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The subprime credit crisis and contagion in financial markets ☆

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ABSTRACT

I conduct an empirical investigation into the pricing of subprime asset-backed collateralized debt obligations (CDOs) and their contagion effects on other markets. Using data for the ABX subprime indexes, I find strong evidence of contagion in the financial markets. The results support the hypothesis that financial contagion was propagated primarily through liquidity and risk-premium channels, rather than through a correlated-information channel. Surprisingly, ABX index returns forecast stock returns and Treasury and corporate bond yield changes by as much as three weeks ahead during the subprime crisis. This challenges the popular view that the market prices of these "toxic assets" were unreliable; the results suggest that significant price discovery did in fact occur in the subprime market during the crisis.

1. Introduction

During the past three years, financial markets have suffered catastrophic losses. These were originally triggered by the threat of massive defaults by subprime borrowers in the mortgage markets. The resulting subprime crisis of 2007 led rapidly to massive declines in the market values of large portfolios of highly rated asset-backed securities (ABS) held by many financial institutions. In addition, the subprime crisis brought about an almost complete halt to the fledgling structured-credit market, a serious credit crunch for both individuals and financial institutions, and a major decline in the liquidity of debt securities in virtually every market.

In 2008, the subprime crisis spilled over and became the catalyst for a much broader global financial crisis. During the year, the markets reeled from the collapse or forced mergers/bailouts of Bear Stearns, AIG, Fannie Mae, Freddie Mac, Lehman Brothers, IndyMac Bank, Merrill Lynch, Wachovia, Washington Mutual, and many others. Concerns about the long-term financial viability of the U.S. Treasury, which has provided an unprecedented amount of liquidity, capital, and financial guarantees to the market, has resulted in credit default swaps on the U.S. Treasury trading at spreads as high as 100 basis points. Much of the intervention by the Treasury and the Federal Reserve in the financial markets has been motivated by the objective of avoiding broader contagion and spillovers to other markets and sectors of the economy.

Understanding the nature of contagion in financial markets is of fundamental importance and there is an

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extensive literature addressing its causes and effects. Important recent papers on contagion include Allen and Gale (2000), Kyle and Xiong (2001), Kodres and Pritsker (2002), Kiyotaki and Moore (2002), Kaminsky, Reinhart, and Vegh (2003), Allen and Gale (2004), Brunnermeier and Pedersen (2005, 2009), and many others. From a research perspective, the crisis in the subprime asset-backed market provides a near-ideal "laboratory" for studying the role that contagion may play in financial markets when an asset class becomes severely distressed.[1]

The contagion literature identifies at least three possible mechanisms by which shocks in one market may spill over into other markets. First, Kiyotaki and Moore (2002), Kaminsky, Reinhart, and Vegh (2003), and others describe mechanisms in which negative shocks in one market represent the arrival of economic news that directly affects the collateral values or cash flows associated with securities in other markets. In this mechanism, contagion can be viewed as the transmission of information from more-liquid markets or markets with more rapid price discovery to other markets. Second, Allen and Gale (2000), Brunnermeier and Pedersen (2009), and others show how investors who suffer losses in one market may find their ability to obtain funding impaired, potentially leading to a downward spiral in overall market liquidity and other asset prices via a "flight to quality." In this mechanism, contagion occurs through a liquidity shock across all markets. Third, Vayanos (2004), Acharya and Pedersen (2005), Longstaff (2008), and others imply that a severe negative shock in one market may be associated with an increase in the risk premium in other markets. In this mechanism, contagion occurs as negative returns in the distressed market affect subsequent returns in other markets via a time-varying risk premium.

The objective of this paper is to shed some light on the mechanisms involved in financial contagion by studying the subprime asset-backed collateralized debt obligation (CDO) market during the 2006–2008 period and exploring how negative shocks affected other markets as the subprime crisis of 2007 unfolded and then evolved into the global financial crisis of 2008. The study is based on an extensive data set of prices for the ABX indexes of subprime mortgage-related asset-backed CDOs. Using a vector autoregression (VAR) framework, I examine the extent to which ABX returns are related to returns in other financial markets as well as to market leverage and trading activity measures.

Several key results emerge from this analysis. First, despite the lower liquidity of the asset-backed CDO market, I find that ABX index returns developed significant predictive ability (Granger causality) for subsequent stock market returns, Treasury yield changes, corporate bond spread changes, and changes in the VIX volatility index as the 2007 subprime crisis unfolded. In fact, ABX returns have significant forecast power for stock returns, Treasury yield changes, corporate yield spread changes, and changes in the VIX as far as three weeks ahead. Treasury bond prices increase in response to negative shocks to asset-backed CDO values, consistent with a flight-to-quality pattern. This effect, however, is much stronger for short-term Treasury bonds than for longer-term Treasury bonds. In contrast, negative shocks to the ABX indexes map into significant subsequent negative returns for the Standard and Poors (S&P) 500 index as well as for the subset of financial firms in the S&P 500. Thus, I find strong evidence of contagion in the financial markets during the 2007 subprime crisis.

Second, I find that this forecast ability dissipates during 2008 as the subprime crisis gave way to the broader global financial crisis. Thus, contagion appeared to spread from the ABX market at the beginning of the crisis when subprime losses were the primary concern. After concerns about a meltdown of the general financial markets and the potential for a global depression became widespread in 2008, however, the ABX market no longer functioned as a vector of contagion (and no longer Granger-caused returns) in other markets. Intuitively, this is consistent with the usual view of contagion as a major shock or event in which there is a significant but temporary increase in the linkages between different financial markets.

Taken together, these results provide a number of important insights about the nature of the mechanisms driving contagion across markets in the present crisis. For example, finding that shocks tended to be transmitted with a lag from the less-liquid ABX index market to the highly liquid stock and Treasury bond markets argues against a correlated-information view of financial contagion. We would expect price effects to be contemporaneous in the highly liquid stock and Treasury bond markets if contagion was due to correlated information. Thus, the results (which, of course, are limited to the specific episode studied) appear to be more consistent with either the liquidity-induced contagion mechanisms presented by Allen and Gale (2000), Kodres and Pritsker (2002), and Brunnermeier and Pedersen (2005), or the risk-premium contagion mechanisms implied by Vayanos (2004), Acharya and Pedersen (2005), and Longstaff (2008).

To explore this latter implication in more depth, I again use a VAR framework to explore the relation between ABX index returns and various measures of market activity, liquidity, and funding availability. I find that shocks in the ABX market have significant predictive power for trading activity in financial stocks, trading disruptions in the fixed-income markets, and the availability of short-term asset-backed financing during the crisis. These results reinforce the view that market- and funding-liquidity effects were a major factor in the transmission of contagion during the subprime crisis.

The remainder of this paper is organized as follows. Section 2 briefly reviews the literature on contagion in financial markets. Section 3 provides an introduction to

[1] Important papers focusing on the valuation of distressed assets include Shleifer and Vishny (1992), Asquith, Gertner, and Scharfstein (1994), Opler and Titman (1994), Clark and Ofek (1994), John and Ofek (1995), Andrade and Kaplan (1998), Pulvino (1998), Kahl (2002), Longstaff (2004), Vayanos (2004), Acharya and Pedersen (2005), Brunnermeier and Pedersen (2005), Carlin, Lobo, and Viswanathan (2007), and Longstaff and Myers (2009).

the asset-backed CDO market. Section 4 describes the ABX indexes and the other data used in the study. Section 5 presents the empirical test for contagion. Section 6 examines the implications of the subprime crisis for market liquidity. Section 7 summarizes the results and presents concluding remarks.

2. Contagion in financial markets

The literature on contagion in financial markets is far too extensive to review fully here. Kindleberger (1978), Dornbusch, Park, and Claessens (2000), and Kaminsky, Reinhart, and Vegh (2003), however, provide excellent surveys. Generally, this literature has focused on contagion effects across countries. Contagion, however, is possible in virtually any set of financial markets. In this section, I will simply summarize some of the key implications of the contagion literature for the behavior of security prices during periods of extreme market distress.

Following Dornbusch, Park, and Claessens (2000), Kaminsky, Reinhart, and Vegh (2003), Bae, Karolyi, and Stulz (2003), and many others, I adopt a working definition of financial contagion as an episode in which there is a significant increase in cross-market linkages after a shock occurs in one market. The literature identifies at least three major channels by which contagion effects can be propagated through different financial markets.

