{k=1}^{K_2} \theta_{pk} z_{t-k})}. \end{aligned} \quad (4)$$

The model is estimated using the Expectation Maximization (EM) algorithm presented by Hamilton (1990).

VI.2 TVTP MS-VAR Results

Firstly, we plot the smoothed probabilities of the system being in a crisis regime. We calculate these probabilities as follows:

$$P(s_t = i | F_T; \theta), i = 1, 2, \quad (5)$$

in which F_T denotes the collection of all observed variables up to and including time T. In other words all information in the sample and θ is the vector of parameters $(\alpha(st), \beta_k(st), \sigma_{st}^2, p_{11}, p_{22}, p_{12}, p_{21})$. Smoothed estimates are then computed via the backward recursion algorithm as presented by Kim (1994) and Hamilton (1994). Figure 3 illustrates the smoothed probabilities obtained from both indexes analyses.

[Insert Figure 3 about here]

These suggest that the watershed of regimes occurs mid-2007, with the crisis regime dominating thereafter until the end of the sample. This suggests that exogenously imposing the crisis regime to begin in January 2007, as in Longstaff (2010), may not be realistic. Furthermore, treating 2007 as a single period for analysis ignores the structural break that occurs midway through the year and thus may create problems for the original analysis. We observe a fall in these probabilities in the spliced ABX system between July and September 2008, which may be an effect of splicing the data. The smoothed probabilities for the ABX 06-1 index analysis exhibit less spikes. This difference is again probably due to the fact that the ABX 06-1 index is a continuous variable and so avoids the jumps induced by splicing the indexes together.

Our first task is to classify two regimes, a low-volatility non-crisis regime and a high-volatility crisis regime. Turning first to the spliced ABX index TVTP MS-VAR analysis Table 2 reports means and standard deviations for each variable in each regime, along with the coefficients on the transition probabilities. These coefficients can be viewed as a measure of persistence of a regime. Significant coefficients indicate that the regime under consideration is persistent, that is, it is highly likely that whatever state prevails at $t-1$ will prevail at t.

[**Insert Table 2 about here**]

The results reported in Table 2 indicate that two regimes are identifiable. The standard deviation of each variable increases following the watershed of regimes, and standard deviations are statistically different from zero in regime two, the crisis regime. Also, significant coefficients on the indicated transition probabilities suggest that the crisis regime is persistent.

Table 2 reports that the ABX AAA-rated asset mean returns become increasingly negative after the regime switch, as expected. However, S&P 500 index mean returns actually increase. This may be due to the S&P 500 experiencing losses much later than the spliced ABX index. The Treasury spread mean falls slightly following the watershed of regimes, indicating that this spread was narrowing following the crisis. Intuitively this is not the result we expect, but the change is relatively small. The mean changes of the corporate spread become negative following the regime switch implying that this spread narrowed during the crisis and the VIX becomes negative in the crisis regime, indicating a decrease in this variable. These results suggest that, given the long duration of the ABX crisis, investors became optimistic about general market volatility and corporate bond markets earlier than they did about any potential recovery in the market for subprime mortgage-backed securities. Also, the crisis was not coincident across markets and so would have affected them at different times depending on market events.

As a preliminary analysis of how the relationship between the ABX asset and the financial market variables may have changed following the crisis, Table 3 reports the correlation coefficients between them in each regime.

[**Insert Table 3 about here**]

The correlation between the ABX asset and the S&P 500 index increases following the switch from a non-crisis to a crisis regime, as expected. Although the ABX asset is negatively correlated with each other financial market variable in both regime, it becomes less so after the watershed of regimes. This indicates that, although still negative, there was increase in the correlation between these assets once the crisis hit the system. However, as shown by Forbes & Rigobon (2002), an increase in correlation does not necessarily constitute contagion. We therefore examine the coefficients on the AAA-rated ABX variable in each of the indicated VAR equations in order to ascertain if there was any change in the relationships between these assets after the regime switched. Results are reported in Table 4. T-statistics are reported in parentheses.

