Mortgage Securitization, Housing Market and Real Output:

A Time-Series Causality Test Using Structural VAR

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ABSTRACT

This research studies the effects of mortgage securitization on the real economy and housing market. I estimate the dynamic response of housing market risk and aggregate U.S. production output to shocks of mortgage securitization and banks' ownership of mortgage-backed security (MBS), and analyze the benefit and detriment of mortgage securitization to the real economy and housing market. The shocks are identified empirically from a structural vector autoregression (SVAR) using restrictions that are consistent with a wide class of theoretical models. I found that securitization reduces housing risk and increases real output. Although commercial banks' ownership of MBS is intended to reduce information asymmetry in mortgage lending market, the increasing risk of housing market and the reduction of production output after initial shocks of banks' MBS ownership suggest that market participants might have neglected the risks associated with investing in MBS.

Keywords: securitization, mortgage-backed securities, structural VAR

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I. INTRODUCTION

The securitization of residential mortgage has become a subject of intense national interest and debate. Many have questioned the wisdom of the originate-to-distribute model of mortgage underwriting and others have focused on the conflicts inherent in the role of financial institutions assembling securitization pools and then selling them to investors. The dominant view prior to the current financial crisis was that securitization is beneficial for the financial market. Securitization transforms relatively illiquid individual mortgages into liquid and tradable mortgage-backed securities. It allows mortgage originators to replenish their funds, which can then be used for additional origination activities. MBS is frequently more efficient and lower cost source of financing in comparison with other bank and capital markets financing alternatives. It allows issuers to diversify their financing sources, by offering alternatives to more traditional forms of debt and equity financing. MBS issuers can remove assets from their balance sheet, which can help to improve various financial ratios, utilize capital more efficiently and achieve compliance with risk-based capital standards. Therefore theoretically, securitization should serve to reduce risk by spreading it more widely and furthermore, it helps complete the market in the sense of Arrow-Debreu (1954), as suggested by Gaur, Seshadri and Subrahmanyam (2010).

The ongoing financial crisis of 2007-09 triggered by the subprime mortgage delinquencies signaled the end of a favorable period of mortgage securitization and housing market boom. It seems to suggest some side-effects of mortgage securitization, mainly lax screening by mortgage lenders. The dominant view, as summarized by Plantin (2010), is that mortgage securitization reduces banks' incentives to screen and monitor their borrowers in housing market boom period and the consequent degradation in mortgage quality in turn amplified the market downturn. This agency problem in securitization has been empirically investigated and confirmed by Keys, Mukherjee, Seru and Vig (2009 and 2010), Mian and Sufi (2009 and 2010), Mian, Sufi and Trebbi (2008).

Alternatively, Gennaioli, Shleifer, and Vishny (2011) suggest that market participants have neglected the risks of mortgage securitization, which can increase financial fragility even in the absence of leverage. New securities are over-issued when investors neglect low probability risks in accounting for the nature of financial innovation such as mortgage securitization. The market for new securities (MBS) is fragile because when news about unattended risks (national house prices plunge and mortgage defaults rise) catches investors by surprise, they dump the "false substitutes" (MBS) and fly to the safety of traditional securities (Treasury bonds). The authors claim that such neglected risk explains why the sharp decline in home prices and increase in mortgage defaults came as a substantial surprise to the market in the summer of 2007.

Despite the importance of understanding the benefit and detriment of mortgage securitization to the real economy and housing market, there is relatively little empirical evidence on the difference between the agency view and the neglected risk view of the issue. This paper extends previous empirical research by applying a time-series econometric method, namely, structural vector autoregression (SVAR), to study the effect of mortgage securitization on the real economy and housing market. I contribute new time-series causality evidence for a 27-year period from 1983 to 2009 in which securitization became the dominant source of financing for the U.S. residential mortgage market. The shocks are identified empirically from a SVAR using restrictions that are consistent with a wide class of theoretical models. I found that securitization help complete the market. Although commercial banks' ownership of MBS is intended to reduce information asymmetry in mortgage lending market, the increasing risk of housing market and the reduction of production output after initial shocks of banks' MBS ownership suggest that market participants might have neglected the risks of mortgage securitization as in Gennaioli, Shleifer, and Vishny (2011).