The first channel can be termed the correlated-information channel. In this mechanism, a shock to one financial market signals economic news that is directly or indirectly relevant for security prices in other markets. Note that this could be consistent with the revelation of information about economic factors affecting multiple markets. For example, Dornbusch, Park, and Claessens (2000) describe direct effects occurring through fundamentals such as trade links. Kiyotaki and Moore (2002) describe a balance-sheet channel in which losses in one market translate into declines in the equity of other firms holding the distressed assets. King and Wadhwani (1990) present a model in which contagion occurs as rational agents attempt to infer information from price changes in other markets. A common implication throughout the correlated-information literature is that contagion occurs rapidly via the price-discovery process. Thus, this channel should result in immediate price effects in the markets affected by the distress event, particularly when these markets are more liquid than the market in which the original distress event occurs. This implication of the correlated-information contagion mechanism can be directly tested using a VAR framework.[2]

The second channel can be designated the liquidity channel. In this mechanism, a shock to one financial market results in a decrease in the overall liquidity of all financial markets. In turn, this may affect investor behavior and asset prices. For example, Allen and Gale (2000) present a model in which banks have cross holdings of deposits across regions. In this model, financial shocks cause banks to liquidate these cross holdings, thereby denying liquidity to other regions. Kodres and Pritsker (2002) present a model in which contagion occurs as losses in one market force economic agents to either liquidate leveraged positions or to rebalance their portfolios in response. Brunnermeier and Pedersen (2009) argue that agents who experience losses in one market may find their ability to obtain funding impaired, which would then result in declines in the liquidity of the other financial assets in the markets. A key implication of this liquidity-related channel of contagion is that a distress event may be associated with subsequent declines in the availability of credit and increases in trading activity in other markets. Note that this spiraling mechanism might play out over an extended period.

The third channel can be termed the risk-premium channel. In this mechanism, financial shocks in one market may affect the willingness of market participants to bear risk in any market. Thus, prices in all markets may be affected as equilibrium risk premia adjust in response. For example, Vayanos (2004) and Acharya and Pedersen (2005) present models in which shocks such as those that might result from a distress event translate into major changes in the equilibrium risk premia of assets in the economy. An important implication of this time variation in risk premia is that return shocks to the distressed security may be predictive for the subsequent returns of other assets. This follows because when the risk premium for an asset increases during the current period, it also impacts the distribution of future asset returns. In turn, this feedback effect can induce predictability into the time series of realized asset returns.

These contagion channels all have different implications for the behavior of security prices across markets when a distress event occurs. It is important to note, however, that there may also be similarities between the different channels.[3] I will explore the empirical implications of the various channels later in the paper.

3. The subprime asset-backed CDO market

In the current crisis, tranches or CDOs based on the cash flows of portfolios of subprime home-equity loans were originally the major source of credit losses for many financial institutions. Accordingly, I focus primarily on these securities throughout this study. This section

[2] This argument is clearly predicated on the assumption that markets are informationally efficient. If it takes an extended period to incorporate information revealed in one market into other markets, then it will clearly be more difficult to differentiate effects of the correlated-information channel from those implied by other channels. I am grateful to the referee for this insight.

[3] For example, there is clearly a relation between credit risk and liquidity. In fact, a significant factor during the subprime crisis of 2007 may have been credit-risk-induced illiquidity as investors were leary of taking positions in complex mortgage-related securities. On the other hand, an important factor in the global financial crisis of late 2008 may have been illiquidity-induced credit risk as major financial institutions faced default because they were unable to liquidate positions and collateralize their liabilities. I am grateful to the referee for pointing out this issue.

Table 1
Countrywide Home Loans, Inc. subprime ABS CDO structure CWABS 2006-1.

This table reports some of the contractual terms for the subprime ABS CDO structure issued by Countrywide Home Loans, Inc. through Lehman Brothers in February 2006. The issuing entity is designated as CWABS Asset-Backed Certificates Trust 2006-1. Of the total notional amount underlying the CDO, approximately $500 million is based on subprime fixed-rate mortgages while $400 million is based on subprime floating-rate mortgages. The L in the initial pass-through rate represents one-month LIBOR. The seniority ranking n/m means that the tranche's seniority is n-th out of m tranches.

Tranche	Notional amount	Price to public	Under-writer fee	Initial pass-through rate	Maturity	Initial Moody's rating	Initial S&P rating	Seniority ranking
AF-1	147,232,000	100.0000	0.0521	L+ 0.130%	Nov 2025	Aaa	AAA	1/7
AF-2	22,857,000	99.9995	0.1042	5.281%	May 2027	Aaa	AAA	1/7
AF-3	90,995,000	99.9998	0.1563	5.384%	Jul 2033	Aaa	AAA	1/7
AF-4	21,633,000	99.9985	0.2500	5.714%	Sep 2034	Aaa	AAA	1/7
AF-5	38,617,000	99.9987	0.3333	5.884%	Jul 2036	Aaa	AAA	1/7
AF-6	44,200,000	99.9980	0.4167	5.526%	May 2036	Aaa	AAA	1/7
MF-1	13,260,000	99.9981	0.4167	5.917%	May 2036	Aa1	AA+	2/7
MF-2	12,155,000	99.9972	0.5000	6.016%	May 2036	Aa2	AA+	3/7
MF-3	7,293,000	99.9965	0.5833	6.115%	Apr 2036	Aa3	AA	4/7
MF-4	6,409,000	99.4627	0.8333	6.200%	Apr 2036	A1	AA−	5/7
MF-5	6,188,000	98.9985	1.0000	6.200%	Mar 2036	A2	A+	6/7
MF-6	5,525,000	98.5371	1.2500	6.200%	Feb 2036	A3	A	7/7
AV-1	139,560,000	100.0000	0.0522	L+0.080%	Jul 2028	Aaa	AAA	1/8
AV-2	115,712,000	100.0000	0.1033	L+0.190%	May 2035	Aaa	AAA	1/8
AV-3	25,042,000	100.0000	0.1033	L+0.300%	Jun 2036	Aaa	AAA	1/8
MV-1	14,320,000	100.0000	0.4167	L+0.390%	May 2036	Aa1	AA+	2/8
MV-2	13,067,000	100.0000	0.5000	L+0.410%	May 2036	Aa2	AA+	3/8
MV-3	7,518,000	100.0000	0.8333	L+0.440%	May 2036	Aa3	AA	4/8
MV-4	6,802,000	100.0000	0.9167	L+0.560%	Apr 2036	A1	AA−	5/8
MV-5	6,802,000	100.0000	0.9667	L+0.600%	Apr 2036	A2	A+	6/8
MV-6	5,907,000	100.0000	1.0000	L+0.660%	Mar 2036	A3	A	7/8
MV-7	5,549,000	100.0000	1.0833	L+1.300%	Mar 2036	Baa1	A	8/8

provides a brief introduction to the asset-backed CDO market.

Large quantities of subprime asset-backed CDOs were issued during the past several years and were widely viewed as one of the most important financial innovations of the past decade. According to the Securities Industry and Financial Markets Association, the total U.S. issuance of asset-backed securities during the 2005–2008 period was $2.154 trillion, and the total U.S. issuance of CDOs during the same period was $987 billion.

Asset-backed tranches or CDOs share many features in common with CDOs for corporate bonds. As described in Longstaff and Rajan (2008) and Bhansali, Gingrich, and Longstaff (2008), a CDO is created by an issuer first forming a portfolio of loans, either by lending money directly, or by buying debt securities in the marketplace.[4] In the ABS market, these loans could consist of first mortgages, second mortgages, loans on manufactured homes, credit card receivables, auto loans, student loans, and even account receivables.[5] Once the portfolio is formed, the CDO issuer sells tranches based on the cash flows scheduled to be generated by the underlying loans. Typically, the tranches vary in terms of their subordination. For example, the equity or residual tranche receives a high coupon on its principal amount, but is first in line to absorb any credit losses suffered by the underlying portfolio. On the other hand, a supersenior tranche might only receive a coupon of LIBOR plus 20 basis points, but would not suffer any credit losses until after the total credit losses for the portfolio exceeded, say, 15%.

In effect, an asset-backed CDO structure could be viewed as a synthetic lender where the assets consist of, say, subprime home-equity loans and where the capital structure consists of equity, subordinated debt, and senior debt (all often in the form of floating-rate notes).[6] From a CDO issuer's perspective, the advantage of issuing CDOs is that it allows the issuer to make loans, repackage them, and then sell them to third parties, thereby allowing the issuer to earn fees from originating and then servicing the loans without having to commit capital permanently. Of course, this originate-to-distribute mechanism creates a number of moral-hazard risks as the issuer is aware that he may bear very little of the credit losses on the loans he makes since they will be sold as repackaged CDOs.

To provide an illustration of a typical subprime asset-backed CDO, Table 1 gives the details of a $900 million CDO sponsored by Countrywide Home Loans, Inc. and issued through Lehman Brothers in February 2006. The issuing entity is designed as CWABS Asset-Backed Certificates Trust 2006-1. Of the total notional amount underlying the CDO, about $500 million is based on subprime fixed-rate mortgages, while $400 million is based on subprime floating-rate mortgages. On the fixed-rate side, the CDO consists of 12 separate tranches. The first six are equal in

[4] Alternatively, a synthetic CDO could be constructed through the use of credit default swaps.

[5] For an excellent review of the ABS market, see Rajan, McDermott, and Roy (2007).