[**Insert Table 4 about here**]

Following our definition of contagion as a significant change in cross-market linkages following a shock in one market we fail to reject the null hypothesis of no contagion based on the results presented in Table 4. None of the coefficients are statistically different from zero in either regime suggesting that the ABX had no significant effect on the financial market variables in either non-crisis or crisis times. This result is in direct contrast to that presented in Longstaff (2010) in that we find no evidence of any lead-lag relation between ABX index returns and changes in the financial market variables analysed, no forecast power from the indexes and, thus, no evidence of price discovery. We do, however, find evidence of Granger-causality from some of the financial market variables to the spliced ABX index during the non-crisis period.[6] Specifically, stock market returns and changes in the VIX index Granger-cause subsequent returns in the spliced ABX index. These interdependencies then dissipate in the crisis regime, suggesting that these assets behaved independently during the turbulent period as investors exited the asset-backed security sector. This indicates that, as the crisis evolved from a subprime security-backed problem to a broader global crisis risks were propagated through other channels. Possible channels include real estate market and the asset-backed commercial paper (ABCP) market. It is likely that shocks were filtered through such markets before reaching the financial markets examined here, meaning that that risk transmission to these financial variables was not instantaneous.

Next we turn to the ABX 06-1 index TVTP MS-VAR analysis. First we classify a low-volatility non-crisis and a high-volatility crisis regime by analysing the volatility of the variables in each state. Table 5 reports means and standard deviations for each variable in each regime, along with the coefficients on the transition probabilities.

[Insert Table 5 about here]

As the standard deviation of each variable increases following the watershed of regimes we can easily identify a non-crisis and a crisis regime. Again, all crisis regime standard deviations are highly significant and the significant coefficients on the indicated transition probabilities suggest that the crisis regime is persistent.

Turning to the means of each variable in both regimes, Table 5 reports that, unsurprisingly, the mean returns of the AAA-rated ABX asset and the S&P 500 index both become negative in the crisis period. This is in contrast to the results presented for the spliced ABX index, in which the S&P index expected mean increases following the regime switch. This suggests that in the VAR system driven by changes in the actual traded ABX asset the S&P 500 index began to fall earlier than in that driven by the spliced ABX index asset, indicating differences between the two ABX indexes.

The mean of the Treasury bond changes becomes positive following the watershed of regimes implying that this spread widened during the crisis as the difference between short- and long-term Treasury bonds increased. Again both the corporate spread and VIX mean changes become negative, although not statistically significant, pointing to investor sentiment regarding these markets improving earlier than that regarding the ABX market.

Table 6 reports that the correlation between the AAA-rated ABX asset and the other financial market variables in both regimes.

[Insert Table 6 about here]

The ABX asset becomes more correlated with the S&P 500 index and the corporate spread following the watershed of regimes. However, it becomes negatively correlated with both the VIX and the Treasury bill spread, suggesting that a fall in the ABX corresponds to an increase in changes in both the VIX and the government spread. Table 7 provides the coefficients on the AAA-rated ABX variable in the indicated VAR equations.

[Insert Table 7 about here]

Again, we observe no significant coefficients and so we fail to reject the null hypothesis of no contagion from the ABX 06-1 index to the

[6] In order to conserve space these are not reported here. Full results are available upon request.

financial market variables examined. As mentioned earlier this could be because the shocks were transmitted through different channels, such as the asset-backed commercial paper (ABCP) market, before reaching equity, Treasury, corporate bond and volatility markets. As in the spliced ABX index analysis we find the stock market and volatility market measures Granger-cause ABX 06-1 index returns in the non-crisis regime indicating that before the crisis hit these markets significantly affected the asset-backed security market. This is reasonable, given that during this time these assets were growing in popularity and were closely monitored by market participants as a means of gauging the subprime market risk and so had links with equity market conditions and general market volatility. During 2007, however, there is no evidence of linkages among the financial market variables and either ABX index. As the subprime crisis hit, investors began to rapidly reassess the risk of these products, subsequently exiting this market. Trades in these securities slowed down as concerns regarding counterparty risk increased and general market liquidity dried up. Risks from the ABX indexes quickly became overshadowed by credit shortages and the ability of institutions to roll over debt. It is likely then that these risks transmitted to markets in a more rapid fashion than those emanating from the ABX. The ABX market is closely linked to the ABCP market and the real estate market so it is likely that these markets would have been negatively affected by its collapse sooner than the financial markets analysed here. Risk may then have filtered down to these markets through these channels.