Mortgage securitization is a process to transform illiquid mortgages including residential and commercial mortgages to liquid financial securities, mainly fixed income instruments and their derivatives. Securitization is often called structured finance process that distributes risk by aggregating mortgages in a pool, often by selling all mortgages to a special purpose vehicle (SPV), then issuing new securities backed by the mortgages and their cash flows. The securities are sold to investors who share the risk and reward from those assets. The mortgage-backed securities (MBS) market is large and growing. From 1980 to 2009 the outstanding size of the 1-4 family mortgage-backed security in U.S. has grown dramatically from 111 millions to 7 trillions, whereas the outstanding size of the underlying mortgage assets has grown from 1 trillion to 11 trillion.[1] This implies average securitization rate of 64% in 2009.

Securitization of residential mortgage over the last thirty years has transformed the entire process of financial intermediation. Historically, when the banks lent funds to the

[1] Mortgage Market Statistical Annual (Volumes I & II) of Inside Mortgage (2010)

borrowers, banks held onto the mortgage until the mortgage was paid off or the house was sold. Consequently, the largest holders of mortgage debt were private banks before the securitization waves. The first wave of mortgage securitization occurred in the 1970s when government-insured mortgage securities were issued to aid the development of a national secondary market. These securities increased the liquidity of depository institutions during high interest rate periods when disintermediation curtailed available saving flows. The second wave of mortgage securitization took place in the 1980s when the volatile interest rate environment contributed to the creation of a wide variety of new mortgage contracts and complex mortgage securities. These innovative derivatives improved the linkage between the mortgage market and the capital market by drastically altering the functions of different financial institutions. Credit insurance and portfolio function were shifted from depository institutions to large government-sponsored entities (GNMA, FNMA and FHLMC). The third wave of mortgage securitization in the mid-1990s was partly fueled by the aggressive participation of some of the largest investment and commercial banks. They became the innovators for the more general movement to securitize every form of asset (asset-backed security or simply ABS which includes auto loans, credit card receipts, equipment leases, home equity loans, student loans, and etc.) and create more complex financial instruments to create new ways to invest and control risk (Fligstein and Goldstein 2010). This created a huge expansion in consumer credit markets.

The process of securitization is complicated. Mortgage loans are purchased from banks, mortgage companies, and other originators. These loans are assembled into pools. While a residential mortgage-backed security (RMBS) is secured by primarily single-family real estate, a commercial mortgage-backed security (CMBS) is secured by commercial and multifamily properties, such as apartment buildings, retail or office properties, hotels, schools, industrial properties and other commercial sites. A CMBS is usually structured differently than a RMBS. Thirdly, these pools are securitized through various legal methods dependent on the type of MBS and jurisdiction. This securitization is done by government agencies, government-sponsored enterprises, and private entities which may offer credit enhancement features to mitigate the risk of prepayment and default associated with these mortgages. Since residential mortgages in the U.S. have the option to pay more than the required monthly payment (curtailment) or to pay off the loan in its entirety (prepayment), the monthly cash flow of an MBS is not known in advance, and therefore presents risk to MBS investors. These securities are usually sold as bonds, but financial innovation has created a variety of securities that derive their ultimate value from mortgage pools. In the U.S. most MBS's are issued by the Federal National Mortgage Association (Fannie Mae) and the Federal Home Loan Mortgage Corporation (Freddie Mac), U.S. government-sponsored enterprises. Ginnie Mae, backed by the full faith and credit of the U.S. government, guarantees that investors receive timely payments. Some private institutions, such as brokerage firms, banks, and homebuilders, also securitize mortgages, known as private mortgage securities.

MBS is often used by investment banks to monetize the credit spread between the origination of an underlying mortgage (private market transaction) and the yield demanded by bond investors through bond issuance (typically, a public market transaction). MBS is frequently more efficient and lower cost source of financing in comparison with other bank and capital markets financing alternatives. It allows issuers to diversify their financing sources, by offering alternatives to more traditional forms of debt and equity financing. MBS issuers can remove assets from their balance sheet, which can help to improve various financial ratios, utilize capital more efficiently and achieve compliance with risk-based capital standards.

Securitization is designed to reduce the risk of bankruptcy and thereby obtain lower interest rates from potential lenders. In most securitized investment structures, the investors' rights to receive cash flows are divided into tranches: senior tranche investors lower their risk of default in return for lower interest payments, while junior tranche investors assume a higher risk in return for higher interest. Therefore theoretically, securitization should serve to reduce credit risk by spreading it more widely and furthermore, it helps complete the market in the sense of Arrow-Debreu (1954), as suggested by Gaur, Seshadri and Subrahmanyam (2010).