[6] See the discussion in Longstaff and Myers (2009).

seniority but differ in terms of their coupon rates and collateral. The other six tranches are subordinated sequentially, with the MF-6 tranche absorbing the first $5.525 million in losses, the MF-5 tranche absorbing the next $6.188 million in losses, etc. A similar structure applies on the floating-rate side of the portfolio with the MV-7 tranche absorbing the first $5.549 million of losses, the MV-6 tranche absorbing the next $5.907 million of losses, etc. The average FICO credit score for the fixed-rate and floating-rate loans is 611 and 618, respectively, placing these loans squarely in the subprime category. Interestingly, while some of the underlying mortgages bear low "teaser" rates, many carry very high mortgage rates; the mortgage rates for the loans in the underlying portfolio vary from 4.95% to 12.00%. Given the different positions of the tranches in the capital structure "pecking order," it is not surprising that the tranches can have different credit ratings. Table 1 shows that the initial credit ratings for the tranches offered range from Aaa/AAA to Baa1/A.

Since each of these CDO tranches can be viewed as either a fixed-rate bond or a floating-rate note, the prices of these securities are generally quoted per $100 notional. To illustrate, the MF-1 tranche in the CWABS 2006-1 example has a Bloomberg quoted price of 65.00 on December 4, 2007. Thus, an investor who acquired this tranche at the issue price of 99.99814 on February 8, 2006 would have a mark-to-market loss of nearly 35%. Given that this tranche initially had a credit rating of AA1/AA+, the subsequent large decline in the value of the tranche argues that the initial credit ratings may have been overly optimistic.

From the perspective of the asset-backed CDO markets, there are several key events or threads that underlie the current distressed state of the market. First, the recent wave of subprime defaults and declines in housing values has created severe uncertainty about what the ultimate magnitude of credit losses will be. Second, given the inherent complexity of the underlying loan portfolios on which asset-backed CDOs are based (as evidenced from the Countrywide example in Table 1), participants in the financial markets apparently placed too much reliance on the credit ratings provided by the ratings agencies in making investment and pricing decisions. For example, see the discussion in Benmelech and Dlugosz (2009). When the rating agencies began to backtrack from their previous optimistic ratings in mid-2007 and the liquidity in secondary CDO markets dried up, many investors were left with what Clarida (2007) describes as almost-Knightian uncertainty as to what their asset-backed CDO positions were actually worth.

4. The ABX indexes

To measure the returns on subprime CDOs, I use market quotations for the widely known ABX indexes maintained by Markit Group Ltd. These indexes consist of daily closing values obtained from market dealers for subprime home-equity-related CDOs of various credit ratings.[7] In particular, the ABX indexes consist of five separate indexes, where each of these indexes is based on the market quotations of a specific basket of distinct subprime CDO tranches.

The AAA index is based on a portfolio of 20 subprime home-equity CDOs with initial credit ratings of AAA. The AA index is based on a portfolio of 20 subprime home-equity CDOs with initial credit ratings of AA. Similarly, the other three indexes are based on portfolios of subprime home-equity CDOs with credit ratings of A, BBB, and BBB−, respectively. Each index is a simple average of the prices for the 20 CDOs or tranches in the basket, where prices are quoted relative to a $100 notional position.

The 20 subprime deals that appear in each basket are chosen from among the qualifying deals of the largest subprime home-equity ABS shelf programs during the six-month period preceding the formation of the indexes. The algorithm for choosing the 20 subprime CDOs to be included in each index limits the same loan originator to four deals and the same master servicer to six deals. The minimum deal size is $500 million. Each CDO (tranche) must have a weighted-average life between four to six years as of the issuance date (except the AAA tranche which must be greater than five years). The tranches must be rated by Moody's and Standard and Poors; the lesser of the ratings applies. At least 90% of a deal's assets must be first-lien mortgages, and the weighted-average FICO credit score for loans underlying the tranche must be less than 620. Deals must pay on the 25th of each month and referenced tranches must bear interest at a floating-rate benchmark of one-month LIBOR. The five ABX indexes are reconstituted every six months. The first series of ABX indexes were formed in January 2006 and designated the ABX.HE 1 AAA, AA, A, BBB, and BBB− indexes. The second series of ABX indexes were formed in July 2006 and designated the ABX.HE 2 AAA, AA, A, BBB, and BBB− indexes. Similarly formed were the ABX.HE 3 and ABX.HE 4 indexes in January 2007 and July 2007, respectively. Once the subprime crisis began in the latter part of 2007, however, subprime CDO issuance declined precipitously and new ABX indexes were no longer formed. Thus, the ABX.HE 4 index remains the on-the-run or most-recently created ABX index from mid-2007 to the end of the sample period.

Market quotations for the ABX indexes can be difficult to obtain. Fortunately, I was given access to a proprietary data set by a major fixed-income asset management firm that includes daily closing values for all of the ABX.HE 1, 2, 3, and 4 indexes for the three-year period from the inception of the ABX index in January 19, 2006 to December 31, 2008.

Table 2 provides a brief chronology of some of the major crisis events during the 2006–2008 period. This timeline suggests that the ongoing crisis could be viewed as having two distinct phases. The first was the subprime crisis of 2007 in which investors and financial institutions

[7] Market makers for the ABX indexes during most of the sample period included Bank of America, BNP Paribas, Deutsche Bank, Lehman Brothers, Morgan Stanley, Barclays Capital, Citigroup, Goldman Sachs, RBS Greenwich Capital, UBS, Bear Stearns, Credit Suisse, JP Morgan, Merrill Lynch, and Wachovia.

Table 2
Timeline of the subprime and financial market crises. Source: Reuters, Federal Reserve of St. Louis.

Late 2006	The U.S. housing market slows after two years of increases in official interest rates. Delinquencies rise; a wave of bankruptcies.
Feb-7-2007	Europe's biggest bank, HSBC Holdings, blamed soured U.S. subprime loans for its first-ever profit warning.
Apr-2-2007	Subprime lender New Century Financial Corp. files for bankruptcy.
Jun-20-2007	Two Bear Stearns funds sell $4 billion of assets to cover redemptions and expected margin calls arising from subprime losses.
Jul-10-2007	Standard & Poor's said it may cut ratings on some $12 billion of subprime debt.
Jul-17-2007	Bear Stearns says two hedge funds with subprime exposure have very little value; credit spreads soar.
Jul-20-2007	Home foreclosures soar 93% from the previous year.
Aug-9-2007	BNP Paribas suspends redemptions in $2.2 billion of asset-backed funds; says it cannot determine security values.
Sep-13-2007	UK mortgage lender Northern Rock seeks financial support from the Bank of England; report sparks a run by worried depositors.
Oct-1-2007	Swiss bank UBS said it would write down $3.4 billion in its fixed-income portfolio; first quarterly loss in nine years.
Oct-30-2007	Merrill Lynch ousts Chairman and Chief Executive Stan O'Neal after reporting biggest quarterly loss in company's history.
Nov-4-2007	Citigroup announces a further $8-11 billion of subprime-related writedowns and losses. Charles Prince resigns as CEO.
Dec-12-2007	Central banks coordinate the launch of the temporary Term Auction Facility (TAF) to address pressures in short-term funding markets.
Jan-1-2008	Bank of America purchases Countrywide Financial in an all-stock transaction.
Feb-13-2008	President Bush signs the Economic Stimulus Act of 2008 into law.
Mar-11-2008	Federal Reserve announces creation of Term Securities Lending Facility (TSLF).
Mar-16-2008	Federal Reserve announces creation of Primary Dealer Credit Facility (PDCF).
Mar-24-2008	JP Morgan acquires Bear Stearns in rescue partially financed by Federal Reserve Bank of New York.
Jun-5-2008	Standard & Poor's announces downgrade of monoline insurers AMBAC and MBIA.
Jul-11-2008	Office of Thrift Supervision closes IndyMac Bank, F.S.B.
Sep-7-2008	Federal Housing Finance Agency places Fannie Mae and Freddie Mac in government conservatorship.
Sep-15-2008	Bank of America announces purchase of Merrill Lynch; Lehman Brothers files Chapter 11 bankruptcy.
Sep-16-2008	Federal Reserve authorizes lending up to $85 billion to AIG.
Sep-25-2008	Office of Thrift Supervision closes Washington Mutual Bank.
Sep-29-2008	Federal Deposit Insurance Corporation (FDIC) announces that Citigroup will purchase the banking operations of Wachovia Corp.
Oct-3-2008	Congress passes Emergency Economic Stabilization Act establishing $700 billion The Troubled Asset Relief Program (TARP).
Nov-25-2008	Federal Reserve Board announces creation of Term Asset-Backed Securities Lending Facility (TALF).
Dec-19-2008	U.S. Treasury authorizes loans for General Motors and Chrysler from the TARP.

holding subprime credit-related assets experienced major losses. The second is the global financial crisis of 2008 which was marked by massive deleveraging as well as by failures of major financial institutions with general credit exposure as the economy slid rapidly into recession.

Fig. 1 plots the time series of ABX index values for each of the three years 2006, 2007, and 2008. As illustrated, the ABX indexes were generally close to par during much of 2006, although the ABX BBB and BBB− began to decline toward the end of 2006. During the first part of 2007, the ABX BBB and BBB− indexes continued their decline. Around the middle of 2007, however, the other ABX indexes began to decrease. By the end of 2007, the ABX AAA index was below 80 and the other indexes were all below 50. During 2008, all of the ABX indexes continued to decline steadily and ended the year below 10, with the exception of the ABX AAA index which dipped below 30 but recovered somewhat to 40 at the end of 2008.