Clearly, these results are in striking contrast to those obtained by Longstaff (2010). Firstly, we find no evidence of cross-market contagion. Also, many of the expected means and correlations are considerably different among the two data sets. Finally, the ex-post smoothed probabilities suggest that exogenously imposing a crisis regime to begin in January 2007 may not be appropriate. It is therefore important that we address why these differences may occur.

As discussed above the spliced ABX index is a combination of the four ABX indexes, spliced together at each subsequent vintage issuance date. The dominant index is therefore the 07-2 index, which would be the riskiest of the four as it was issued in July 2007 and backed by loans originated in early 2007. As well as contrasting to the findings presented by Longstaff (2010), the results from the TVTP MS-VAR analysis are surprising, as they suggest that the financial markets examined experienced no interactions during the crisis regime. In order to investigate this further we perform a number of robustness checks. Firstly, we perform several diagnostic tests on the standardized expected residuals from the above models. Secondly, we re-perform the TVTP MS-VAR analysis employing the BBB-rated ABX asset as an endogenous variable in an effort to ascertain if contagion many have emanated from this riskier asset. Finally, we perform trivariate TVTP MS-VAR analyses in order to address if the methodology, and in particular the dimensionality of our application, may have influenced the results.

VII. Robustness Checks

VII.1 Diagnostic Tests on Standardized Expected Residuals

Due to the state variable s_t, residuals are unobservable so we must calculate the standardized expected residuals. Following Maheu & McCurdy (2000) and using equation (2) these are calculated as follows:

$$\sum_{s_t,\dots s_{t-1}} \frac{Y_{i,t} - E[Y_{i,t}]|s_t, \dots, s_{t-1}, Y_{i,t-1}}{\sigma(st)} P(s_t, \dots, st-1|Y_{t-1}). \quad (6)$$

Table 8 presents the results of diagnostic tests on these residuals.

[Insert Table 8 about here]

Columns 1 and 2 of Table 8 report the LM test for serial correlation in the standardized expected residuals of each variable examined in both analyses. For the majority of variables we cannot reject the null of no serial correlation at both one and four lags. To test for Normality we use the Anderson-Darling test. Column 5 indicates that the majority of expected standardized residuals in the spliced ABX analysis are normally distributed but in most cases for the ABX 06-1 index analysis we reject normality. We find considerable evidence of ARCH effects at both lags one and four. Such a result suggests that an alternative approach, such as a switching ARCH model, may be more appropriate. However, given the relatively short time span of the data such a model may prove difficult to estimate. It should also be noted that, as Maheu & McCurdy (2000) point out, *"since we do not know the asymptotic distribution of the LB statistic using the standardized expected residuals, specification tests should be interpreted with caution."*

VII.2 TVTP MS-VAR Analysis 2

In order to check the robustness of the above results the analysis is repeated with various ABX endogenous variables and various ABX information variables. Firstly, all other ABX assets are included in each analysis as an information variable in place of the AA-rated asset and the results do not change qualitatively. Next, the BBB-rated ABX asset is included as an endogenous variable in each analysis, in place of the AAA-rated asset.[7] In order to conserve space the results are not presented here but again we observe no evidence to support contagion from the ABX indexes to the financial market variables, however we do observe some persistence in the crisis regime.[8] Overall these results indicate that our main analysis is robust.