The financial crisis of 2007 triggered by the subprime mortgage delinquencies signaled the end of a favorable period of mortgage securitization and housing market boom. It seems to suggest some side-effects of mortgage securitization, mainly lax screening by mortgage lenders. The dominant view, as summarized by Plantin (2010), is that mortgage securitization reduces banks' incentives to screen and monitor their borrowers in housing market boom period and the consequent degradation in mortgage quality in turn amplified the market downturn. This agency problem in securitization has been empirically investigated and confirmed by Keys, Mukherjee, Seru and Vig (2009 and 2010), Mian and Sufi (2009 and 2010), Mian, Sufi and Trebbi (2008).

The present study extends previous empirical research on the effect of mortgage securitization on the real economy and housing market by using structural SVAR. I contribute new time-series causality evidence for a 27-year period from 1983 to 2009 in which securitization became the dominant source of financing for the U.S. residential mortgage market. The remainder of the paper is organized as follows. Section II reviews the relevant prior research on securitization and financial innovation in general. Section III presents the sample data and measurement choice. Section IV introduces the time-series empirical method. Section V evaluates the results. Section VI concludes.

II. RELATED LITERATURE

Understanding the economics of securitization in residential and commercial mortgages is of fundamental importance and there is an extensive literature addressing the theoretic benefits and empirical effects of MBS market. Important recent papers on the theory of securitization include Shin (2009), Allen and Carletti (2006), Chiesa (2008), and Gaur, Seshadri and Subrahmanyam (2010), Parlour and Plantin (2008), Makarov and Plantin (2011), Plantin (2010), and Malherbe (2010). This strand of theoretical literature focuses on two main themes: market completeness and asymmetric information.

The securitization literature identifies at least two mechanisms by which securitization help complete the financial market in the Arrow and Debreu (1954) sense. First, Allen and Carletti (2006) show that credit risk transfer can be beneficial when banks face uniform demand for liquidity. In this mechanism, securitization improves risk sharing among all investors, but it can also induce contagion due to systemic effects and lead to a Pareto reduction in welfare. Second, Gaur, Seshadri and Subrahmanyam (2010) suggest that pooling and tranching are valuable in reducing ambiguity surrounding the valuation of new real investment in incomplete market. In a complete market, there is no benefit from pooling and tranching, and the standard asset pricing model can price the traded assets. However in an incomplete market, the value of a real asset can not always be uniquely computed using capital market prices. By pooling and tranching cash flows of underlying assets, securitization help price discovery.

The securitization literature also provides insight into the asymmetric information problems including moral hazard and adverse selection that can arise in securitization. Gorton and Pennacchi (1995) give an early and fundamental discussion of the first problem of asymmetric information in credit risk transfer: moral hazard. An important characteristic that is often attributed to banks is a special ability to monitor borrowers that increases the probability of loan repayment. However, this monitoring can not be observed by outsiders, which leads to a moral hazard problem. With loan sales being the only instrument available in their model, Gorton and Pennacchi (1995) show how a bank can overcome the moral hazard problem by continuing to hold a fraction of the loan, and offering explicit guarantees on loan performance. This loan ownership structure after loan sales improves the incentive of the bank to keep monitoring the firm. They conclude that if a bank can implicitly commit to holding certain fraction of a loan, or to provide limited recourse, the moral hazard associated with loan sales is reduced.

Greenbaum and Thakor (1987) consider another problem of asymmetric information in credit risk transfer: adverse selection, by examining a bank's choice of whether to fund the loans by deposits or to sell the loans. With common knowledge of loan quality and laissez faire banking, the choice is irrelevant. With adverse selection, the high-quality loans are sold or securitized, and the low-quality loans are funded with deposits. Duffee and Zhou (2006) include both moral hazard and adverse selection problems by extending the model of Gorton and Pennacchi (1995). Because banks have better private information about the creditworthiness of their borrowers, their assessment of the loan default likelihood is likely to be different to outsiders' assessment. The authors show that credit derivatives, as an instrument of risk transfer, help alleviate the lemons problem that plagues the loan sales market. However when the asymmetric information problem is severe, credit risk transfer benefits the bank only if it makes a high-quality loan, and this benefit is overweighed by an increase in deadweight cost if the bank makes a low-quality loan. Therefore, bank profits fall on average across both high-quality and low-quality loan states. The authors conclude that although credit derivatives market is useful to banks in general, the introduction of credit derivatives market could shut down the loan sales market. The net effect depends on the severity of asymmetric information: the bank is better off if the problem is moral hazard, and the bank is worse off if the problem is adverse selection.