Table 3 provides summary statistics for the ABX index returns. Fig. 2 plots the time series of ABX index returns for each of the three years in the sample period. Note that these returns are based on weekly changes in the ABX index levels (weekly coupon accruals are not included in the ABX index returns). Table 3 shows that the returns on the ABX indexes became increasingly negative during the sample period. During 2006, the two highest-rated indexes actually experienced positive returns. During 2007 and 2008, the AAA index experienced negative returns, but these were not nearly as severe as for the other indexes. Not surprisingly, the volatility of ABX index returns was significantly higher in 2007 and 2008 than in 2006. Interestingly, the volatility of ABX index returns is not monotonically related to credit rating; the ABX A index was the most volatile index during 2007 while the ABX AA index was the most volatile index during 2008.

Table 3 also shows that there were major changes in the relation between the different ABX indexes during the sample period. During 2006, the average correlation of returns across all indexes was 0.500. During 2007, this measure increased to 0.744. During 2008, the average correlation of returns across all indexes declined to 0.587, approximating its value during the 2006 pre-crisis period.

5. Testing for contagion

In studying the nature of contagion in financial markets, it is helpful to have two key elements. First, I must be able to identify an event window for the distress event. Second, I must be able to identify a vector of contagion which can then be used to test for changes in linkages across markets associated with the distress event. The subprime crisis of 2007 provides a nearly textbook example of a potential contagion event in which both of these elements are present. In particular, the subprime crisis began during early 2007 as market participants gradually began to fear that the cash flows from their holdings of asset-backed CDOs might ultimately be far less than they had anticipated given the high credit ratings that these securities initially carried.

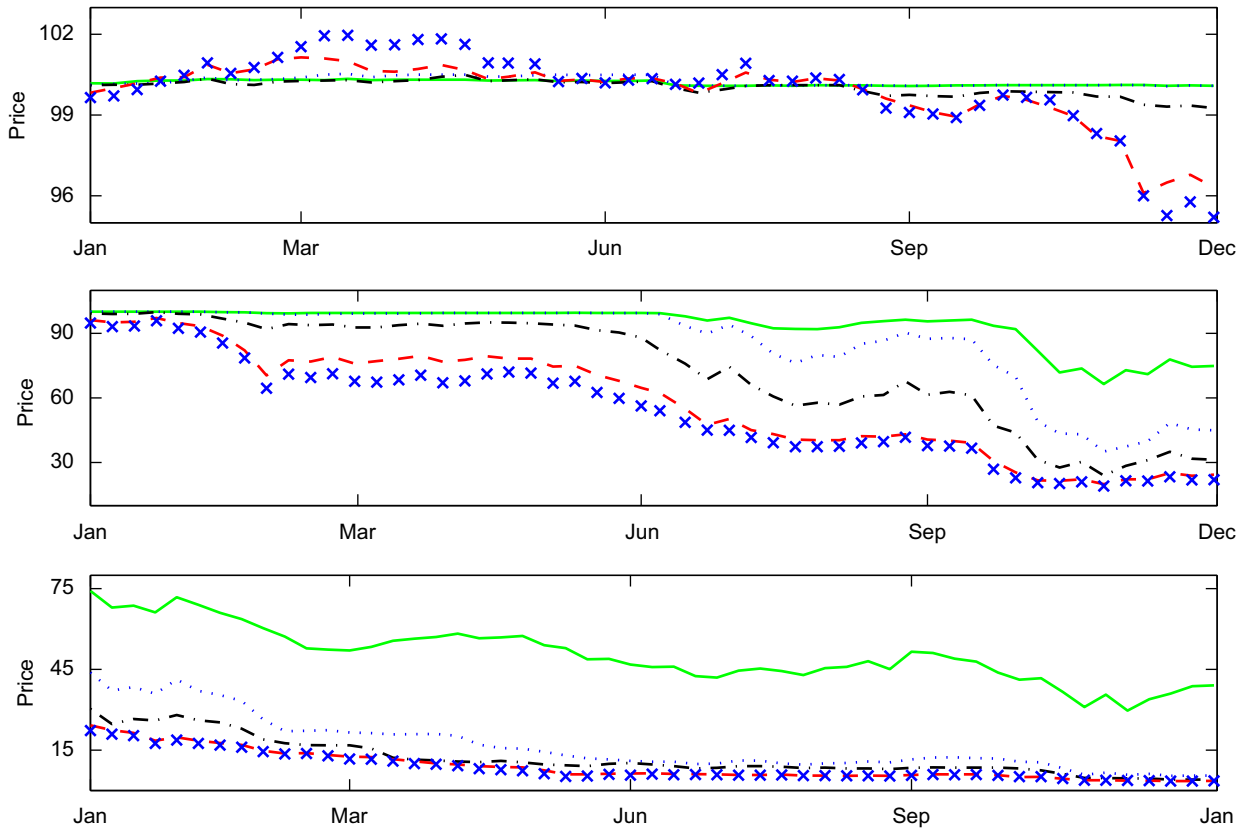

Fig. 1. The upper, middle, and lower panels plot the ABX subprime indexes weekly for 2006, 2007, and 2008, respectively. The solid gray line represents the AAA index; the dotted line, the AA index; the dashed-dotted line, the A index; the dashed line, the BBB index; the x's, the BBB− index.

Table 3
Summary statistics for ABX home-equity CDO tranche weekly returns.

This table reports summary statistics for the weekly percentage price changes for the indicated ABX indexes for each year. Each of the five ABX indexes represents an average of the prices of 20 subprime residential mortgage-backed CDOs with the same rating. Specifically, the AAA index is an average of 20 subprime CDOs with the rating of AAA; the AA index is an average of 20 subprime CDOs with the rating of AA; etc. The ABX indexes are maintained by Markit Group Ltd. The ABX indexes are reconstituted every six months, and the most-recently constructed indexes are denoted the on-the-run indexes. The sample consists of weekly data for the on-the-run ABX indexes from January 25, 2006 to December 31, 2008.

Year	Rating	Mean	Std. dev	Min.	Max	Correlation				
						AAA	AA	A	BBB	BBB−
2006	AAA	0.002	0.022	-0.045	0.090	1.00				
	AA	0.008	0.042	−0.119	0.130	0.44	1.00			
	A	−0.012	0.100	−0.301	0.140	0.36	0.50	1.00		
	BBB	−0.067	0.393	−1.979	0.465	0.23	0.32	0.77	1.00	
	BBB−	−0.087	0.462	−2.081	0.535	0.33	0.44	0.76	0.85	1.00
2007	AAA	−0.551	3.465	−12.230	9.737	1.00				
	AA	−1.447	6.867	−29.754	21.416	0.85	1.00			
	A	−2.229	8.077	−28.787	18.774	0.80	0.89	1.00		
	BBB	−2.779	6.666	−21.429	13.595	0.58	0.69	0.80	1.00	
	BBB−	−2.840	6.824	−26.618	12.940	0.51	0.60	0.77	0.95	1.00
2008	AAA	−1.016	6.443	−16.573	14.839	1.00				
	AA	−3.499	8.527	−29.697	14.838	0.75	1.00			
	A	−3.544	6.996	−23.980	9.845	0.44	0.69	1.00		
	BBB	−3.407	5.373	−20.000	6.594	0.44	0.62	0.53	1.00	
	BBB−	−3.203	5.792	−16.238	12.030	0.39	0.59	0.52	0.90	1.00