VII.3 Trivariate TVTP MS-VAR Analysis

Our results are unusual as they suggest that during the crisis regime all financial markets examined behaved independently, suggesting that the fact that they all experienced an increase in volatility and an increase in correlation with one another was coincidental. One reason we may observe such results could be a consequence of the large number of parameters in the model that require simultaneous estimation from a relatively short data set. A highly nonlinear model such as the TVTP MS-VAR model employed is extremely sensitive to the inclusion of many variables and lags (Manzan, 2004). Therefore, in an effort to reduce the dimensionality of the model, and to obtain clearer results, we employ one lag trivariate TVTP MS-VARs using the system presented in equation (2). We use every possible pair of financial market variables plus the AAA-rated ABX asset in the system, yielding six separate trivariate models for each ABX index. In order to conserve space the results are not presented here but are available on request and will be discussed. As before, two regimes are easily identified as volatility increases once the system enters a crisis regime for every variable. Mean returns are also reasonable, for example S&P 500 mean returns become negative in the crisis regime. The crisis regime is also persistent in all estimations and the smoothed probabilities again suggest that the system entered a crisis regime in mid-2007.

Turning first to the spliced ABX index analyses, the trivariate analyses suggest that there is some evidence of contagion from the ABX asset to the S&P 500, as ABX returns Granger-cause subsequent stock market returns in the crisis regime. However, the coefficients are statistically different from zero at only the 10% level. There is also evidence of significant linkages between U.S. Treasury and corporate debt markets in the crisis regime, which could be indicative of a "flight to quality" by investors. There is also evidence of contagion between government and corporate bond markets in the ABX 06-1 index analyses. We also find evidence of increased sensitivity to the ABX market in all other markets in the traded index analyses, although not present in each pair

[7] The BBB- rated asset was also included but, possibly due to stagnant prices during the crisis regime, provided imprecise estimates.

[8] Full results are available on request.

analysed.
These results again highlight the differences between the spliced and traded indexes and also shed some light on the observed differences in results between our original analyses and those reported in Longstaff (2010). They indicate that when the crisis is correctly identified there is indeed evidence of increased interactions between the financial markets analysed in the crisis regime, however this contagion is not as widespread as that suggested in Longstaff (2010). Again, this could be due to the timing of market events and contagion filtering down from markets more closely related to the asset-backed securities market to the financial markets examined, meaning we would not observe a link as direct as that reported in Longstaff (2010). The results we present are in fact more consistent with those reported in Longstaff (2010) for the "global-crisis" period of 2008, in which there is little evidence of contagion. This suggests that the credit crisis led to decreased linkages between the ABX market and the other financial markets, as investors were rapidly exiting the asset-backed securities market and concerns were turning more toward liquidity.
In terms of methodology, the original application essentially ignored the structural break that occurred in 2007, indicating that accurately dating the crisis is crucial to the analysis. Employing a four lag model, as in Longtaff (2010) and failing to take into account the structural break in mid-2007 could induce persistence in the model (Perron, 2006), causing the differences in results.

VIII. Conclusions

This analyses contagion from the U.S. subprime mortgage-backed securities market by following and extending the VAR framework presented in Longstaff (2010). In order to do so we employ a Markov-switching VAR with time-varying transition probabilities. We apply the analysis to both the spliced ABX index employed by Longstaff (2010) and a traded ABX index, the ABX 06-1. The results allow us to determine a low-volatility non-crisis regime and a high-volatility crisis regime. We also determine, via ex-post smoothed probabilities of the system being in crisis regime, that the watershed of regimes occurs in mid-2007, with the risky regime dominating thereafter until the end of the sample. Our VAR analysis suggests that the ABX indexes did not serve as a source of contagion to these markets during the 2007-2009 crisis, which is in striking contrast to the findings of Longstaff (2010).
In an effort to reduce the dimensionality of the model, and better capture contagion, we employ trivariate VAR analyses, the results of which yield some tentative evidence of contagion, although not as widespread as that reported by Longstaff (2010). Dating the crisis appears to be crucial, as in the original application the crisis period is an amalgamation of the tranquil start to 2007 followed by a turbulent second half. Again, breaking the crisis at the end of that year doesn't receive any support in our regime-switching model and in fact, our overall results are more in line with his reported 2008 sample where there is little or no evidence of contagion.