In recent research, Parlour and Plantin (2008) analyze credit risk transfer through the bank-borrower relationship. Different to the risk transfer instrument of credit derivatives in Duffee and Zhou (2006), Parlour and Plantin (2008) use loan sales as an instrument of credit risk transfer, and generate an adverse selection problem by a bank that has a stochastic discount shock and can exploit proprietary information. They find that a liquid market of credit risk transfer can arise, but the socially inefficient outcome may result. The endogenous degree of liquidity is not always socially efficient because there might be excessive trade in high-quality bonds but inefficient liquidity in low-quality bonds. Wagner and Marsh (2006) go beyond the credit risk transfer within the banking system to include cross-sector risk transfer. They argue that the incentive of banks to transfer credit risk is aligned with the regulatory objective of improving stability and welfare, and the risk transfer from banks to non-banks is more beneficial than the risk transfer among banks.

In regard to the linkage between securitization and financial stability, Shin (2010) points out that the importance of securitization for financial stability derives from the ability of the shadow banking system to increase total supply of credit to end borrowers[2]. The prior literature has identified two mechanisms that securitization could drive the growth of credit. The first mechanism is from supply-side. Bernanke and Blinder (1988) and Kashyap and Stein (2000) emphasize the liquidity structure of the bank's balance sheet, and Van Den Heuvel (2002) stress the cushioning effect of the bank's regulatory capital to explain the fluctuation of the credit. The second mechanism to cause fluctuation in credit is due to the shifts in the demand for credit as in Bernanke and Gertler (1989) and Kiyotaki and Moore (1997). The changing strength of the borrower's balance sheet and the resulting change in the creditworthiness of the borrower drive the fluctuation of the credit. A negative shock reduces labor demand and lowers wage, and it in turns deteriorate individual's net worth, reduces debt capacity and amplifies the downturns. Shin (2010) extends this supply-side factor to explain the origin of the ongoing subprime crisis. The greater risk-taking capacity of the shadow banking system leads to an increased demand for new assets to fill the expanding balance sheets and leverage. Shin (2010) suggests a picture of an inflating balloon which fills up with new assets, and as the balloon expands, banks search for new assets to fill the balloon.

III. DATA

To investigate the time-series economic causality problem among securitization, market risk, production output, moral hazard, and risk ignorance by investors, I rely on data from various publicly available databases: The Inside Mortgage Finance Publications' Mortgage Market Statistical Annual, Federal Reserve Board's Flow of Funds, Federal Housing Finance Agency's (FHFA) home price index, and Federal Reserve Economic Data (FRED).

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[2] The financial crisis literature covers more general discussion on the roots and mechanisms of bubble and crash, such as Abreu and Brunnermeier (2003) on synchronization, Shileifer and Vishny (1997), Abreu and Brunnermeier (2003) and Brunnermeier and Nagel (2004) on limited arbitrage, Brunnemeier and Pedersen (2008) on funding liquidity due to margin requirement.

Mortgage Market Statistical Annual provides comprehensive data on all US mortgage loan originations and servicing including agency, non-agency, subprime, nontraditional products, and home-equity lending as well as extensive statistics on loan securitizations. The historical data of new mortgage issuance and banks' holding in mortgage-backed securities are gathered through Inside Mortgage Finance's research and surveys from 1980 to 2010. The banks' ownership of MBS is the ratio of their aggregate holdings in MBS to the new mortgage issuance.

Flow of Funds dataset provides the dollar amount of US mortgages held by nonfinancial firms, and the amount of mortgage-backed securities issued in each month. This dataset allows me to create the quarterly securitization rate from 1970 to 2010. Real GDP, 3-month Treasury rate, oil price are taken directly from Federal Reserve Economic Data (FRED).

To estimate the housing market risk, I first construct a portfolio of residential REITs from Compustat using the firms in GICS 4040 industry (specifically GICS 40402050 sub-industry) engaged in the acquisition, development, ownership, leasing, management and operation of residential mortgages and properties including multifamily homes, apartments, manufactured homes and student housing properties.[3] Then I calculate the equally-weighted daily returns of this REIT portfolio for each calendar quarter. Finally I estimate the standard deviation of the REIT portfolio's returns within the quarter, and I call it quarterly House Price Risk in the following time-series regression analysis.

By matching the year and quarter of all datasets, the time period of the entire data sample is from the first quarter of 1983 to the fourth quarter of 2009. The variables are defined in Table I.

[Insert Table I here]

The summary statistics of the real variables are shown in Table II.

[Insert Table II here]

The correlation matrix is in Table III.

[3] GICS (Global Industry Classification Standard) is developed by Standard & Poor's and MSCI Barra. It consists of 10 sectors, 24 industry groups, 68 industries and 154 sub-industries.