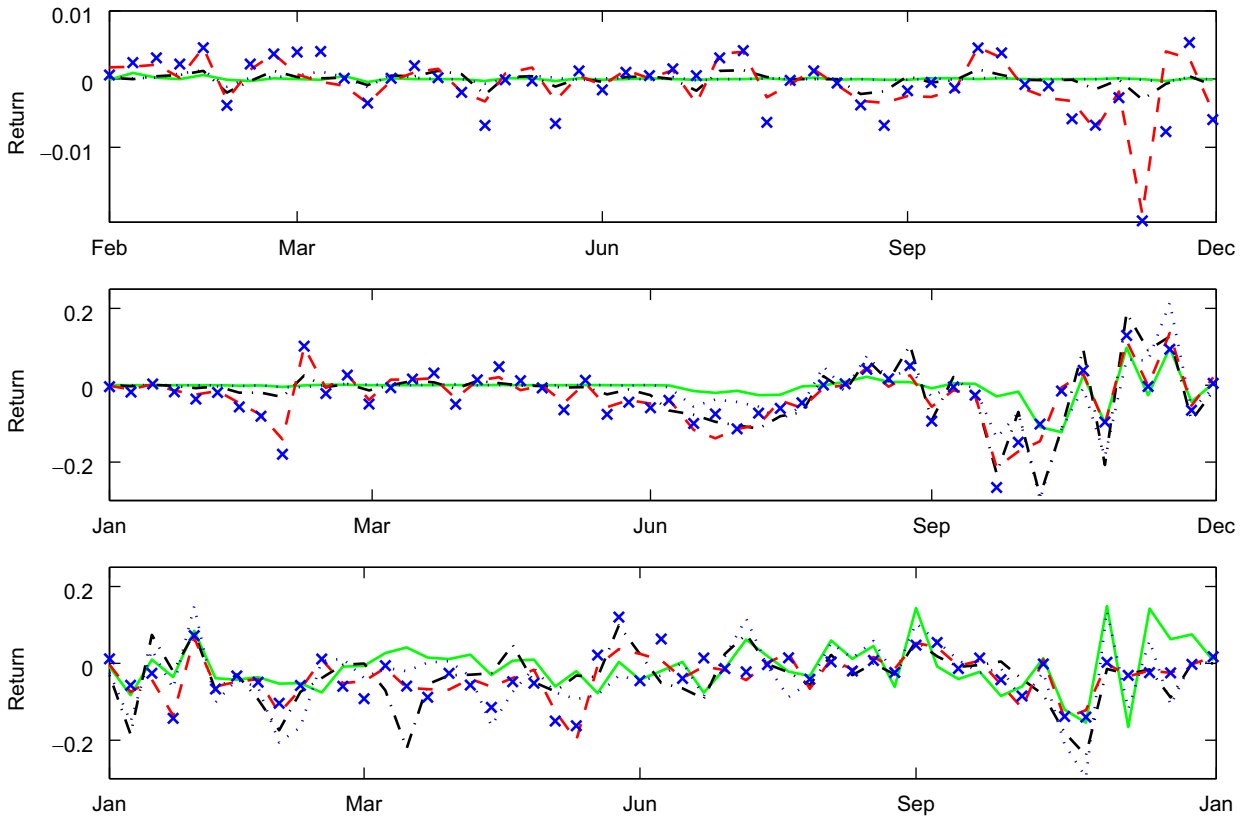

Fig. 2. The upper, middle, and lower panels plot the weekly ABX subprime index returns for 2006, 2007, and 2008, respectively. The solid gray line represents the AAA index; the dotted line, the AA index; the dashed-dotted line, the A index; the dashed line, the BBB index; the x's, the BBB− index.

Thus, asset-backed CDOs can clearly be viewed as the prime vector of contagion. By early 2008, however, the subprime crisis began to evolve into the global financial crisis as these fears were realized with the failures of Bear Stearns, IndyMac Bank, Washington Mutual, Lehman Brothers, AIG, Fannie Mae, Freddie Mac, Merrill Lynch, and many others. Thus, it is natural to divide the sample period into three distinct periods: the 2006 pre-crisis period, the 2007 subprime-crisis period, and the 2008 global-crisis period.[8]

To explore the empirical implications of the contagion literature for the subprime crisis, the approach will be to test whether there is an increase in the cross-market linkages between the asset-backed CDO market and other major financial markets during the subprime crisis. This approach is motivated by the standard definition in the literature of contagion as a change in the linkages between markets following a distress event. Specifically, I apply a vector autoregression (VAR) framework that allows us to estimate the relation between asset-backed CDO returns and returns in other financial markets separately during the three subperiods of the sample period. This allows us to examine directly whether cross-market linkages during the 2007 subprime crisis differed from those during the other two periods.

[8] I am grateful to the referee for suggesting this approach.

5.1. The VAR variables

As measures of the returns in the distressed asset-backed CDO market, I use the returns on the ABX indexes (formed from the on-the-run series, e.g., rolling the series from ABX-HE 1 to ABX-HE 2 when the latter index is constructed, etc.). Specifically, I use the weekly (Wednesday to Wednesday) returns for the corresponding on-the-run ABX index. Altogether, I have five such on-the-run series of returns, each representing a different credit rating, which I designate ABX_{AAA}, ABX_{AA}, ABX_{A}, ABX_{BBB}, and ABX_{BBB-}.

In testing for financial contagion in other financial markets, I will focus on a number of major fixed-income, equity, and volatility markets. To capture changes in the Treasury bond market, I use weekly changes (over the same period as for the ABX returns) in the constant maturity one- and 10-year Treasury yields (obtained from the Federal Reserve Board's Web site). Yields are measured in percentage terms. Thus, a one-basis point yield change from, say, 4.50 to 4.51 equals 0.01. To capture changes in corporate bond spreads, I use the Moody's Aaa and Baa corporate yield indexes and compute the spread by subtracting the 10-year Treasury yield from these index values. The weekly Moody's data are obtained from the Federal Reserve Board.

To capture changes in the stock market, I use two different measures. Specifically, I collect weekly return

data for both the S&P 500 index and the S&P 500 subindex of financial firms (dividends omitted from both return series). This subindex consists of roughly 80 to 90 commercial and investment banks, insurance companies, and home lenders during the sample period. The data for the S&P 500 indexes are obtained from the Bloomberg system. As the measure of volatility, I use weekly changes in the VIX volatility index. The data for the VIX are also obtained from the Bloomberg system.

5.2. The VAR results

Turning now to the question of whether the subprime crisis resulted in increased cross-market linkages between the asset-backed CDO market and other major markets, I estimate the following VAR system:

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

separately for each of the seven different dependent variables Y_t described in the previous section. Specifically, as the dependent variable Y_t, I use the changes in the one- and 10-year Treasury yields, changes in the Moody's Aaa and Baa credit spreads, the returns on the S&P 500 index, the returns on the subindex of S&P 500 financial firms, and changes in the value of the VIX index. The four-week lag structure is suggested by the data and is consistent with the Akaike Information Criterion (AIC). Note that for every specification of the dependent variable Y, I estimate the VAR five different times, each time using a different ABX index. In addition, I estimate the VAR separately for each of the three years in the sample period: 2006, 2007, and 2008.

Table 4 summarizes the VAR estimation results. For each of the three periods in the sample, I report the Newey–West t-statistics for the γ_k coefficients in Eq. (1) and the R^2s from the VARs. Table 4 also reports the p-values for the F-test that the γ_k coefficients are jointly zero.[9] This F-test can also be viewed as a test of the hypothesis that ABX returns Granger-cause subsequent changes or returns in the other financial markets examined. These tests also allow us to determine whether there is a significant difference in the relation between ABX index returns and the other financial markets during the 2007 subprime period.

Turning first to the results from the Treasury bond VARs, Table 4 shows that there is a very clear pattern of contagion during the subprime crisis. In particular, few of the individual t-statistics for the lagged ABX index returns are significant for the 2006 VARs. Similarly, none of the F-statistics are significant for the 2006 VARs. These 2006 results are intuitive since the asset-backed CDO market is much less liquid than the Treasury market. Thus, in ordinary circumstances, I would anticipate that there would be very little information in the ABX indexes that might be useful in forecasting Treasury yield changes.

In striking contrast, all of the F-statistics for the 2007 Treasury yield VARs are significant, indicating that the ABX returns have predictive ability for (or Granger-cause) Treasury yield changes. In addition, many of the individual t-statistics are highly significant in these VARs. The AAA and AA indexes have significant forecast power for both one- and 10-year Treasury yields about one to three weeks ahead, while the other ABX indexes have significant forecast power three to four weeks ahead. Table 4 also shows that all of the significant coefficients for the ABX returns in the 2007 VARs are positive in sign, indicating that a negative shock to the ABX index translates into a decline in Treasury yields, which, in turn, implies an increase in the value of Treasury bonds. Thus, these results are consistent with a flight-to-quality in the Treasury bond market in response to shocks in the subprime market. Interestingly, the magnitude of the coefficients for the 10-year Treasury bonds is roughly the same as that for the one-year Treasury bonds. Recall, however, that the duration and, therefore, the price effect on the value of a 10-year bond is many times that for the one-year bonds. Thus, these results imply large increases in the value of 10-year Treasury bonds stemming from declines in the value of asset-backed CDOs during 2007. The R^2s for the VARs are also very high and compare favorably to those for the forward rate forecasting models presented in Cochrane and Piazzesi (2005).

Finally, Table 4 shows that the forecast ability of ABX returns for Treasury yields largely disappears in the 2008 VARs. The exception is that the F-statistic for the AA index is significant at the 10% level for the 10-year Treasury yield. In addition, a number of the individual t-statistics are significant during 2008. In summary, the onset of the subprime crisis resulted in a significant change in the relation between ABX returns and Treasury bond yields. Prior to the crisis, the ABX indexes have little or no forecast power for the highly liquid Treasury bond market. During the crisis, however, ABX returns developed significant forecast power for Treasury yields. Once the subprime crisis evolved into another form, the ABX indexes were no longer a vector of contagion and the relation between ABX index returns and Treasury bond prices reverted to its pre-crisis nature. Thus, these results provide strong support for the view that the 2007 subprime crisis was accompanied by financial contagion as shocks in the asset-backed CDO market were transmitted to the Treasury bond market.

Focusing next on the corporate bond market, Table 4 shows a very similar pattern. There is little evidence of forecast ability during 2006. The sole exception is that the F-statistic for the AA index is significant for the Moody's Aaa spread. In contrast, all of the ABX indexes have significant forecast ability for both the Moody's Aaa and Baa spreads during 2007. The significant coefficients in these VARs are all negative in sign, implying that declines in ABX values map into wider subsequent corporate spreads. During 2008, the forecast power of the ABX indexes for corporate spreads again dissipates and none of the F-statistics are significant for either the Moody's Aaa or Baa spreads.