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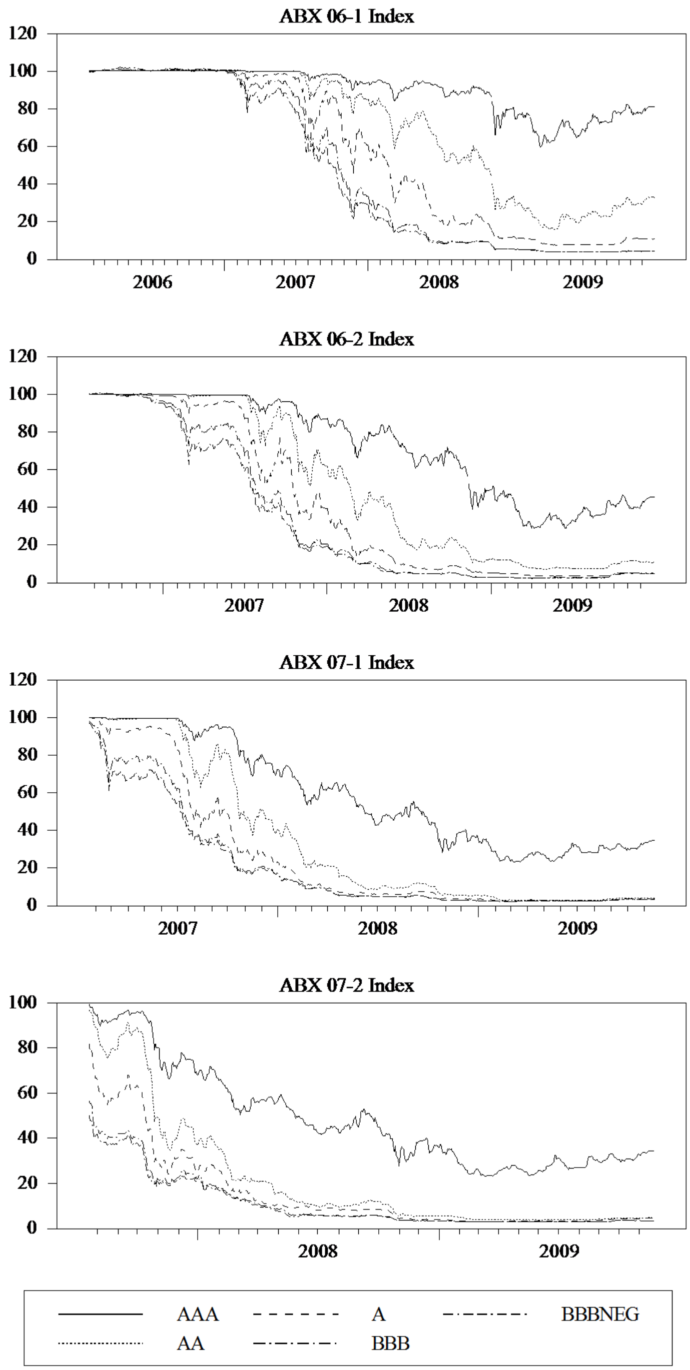