[9] For a discussion of this test of joint significance for the VAR coefficients, see Chapter 11 of Hamilton (1994).

Table 4
VAR Estimation results.

This table reports the Newey–West *t*-statistics for the indicated coefficients from the estimation of the VAR specification shown below, where each VAR is estimated separately for the indicated year. Also reported is the *p*-value for the *F*-test of the hypothesis that $\gamma_1=\gamma_2=\gamma_3=\gamma_4=0$. In this specification, Y denotes the financial market variable that appears as the dependent variable while ABX denotes the ABX index return whose lagged values (along with lagged values of Y) appear as explanatory variables. Each of the five ABX indexes represents an average of the prices of 20 subprime residential mortgage-backed CDOs with the same rating. Specifically, the AAA index is an average of 20 subprime CDOs with the rating of AAA; the AA index is an average of 20 subprime CDOs with the rating of AA; etc. The ABX indexes are maintained by Markit Group Ltd. The ABX indexes are reconstituted every six months, and the most-recently constructed indexes are denoted the on-the-run indexes. One- and 10-year Treasury denote weekly changes in the respective constant maturity Treasury yields. Moody's Aaa and Baa corporate spread denote weekly changes in the spread of these yield indexes over the 10-year Treasury rate. S&P 500 Financials denotes the weekly return (excluding dividends) of the financial stocks in the S&P 500 index. S&P 500 denotes the weekly return (excluding dividends) on the S&P 500 index. VIX denotes weekly changes in the VIX volatility index. The superscript ** denotes significance at the 5% level; the superscript * denotes significance at the 10% level. The sample period is January 25, 2006 to December 31, 2008.

$$Y_t=\alpha+\sum_{k=1}^{4}\beta_k Y_{t-k}+\gamma_k ABX_{t-k}+\varepsilon_t$$

Y	*ABX*	2006						2007						2008					
		γ_1	γ_2	γ_3	γ_4	R^2	*p*	γ_1	γ_2	γ_3	γ_4	R^2	*p*	γ_1	γ_2	γ_3	γ_4	R^2	*p*
One-year Treasury	AAA	−1.04	−0.30	0.29	0.29	0.08	0.91	0.04	2.52**	1.90*	−0.28	0.40	0.00**	−1.35	0.15	1.29	2.31**	0.12	0.43
	AA	0.18	1.48	0.01	0.78	0.06	0.98	2.59**	1.36	3.44**	−0.61	0.48	0.00**	−1.46	1.04	0.21	−0.04	0.09	0.64
	A	−1.22	1.02	−1.21	−1.04	0.15	0.41	−0.12	1.03	7.05**	2.06**	0.54	0.00**	−1.09	1.21	−1.29	0.90	0.10	0.58
	BBB	−1.47	0.21	0.33	−0.55	0.08	0.91	0.49	−0.18	3.75**	2.45**	0.43	0.00**	−2.71*	0.40	−0.19	−0.14	0.11	0.51
	BBB−	−0.74	0.85	−0.56	−0.31	0.07	0.93	0.83	−0.11	3.56**	2.66**	0.39	0.00**	−2.56**	−0.10	−0.06	−1.00	0.12	0.44
10-year Treasury	AAA	0.31	−0.25	1.33	0.65	0.07	0.89	−0.46	7.02**	2.00**	−0.22	0.33	0.01**	−0.51	2.30**	0.62	0.57	0.23	0.19
	AA	2.89**	2.64**	1.24	0.52	0.17	0.27	0.97	1.90*	1.71*	0.32	0.28	0.03**	0.80	2.69**	−0.72	−0.33	0.26	0.09*
	A	−0.45	0.52	−1.37	−0.92	0.11	0.65	0.66	0.99	3.50**	1.97*	0.23	0.01**	0.46	1.53	−1.24	0.74	0.19	0.36
	BBB	−0.74	−0.41	−0.81	0.36	0.06	0.94	1.65	0.17	2.09**	1.92*	0.33	0.01**	−0.43	1.06	−0.41	0.33	0.13	0.86
	BBB−	−0.48	0.91	−1.44	0.13	0.08	0.87	2.68**	−0.32	2.34**	2.65**	0.39	0.00**	−0.58	1.33	−0.82	−0.05	0.16	0.66
Moody's Aaa corporate spread	AAA	1.59	0.16	0.92	−0.98	0.16	0.37	1.01	−3.07**	−2.62**	1.81*	0.34	0.02**	−0.63	−0.88	−0.31	0.81	0.22	0.78
	AA	2.17**	0.44	1.58	−1.57	0.28	0.04**	−0.54	−1.31	−7.28**	2.07**	0.41	0.00**	−0.27	0.44	1.09	0.59	0.20	0.89
	A	1.55	−1.30	1.27	−1.06	0.18	0.28	0.46	−1.60	−9.04**	0.51	0.45	0.00**	−0.42	0.56	1.35	0.10	0.21	0.86
	BBB	1.51	−0.98	0.43	−0.16	0.10	0.76	0.14	−0.94	−2.22**	−0.58	0.42	0.00**	0.38	1.38	1.39	0.22	0.22	0.72
	BBB−	−1.45	−1.02	1.14	−0.01	0.11	0.70	−0.25	−1.01	−2.22**	−1.08	0.33	0.03**	0.41	2.00**	1.39	1.13	0.24	0.57
Moody's Baa corporate spread	AAA	0.49	−1.46	−2.09**	−0.68	0.17	0.40	1.58	−5.89**	−5.12**	1.54	0.53	0.00**	−0.02	−0.62	1.40	1.07	0.23	0.53
	AA	−1.08	−0.39	−0.16	−1.46	0.24	0.12	−0.13	−2.58**	−4.07**	1.22	0.52	0.00**	0.07	0.17	1.42	1.05	0.22	0.63
	A	1.11	−2.18**	0.25	−0.57	0.20	0.24	0.72	−2.48**	−4.67**	−0.70	0.54	0.00**	0.00	0.19	1.63	0.34	0.21	0.72
	BBB	0.87	−1.87*	−0.02	0.13	0.13	0.68	−0.31	−0.96	−2.28**	−1.28	0.45	0.00**	1.09	1.50	1.08	0.17	0.24	0.47
	BBB−	0.37	−1.86*	0.06	0.01	0.13	0.63	−0.54	−1.12	−2.43**	−2.56**	0.40	0.01**	0.91	1.71*	1.08	1.11	0.23	0.47
S&P 500 Financials	AAA	−1.36	−0.45	−0.96	0.86	0.19	0.56	1.09	1.55	0.37	−0.48	0.36	0.41	−0.90	−0.14	0.45	−0.66	0.14	0.88
	AA	−3.56**	−0.36	−0.49	0.75	0.22	0.35	1.91*	−2.13**	2.87**	−0.10	0.47	0.02**	−0.02	0.16	−1.58	−1.29	0.16	0.73
	A	−2.11**	−1.31	−1.09	0.65	0.17	0.17	2.43**	−0.34	2.39**	0.46	0.51	0.01**	0.57	−0.88	−3.01**	−0.93	0.24	0.19
	BBB	−0.87	−1.25	−1.97*	0.73	0.20	0.48	1.77*	0.92	1.68*	1.29	0.50	0.01**	−0.25	−1.16	0.41	−0.54	0.16	0.85
	BBB−	−1.54	−1.27	−0.64	0.54	0.18	0.61	3.24**	0.76	2.08**	1.73*	0.52	0.00**	−0.39	−0.90	0.30	−1.00	0.15	0.82

Table 4 *(Continued)*

Y	ABX	2006						2007						2008					
		γ_1	γ_2	γ_3	γ_4	R^2	p	γ_1	γ_2	γ_3	γ_4	R^2	p	γ_1	γ_2	γ_3	γ_4	R^2	p
S&P 500	AAA	−1.53	−0.04	−0.91	1.16	0.27	0.29	2.08	2.84	0.20	−0.40	0.29	0.09	−2.19	0.15	0.46	−1.47	0.25	0.06
	AA	−4.11**	−0.21	−0.82	1.04	0.30	0.18	1.28	0.91	2.92**	0.23	0.30	0.09*	−1.89*	0.75	−2.01**	−0.87	0.25	0.07*
	A	−1.33	−0.93	−1.17	0.79	0.28	0.26	1.35	0.78	3.11**	1.25	0.36	0.01**	−1.41	0.37	−2.95**	−0.36	0.21	0.17
	BBB	−0.62	−1.14	−1.41	1.20	0.23	0.55	0.58	1.34	1.96*	2.68**	0.44	0.00**	−1.74*	−0.05	−0.99	−0.68	0.21	0.15
	BBB−	−0.98	−1.08	−0.22	0.78	0.20	0.80	1.92*	0.76	2.18**	3.19**	0.41	0.00**	−1.81*	−0.23	−1.26	−0.60	0.21	0.16
VIX	AAA	1.14	−0.25	−0.86	−0.77	0.18	0.70	−4.15**	−2.85**	1.55	0.46	0.34	0.05**	2.07**	0.20	0.90	0.22	0.18	0.22
	AA	2.10**	−1.09	0.23	−0.46	0.16	0.84	−2.27**	−0.90	−0.93	0.31	0.34	0.05**	2.70**	−1.38	2.53**	0.03	0.29	0.02**
	A	1.41	0.13	−0.10	0.69	0.20	0.54	−3.97**	−1.42	−3.76**	−0.61	0.44	0.00**	2.39**	−0.64	1.84*	0.65	0.16	0.32
	BBB	1.62	−0.35	−0.62	0.17	0.16	0.86	−1.82*	−2.59**	−2.82**	−2.09**	0.52	0.00**	1.50	0.58	0.55	0.72	0.19	0.21
	BBB−	1.71*	−0.14	−1.29	1.09	0.20	0.48	−2.67**	−1.63	−2.89**	−2.82**	0.49	0.00**	1.28	0.79	0.53	0.79	0.15	0.39