Figure 1: *ABX raw prices.*

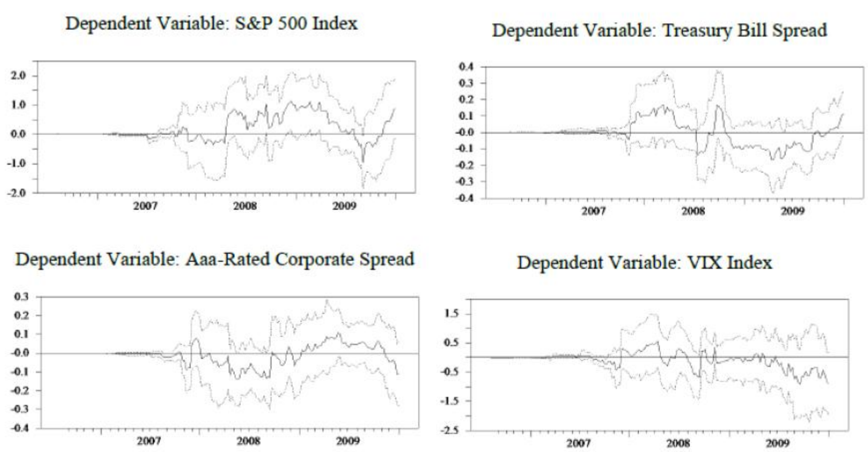

Figure 2: *Spliced ABX Index Rolling VAR Coefficients. Window width = 24.*
The solid black lines are point estimates; the dashed lines are confidence bands.

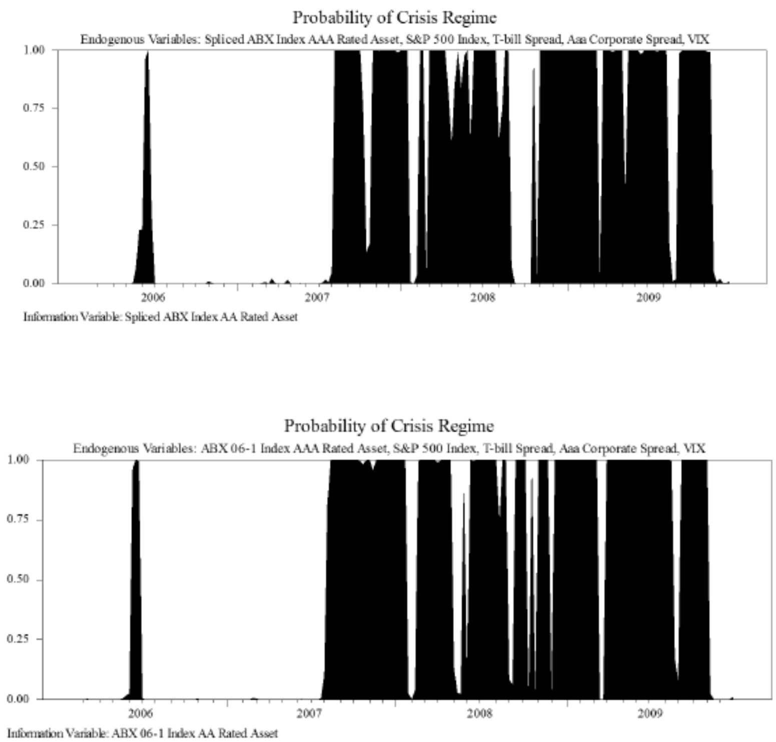

Figure 3: *The upper panel illustrates the smoothed probabilities of the spliced ABX index TVTP MS-VAR system being in crisis; the lower panel illustrates the smoothed probabilities of the ABX 06-1 index TVTP MS-VAR system being in crisis.*

Table 1: *Summary statistics for ABX indexes weekly returns*

*Notes:*This table reports summary statistics for the weekly percentage price changes for the indicated ABX indexes for the entire sample period. The sample consists of weekly data from January 25, 2006 to December 31, 2009. Std.dev. denotes standard deviation; min. denotes minimum value; max. denotes maximum value.