Turning to the results for the S&P 500 indexes, Table 4 shows that there is little or no evidence that ABX returns were able to forecast S&P 500 index returns during the pre-crisis period. In contrast, ABX index returns became highly predictive of stock index returns during the 2007 subprime crisis. Specifically, the *F*-statistics for the lagged AA, A, BBB, and BBB− index returns are significant at the 5% level for the S&P 500 financials, and the *F*-statistics for all five ABX indexes are significant at either the 5% or 10% level for the S&P 500 index. Most of the many significant coefficients are positive in sign, indicating that a negative shock in the ABX index results in a subsequent negative return for the S&P 500 stock index. Again, these results are consistent with the view that the subprime crisis resulted in contagion being spread from the asset-backed subprime market to other much larger and more liquid markets like the stock market. The VAR results also show that the stock market returns are highly predictable on the basis of ex ante data during the 2007 subprime crisis. In fact, the S&P 500 financial subindex displays a stunning amount of predictability, with R^2s ranging from 36% to 52%. These values far exceed most of the stock market predictability results previously shown in the literature.[10] The R^2s for the S&P 500 index returns are also very high, with values ranging from 29% to 41%.

Table 4 also shows that the much of the predictability of ABX index returns for the stock market dissipates in 2008. The *F*-statistics for the lagged ABX index returns are only significant at the 10% level for the AAA and AA indexes in the S&P 500 VARs. Only one of the *t*-statistics for the lagged ABX index returns is significant in the S&P 500 financials VARs. On the other hand, all five of the VARs for the S&P 500 index returns have at least one *t*-statistic that is significant at the 10% level. Thus, the relation between ABX index returns and S&P 500 index returns does not completely revert to its pre-crisis pattern once the subprime crisis evolves.

Finally, Table 4 shows that the results for the VIX VARs are very similar to the others. In particular, there is little evidence of any lead–lag relation between ABX index returns and changes in the VIX during 2006. During 2007, however, all five of the ABX indexes have significant predictive ability at the 10% level for subsequent changes in the VIX. The negative sign for all of the significant *t*-statistics indicates that the VIX increases as negative shocks to the ABS indexes occur. This is very intuitive since the VIX is often designated as a "fear" index; negative financial news often is linked to increases in the volatility of markets as measured by the VIX. During 2008, the ability of the ABX indexes to forecast changes in the VIX dissipates significantly, with only the *F*-statistic for the AA index being significant at the 5% level. Note, however, that a number of the individual *t*-statistics for the lagged ABX index returns remain significant in 2008.

[10] As examples of the recent market predictability literature, see Lettau and Ludvigson (2001) and Cochrane (2008).

5.3. Discussion

Taken together, the evidence that ABX index returns developed significant predictive ability for returns or changes in other major financial markets such as Treasury bonds, corporate bonds, S&P 500 stock indexes, and the VIX during the 2007 subprime crisis provides strong support for the hypothesis that there were spillover contagion effects during this crisis. Cross-market linkages became much stronger and significant during the subprime crisis, consistent with the standard definition of financial contagion. Equivalently, ABX index returns are able to Granger-cause returns in other markets during the subprime crisis (but not before or after the subprime crisis, indicating a change in cross-market linkages).[11]

These results also shed light on the earlier discussion about the nature of the contagion mechanism in financial markets. Recall that the literature on contagion identifies at least three possible channels by which contagion in financial markets might be propagated: the correlated-information channel, the liquidity channel, and the risk-premium channel.

The strong evidence that ABX index returns were able to forecast changes or returns several weeks ahead in much larger and more liquid markets during the 2007 subprime crisis argues against the correlated-information channel as the contagion mechanism. Intuitively, the reason for this is simply that we would expect any relevant information discovered in the ABX markets to be very rapidly incorporated into the actively traded stock, stock index option, and Treasury bond markets. Thus, we would expect that there would be a nearly contemporaneous relation between shocks in the ABX index market and these other financial markets if contagion was spread via the correlated-information channel. Note that illiquidity in the pricing of ABX tranches cannot explain the ability of ABX index returns to forecast the returns in other markets.

By essentially ruling out the correlated-information channel, I am left with the possibility that financial contagion may have been propagated primarily through either the liquidity channel or the risk-premium channel during the subprime crisis (or both). To address this issue more definitively, however, I need to explore in more depth whether a link between the ABX market and trading and liquidity/funding patterns in other markets emerged during the subprime crisis. This analysis is the focus of the next section.

[11] I also examined the reverse VAR specification to determine whether returns in these other markets Granger-caused ABX index returns during the subprime crisis. Intuitively, finding some evidence of Granger-causality in this direction would not be surprising given that most of the other markets examined are much more liquid and actively traded than are the ABX indexes. In actuality, however, the number of significant *F*-statistics for this reverse specification was far fewer than for those reported in Table 4. Also, when the *F*-statistic for the reverse specification was significant, it was nearly always less significant than for the corresponding specification in Table 4.

6. Was there liquidity contagion?

To explore the effects of the subprime crisis on market/funding liquidity, I again use the VAR framework introduced in the previous section. Rather than using asset returns or yields as the dependent variables in the VARs, however, I use a number of measures that attempt to capture weekly changes in the trading patterns or liquidity profiles of key financial markets.

6.1. The liquidity variables

First, to explore whether the subprime crisis is associated with changes in trading patterns in the equity markets, I compute the ratio of the aggregate weekly trading volume for the firms in the S&P 500 subindex of financial firms to the aggregate weekly trading volume for all firms in the S&P 500 index. In computing this ratio for week *t*, I use the volume data for the week immediately before and including the Wednesday of week *t*. The rationale for considering this variable is to examine if ABX index returns forecast or Granger-cause changes in the amount of trading of financials relative to that for a broader set of stocks. Finding that the stocks in the S&P 500 subindex of financial firms are traded more intensively than the remaining S&P 500 firms during the crisis could be consistent with a flight-to-quality or a major rebalancing of portfolios in the financial markets.[12]

Second, as one measure of the trading/liquidity patterns in the fixed-income markets, I collect data on the aggregate amount of fails reported by the New York Federal Reserve. Fails represent repurchase (repo) transactions in which one party fails to deliver the fixed income securities that are the collateral for the repo contract. Since it is costly to fail on a repo contract, market participants attempt to avoid failures whenever possible. Thus, a sudden increase in the amount of fails in the market signals that some type of market disruption may have occurred in bond markets. This implies that the amount of fails each week (measured in $ millions) can provide a measure of liquidity/trading shocks in the fixed-income markets.

Third, as suggested by Brunnermeier and Pedersen (2005), liquidity shocks may take the form of declines in the amount of funding available to leveraged players in the financial markets. In general, measuring changes in the aggregate size of the credit sector over a short period such as a week is challenging. In the current subprime crisis, however, considerable attention has focused on the commercial paper market. Over the past decade, this market has grown to a notional size on the order of $2 trillion and has become a major source of short-term funding for financial institutions, investors, and corporations. Given that the median maturity of commercial paper is on the order of 30 days, changes in the size of this

[12] On the other hand, a change in this trading pattern could also be consistent with an equilibrium in which agents hedge against consumption risks by trading certain sectors of the market more actively than others. I am grateful to the referee for this observation.

Table 5
VAR Estimation results for liquidity and financing variables.