Data set	Rating	Mean	Std.dev.	Skewness	Kurtosis	Min.	Max
Spliced ABX Index	AAA	-0.432	4.749	-0.072	2.709	-16.573	14.839
	AA	-1.338	5.852	-1.453	7.266	-29.754	21.416
	A	-1.410	5.799	-1.420	5.811	-28.786	18.773
	BBB	-1.604	4.764	-1.116	3.825	-21.429	13.595
	BBB-	-1.572	4.950	-1.107	4.468	-26.617	12.941
ABX 06-1 Index	AAA	-0.068	2.599	-0.555	9.487	-14.933	12.209
	AA	-0.386	5.571	0.720	11.475	-26.347	35.223
	A	-0.889	6.058	0.027	3.920	-19.908	24.216
	BBB	-1.323	5.762	-1.535	8.032	-32.947	21.367
	BBB-	-1.349	5.143	-1.978	7.814	-27.130	16.264

Table 2: *Spliced ABX Index TVTP MS-VAR Estimation Results 1*

Notes: This table reports means and standard deviations of the indicated variables in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly returns, S& P 500 Index weekly returns, weekly changes in Treasury Bill spread, weekly changes in Moody's Aaa corporate spread or weekly changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset weekly returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level. θ denotes the coefficient on the indicated transition probability.

	Non-Crisis Regime		Crisis Regime	
	μ	σ	μ	σ
ABX AAA-rated Asset	-0.24	1.79	-0.58	6.01
	(-0.36)	(1.70*)	(-0.35)	(2.71**)
S&P 500 Index	0.09	1.97	0.26	2.87
	(0.14)	(1.68*)	(0.33)	(2.10**)
Treasury Bill Spread	1.91	8.45	1.81	15.27
	(0.97)	(2.24**)	(0.38)	(1.65*)
Aaa Corporate Spread	1.72	10.70	-2.40	15.90
	(0.44)	(1.44)	(-0.72)	(2.23**)
VIX Index	0.56	2.36	-0.95	3.58
	(0.70)	(1.75*)	(-0.92)	(1.70**)
		$\theta_{p1} = 2.23^{*}$	$\theta_{q1} = 2.73^{**}$	
		$\theta_{p2} = 0.34$	$\theta_{q2} = 0.05$	

Table 3: *Spliced ABX Index TVTP MS-VAR Estimation Results 1*

Notes: This table reports the correlation coefficients for the ABX AAA asset and the indicated variables in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly returns, S& P 500 Index weekly returns, weekly changes in Treasury Bill spread, weekly changes in Moody's Aaa corporate spread or weekly changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset weekly returns.

	Non-Crisis Regime	Crisis Regime
$\rho_{AAA,S\&P500Index}$	0.57	0.57
$\rho_{AAA,TreasuryBillSpread}$	-0.22	-0.02
$\rho_{AAA,AaaCorporateSpread}$	-0.54	-0.16
$\rho_{AAA,VIXIndex}$	-0.61	-0.52

Table 4: *Spliced ABX Index TVTP MS-VAR Estimation Results 1*

Notes: This table reports the coefficients on the AAA ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly returns, S& P 500 Index weekly returns, weekly changes in Treasury Bill spread, weekly changes in Moody's Aaa corporate spread or weekly changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset weekly returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

	Non-Crisis Regime		Crisis Regime	
	β_1	β_2	β_1	β_2
S&P 500 Index	-0.35	-0.25	0.02	0.07
	(-1.01)	(-0.64)	(0.18)	(0.45)
Treasury Bill Spread	1.66	0.34	-0.48	0.47
	(0.94)	(0.19)	(-0.54)	(0.56)
Aaa Corporate Spread	-0.53	-0.63	0.12	-1.13
	(-0.31)	(-0.26)	(0.15)	(-1.19)
VIX Index	0.31	0.25	-0.01	-0.01
	(0.79)	(0.47)	(-0.05)	(-0.03)

Table 5: *ABX 06-1 Index TVTP MS-VAR Estimation Results 1*

Notes: This table reports means and standard deviations of the indicated variables in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly returns, S& P 500 Index weekly returns, weekly changes in Treasury Bill spread, weekly changes in Moody's Aaa corporate spread or weekly changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset weekly returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.θ denotes the coefficient on the indicated transition probability.