This table reports the Newey–West *t*-statistics for the indicated coefficients from the estimation of the VAR specification shown below, where each VAR is estimated separately for the indicated year. Also reported is the *p*-value for the *F*-statistic of the hypothesis that $\gamma_1=\gamma_2=\gamma_3=\gamma_4=0$. In this specification, Y denotes the liquidity or financing variable that appears as the dependent variable while ABX denotes the ABX index return whose lagged values (along with lagged values of Y) appear as explanatory variables. Each of the five ABX indexes represents an average of the prices of 20 subprime residential mortgage-backed CDOs with the same rating. Specifically, the AAA index is an average of 20 subprime CDOs with the rating of AAA; the AA index is an average of 20 subprime CDOs with the rating of AA; etc. The ABX indexes are maintained by Markit Group Ltd. The ABX indexes are reconstituted every six months, and the most-recently constructed indexes are denoted the on-the-run indexes. Ratio of trading denotes the ratio of trading volume for the S&P 500 financials to the total trading volume for the S&P 500 index for the week. Fails denotes the total value (measured in $ millions) of settlement failures by primary dealers in the Treasury, agency, mortgage, and corporate bond markets for the week. Change in ABS CP is the weekly change (measured in $ billions) in the aggregate amount of asset-backed commercial paper outstanding. The superscript ** denotes significance at the 5% level; the superscript * denotes significance at the 10% level. The sample period is January 25, 2006 to December 31, 2008.

$$Y_t=\alpha+\sum_{k=1}^{4}\beta_k Y_{t-k}+\gamma_k ABX_{t-k}+\varepsilon_t$$

Y	*ABX*	2006						2007						2008					
		γ_1	γ_2	γ_3	γ_4	R^2	*p*	γ_1	γ_2	γ_3	γ_4	R^2	*p*	γ_1	γ_2	γ_3	γ_4	R^2	*p*
Ratio of trading volume	AAA	−0.48	−0.12	−0.58	−0.29	0.27	0.95	−4.01**	−2.02**	−0.41	−1.96*	0.90	0.00**	0.25	−0.54	0.35	−2.55**	0.56	0.06*
	AA	−0.96	−2.70**	−1.40	−1.51	0.33	0.43	−3.70**	−0.67	−1.90*	−0.74	0.91	0.00**	−1.00	−1.46	0.77	−2.87**	0.55	0.08*
	A	−1.79*	−0.81	−2.01**	0.35	0.36	0.25	−5.00**	−1.02	−2.73**	−1.04	0.92	0.00**	−2.90**	−0.97	2.46**	−0.55	0.53	0.22
	BBB	−1.54	−2.19**	−3.10**	0.22	0.42	0.06*	−3.39**	−1.84*	−2.72**	−1.31	0.91	0.00**	−0.47	−0.24	1.15	−0.78	0.47	0.86
	BBB−	−1.22	−1.13	−2.17**	0.27	0.38	0.16	−3.28**	−3.25**	−2.84**	−1.34	0.91	0.00**	−0.63	0.53	0.78	0.19	0.47	0.95
Fails	AAA	1.18	3.87**	2.07**	−0.60	0.42	0.07*	0.57	0.02	−2.82**	−1.44	0.39	0.09*	−1.05	0.82	0.47	1.43	0.78	0.60
	AA	−0.11	0.62	2.65**	−2.28**	0.41	0.09*	−0.70	3.02**	−2.32**	−2.16**	0.40	0.08*	−0.29	2.47	−1.80*	0.27	0.79	0.27
	A	0.02	−0.34	1.47	−0.39	0.30	0.75	−0.04	2.70**	−1.80*	−1.06	0.36	0.23	−0.53	1.00	−1.75*	0.30	0.78	0.63
	BBB	−0.35	0.42	1.47	−0.75	0.29	0.85	−0.88	1.53	−1.56	−1.33	0.37	0.17	−0.90	1.71*	0.06	−0.38	0.79	0.35
	BBB−	−0.76	0.27	1.00	−0.87	0.32	0.62	−0.32	1.01	−2.01**	−0.64	0.32	0.56	−1.52	2.10**	0.02	−0.27	0.79	0.21
Change in ABS CP	AAA	−0.65	−0.08	1.45	−0.05	0.35	0.84	3.45**	−2.68**	−0.82	0.71	0.46	0.07*	−1.99*	2.62**	0.74	1.71*	0.28	0.02**
	AA	−0.10	−0.00	0.65	−0.21	0.33	0.99	2.26**	−1.03	−2.75**	2.00**	0.50	0.02**	−1.64	1.49	−0.35	1.93*	0.18	0.14
	A	1.96*	−3.13**	1.31	−1.46	0.48	0.05**	2.90**	−0.59	−3.30**	−0.01	0.48	0.04**	−0.52	0.90	−1.22	2.02**	0.13	0.36
	BBB	1.10	−1.11	2.38**	−1.41	0.41	0.30	1.34	−0.05	−1.81*	−0.67	0.42	0.25	−1.07	1.32	−1.24	1.63	0.15	0.28
	BBB−	1.47	−1.23	2.38**	−2.10**	0.43	0.16	1.64	−0.14	−2.11**	−0.81	0.41	0.26	−1.59	1.54	−1.59	1.49	0.16	0.22

market (measured in $ billions) may provide a useful proxy for discretionary changes in the amount of short-term credit provided in the financial markets. I obtain weekly (Wednesday) data on the size of the asset-backed commercial paper market from the Federal Reserve Board's Web site.

6.2. The liquidity VAR results

Table 5 reports the VAR estimation results for the liquidity and financing variables. Focusing first on the ratio of trading volume, Table 5 shows that there is some limited predictability by ABX index returns for the ratio during the 2006 pre-crisis period. The *F*-statistic is significant at the 10% level for the BBB index, while a number of the *t*-statistics are individually significant during 2006. With the onset of the subprime crisis in 2007, however, the evidence of predictability becomes much stronger. In particular, the *F*-statistics for all five ABX indexes are highly statistically significant. In addition, many of the individual *t*-statistics are significant. All of the significant coefficients for the lagged ABX index returns are negative, implying that a negative shock to asset-backed CDO values is associated with an increase in the trading activity of financial firms relative to other firms in the S&P 500. These results suggest that investors did not simply trade the market as the subprime distress event unfolded, but concentrated their trading in the financial sector. During 2008, most of the predictive power of the ABX index dissipates, with only the ABX AAA and AA indexes having *F*-statistics that are significant at the 10% level. Thus, the cross-market linkage between ABX index returns and the ratio of trading activity spiked during 2007, but then essentially returns to its pre-crisis pattern during 2008.

The results for the amount of fails in the fixed-income markets provide some evidence, albeit mixed, that the relation between ABX index returns and fixed-income market liquidity became more pronounced during the 2007 subprime crisis. In particular, four of the individual *t*-statistics for the lagged ABX index returns are significant during 2006. During 2007, however, seven of the individual *t*-statistics are significant. On the other hand, the *F*-statistics for both the AAA and AA indexes are significant during both 2006 and 2007. In contrast, the relation between ABX index returns and fails becomes much weaker during 2008.

Table 5 shows that while there is a weak relation between ABX index returns and changes in ABS commercial paper during 2006, there is a much stronger relation during 2007. Specifically, the *F*-statistics for the AAA, AA, and A indexes are significant at the 5–10% level during 2007, while only the *F*-statistic for the A index is significant during 2006. During 2008, the relation between ABX index returns and changes in ABS commercial paper returns to a level similar to those for 2006. These results are consistent with the model presented by Brunnermeier and Pedersen (2005) in which funding shocks in one market may translate into broad liquidity and valuation shocks in other markets, thereby generating pervasive contagion effects in financial markets.

In summary, these results do provide evidence that the 2007 subprime crisis resulted in significant changes in the patterns of trading activity, liquidity, and funding in the financial markets. Thus, these results are consistent with both the Brunnermeier and Pedersen (2005) funding-illiquidity contagion mechanism as well as with the portfolio rebalancing implications of Allen and Gale (2000), Kodres and Pritsker (2002), and others, and support the view that contagion during the subprime crisis was spread through a liquidity channel which, in turn, was associated with major portfolio rebalancing by market participants. These results are also consistent with Aragon and Strahan (2009) who study the impact of the Lehman bankruptcy on hedge funds.

7. Conclusion

The 2007 subprime crisis provides an ideal opportunity for studying the effects of contagion in financial markets. I use data for the ABX indexes of subprime asset-backed CDOs to examine whether contagion occurred across markets as the crisis developed. Motivated by the frequently adopted definition of contagion in the literature as a significant temporary increase in cross-market linkages after a major distress event, I use a VAR framework to test for changes in the relation between the ABX market and other financial markets after the onset of the crisis.

The results provide strong evidence of an increase in cross-market linkages. Prior to the subprime crisis, ABX returns contain little useful information for forecasting returns in other major markets. After the crisis began, however, the ABX indexes became highly predictive for Treasury bond yields, corporate yield spreads, stock market returns, and changes in the VIX volatility index. In many cases, the less-liquid ABX indexes are able to forecast Treasury yields, corporate yield spreads, stock market returns, and changes in the VIX up to three weeks ahead with surprisingly high R^2s. These results provide strong support that financial contagion spread across markets as the subprime crisis developed. Since I focus only on the subprime crisis, it is important to acknowledge that my results are limited to this specific episode in the markets.

A key aspect of the study is that the results allow us to contrast among the different models of contagion that appear in the extensive literature on the subject. For example, the length of the forecast horizon, in many cases as long as three weeks, argues against the view that contagion is spread via the correlated-information channel. The reason for this is simply that I would expect that price-discovery in the highly liquid stock, Treasury bond, corporate bond, and VIX markets would occur much more rapidly if the source of contagion was correlated information. Furthermore, the evidence that ABX index shocks during the subprime crisis became predictive for equity and fixed-income market trading patterns as well as for the amount of securitized financing is consistent with

contagion having been spread via a liquidity/financing channel as argued by Allen and Gale (2000), Brunnermeier and Pedersen (2005), and others.

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