	Non-Crisis Regime		Crisis Regime	
	μ	σ	μ	σ
ABX AAA-rated Asset	-0.34	0.92	0.22	3.08
	(-0.89)	(2.11**)	(0.21)	(2.39**)
S&P 500 Index	0.47	1.58	-0.23	3.31
	(0.78)	(2.10**)	(-0.23)	(2.19**)
Treasury Bill Spread	-0.54	7.46	3.69	16.31
	(-0.16)	(1.46)	(0.75)	(2.10**)
Aaa Corporate Spread	1.49	8.44	-1.41	16.54
	(0.47)	(1.90*)	(-0.37)	(2.18**)
VIX Index	0.08	1.86	-0.53	4.13
	(0.12)	(2.49**)	(-0.41)	(2.61**)
		$\theta_{p1} = 2.27^{*}$	$\theta_{q1} = 2.90^{*}$	
		$\theta_{p2} = 0.74$	$\theta_{q2} = 0.07$	

Table 6: *ABX 06-1 Index TVTP MS-VAR Estimation Results 1*

Notes: This table reports the correlation coefficients for the ABX AAA asset and the indicated variables in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly returns, S& P 500 Index weekly returns, weekly changes in Treasury Bill spread, weekly changes in Moody's Aaa corporate spread or weekly changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset weekly returns.

	Non-Crisis Regime	Crisis Regime
$\rho_{AAA,S\&P500Index}$	-0.25	0.52
$\rho_{AAA,TreasuryBillSpread}$	0.49	-0.02
$\rho_{AAA,AaaCorporateSpread}$	-0.45	-0.22
$\rho_{AAA,VIXIndex}$	0.15	-0.36

Table 7: *ABX 06-1 Index TVTP MS-VAR Estimation Results 1*

Notes: This table reports the coefficients on the AAA ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly returns, S& P 500 Index weekly returns, weekly changes in Treasury Bill spread, weekly changes in Moody's Aaa corporate spread or weekly changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset weekly returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

	Non-Crisis Regime		Crisis Regime	
	β_1	β_2	β_1	β_2
S&P 500 Index	-0.54	0.13	-0.12	0.01
	(-0.63)	(0.13)	(-0.30)	(0.02)
Treasury Bill Spread	1.13	-1.65	-0.47	0.79
	(0.24)	(-0.39)	(-0.27)	(0.45)
Aaa Corporate Spread	-4.34	-1.37	0.40	-1.16
	(-0.82)	(-0.34)	(0.21)	(-0.52)
VIX Index	0.11	-0.21	0.27	0.07
	(0.08)	(-0.19)	(0.59)	(0.14)

Table 8: *Diagnostic Tests On Standardized Expected Residuals*

Notes: LM(k) is the Breusch-Godfrey Lagrange Multiplier test for no serial correlation up to lag k, ARCH(k) is the Lagrange Multiplier test for the ARCH effects of order k, Normality is the Anderson-Darling test for the null of normality. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Spliced ABX Index Analysis					
Variable	LM(1)	LM(4)	ARCH(1)	ARCH(4)	Normality
ABX AAA-rated Asset	0.04	2.72^{*}	16.16^{**}	9.32^{**}	5.63^{**}
S&P 500 Index	0.05	0.43	4.66^{**}	3.61^{*}	1.30
Treasury Bill Spread	1.40	1.43	3.69^{*}	2.45^{*}	1.89
Aaa Corporate Spread	0.29	0.01	0.04	3.70^{**}	0.98
VIX Index	0.06	0.05	8.01^{**}	8.67^{**}	1.57
ABX 06-1 Index Analysis					
Variable	LM(1)	LM(4)	ARCH(1)	ARCH(4)	Normality
ABX AAA-rated Asset	0.90	8.03^{**}	3.79^{*}	5.65^{*}	6.61^{**}
S&P 500 Index	0.13	3.08^{*}	1.35	0.62	3.58^{**}
Treasury Bill Spread	2.15	0.30	0.87	4.34^{**}	2.58^{**}
Aaa Corporate Spread	0.02	0.75	4.72^{**}	6.46^{**}	1.17
VIX Index	0.12	0.02	2.66	8.18^{**}	4.13^{**}