[Insert Table III here]

IV. METHODOLOGY

The econometric test of time-series causality is conducted using aggregate quarterly data on the U.S. housing market and the macro economy to estimate the dynamic responses of housing market risk and production output to shocks of unanticipated mortgage securitization and banks' MBS ownership. I undertake a structural vector autoregression (SVAR) analysis of the data in which the restrictions used to identify shocks are weak in the sense of being consistent with a wide range of theoretical macroeconomic models. I assume that shocks of securitization and banks' MBS ownership affect the real variables, and the restrictions are set up to satisfy the exact-identification requirement.

A structural VAR is appropriate for this analysis because it allows for investigation of important dynamic characteristics of the real economy by imposing structural restrictions from economic theory. Particularly useful in this research are the impulse response functions and variance decompositions. According to Sims (1980), all variables appearing in the structural VAR could be argued to be endogenous. Econometric theory places only weak restrictions on the reduced form coefficients and on which variables that should enter a reduced-form VAR. He furthermore suggests that empirical research should use small-scale models identified via a small number of constraints. SVARs provide a more systemic approach to imposing restrictions and could lead one to capture empirical regularities which remain hidden to standard regression approaches. However, a concern might arise in the aggregation of economic data: by aggregating economic activities into one single variable like the GDP and house price risk, the geographical characteristics such as the differences of market completeness or risk sharing capability across different locations are largely ignored.

Enders (2009), Lutkepohl (2010), Keating (1992), Bjornland (2000), and Sims (2002) provide textbook treatment of SVAR in technical detail. Sims (1982) Freeman, Williams and Lin (1989) introduce its use in policy analysis, and their methodology is closely related to this research, because essentially the results of this paper will provide empirical evidence for whether a policy to support or discourage mortgage securitization is sound and necessary.

To better understand the real economy, I first study the behavior of a single representative economy in which there are only three real variables: oil price, 3-month T-bill rate and real GDP. Oil price represents the commodity price that can be the cost of production, whereas 3-month T-bill rate is the cost of capital. Real GDP is a gross measure of production output. This parsimonious model describes a representative economy that has a production function similar to the Cobb–Douglas function that is widely used to represent the relationship of an output to inputs. The reduced-form VAR of one lag can be written as the followings:

$$OilPrice_t = \beta_{10} + \beta_{11}OilPrice_{t-1} + \beta_{12}TBillRate_{t-1} + \beta_{13}GDP_{t-1} + \varepsilon_{1t} \quad (1)$$

$$TBillRate_t = \beta_{20} + \beta_{21}OilPrice_{t-1} + \beta_{22}TBillRate_{t-1} + \beta_{23}GDP_{t-1} + \varepsilon_{2t} \quad (2)$$

$$GDP_t = \beta_{30} + \beta_{31}OilPrice_{t-1} + \beta_{32}TBillRate_{t-1} + \beta_{33}GDP_{t-1} + \varepsilon_{3t} \quad (3)$$

Having specified the reduced-form VAR model, the appropriate lag length (*t-1*, *t-2*, and etc.) of this model has to be decided. It is common to choose the lag length based upon a priori knowledge. For example, monetary economists tend to use 4 lags due to the presence of seasonality in the quarterly macroeconomic time-series data. However, a large lag length relatively to the number of observations will typically lead to a poor and inefficient estimation of coefficients β_{ij} (for equation *i* and coefficient *j*). On the other hand, a short lag length will induce spurious significant coefficients, as unexplained information is left in the disturbance terms ε_{it} (for equation *i* at time *t*). The alternative approach is to use a statistical method such as Akaike (1974) information criterion (AIC), Schwarz (1978) Bayesian information criterion (BIC)[4], and Hannan and Quinn (1979) information criterion (HQIC). It is actually preferred and recommended by many econometrics textbooks including Enders (2009) and Lutkepohl (2010).

Yule (1926), Granger and Newbold (1974) and Phillips (1986) have observed that the ordinary least square regression of two nonstationary variables may produce spurious regression results. Thus, it is necessary to test for stationarity of the variables before estimating the model. The results of augmented Dickey-Fuller (ADF) test and Phillips–Perron (PP) test (Panel A of Table IV) indicate the existence of unit-root in the real variables in levels. By taking the first-difference on the real variables, the new time-series data becomes stationary, as the ADF and PP test results shown in Section B of Table IV.

[Insert Table IV here]

[4] Akaike (1977) develops his own Bayesian formalism independent of Schwarz (1978), now often referred to as Akaike's Bayesian Information Criterion (ABIC).

The results of Akaike information criterion (AIC), Schwarz-Bayesian information criterion (BIC), and Hannan-Quinn information criterion (HQIC) suggest the optimal length of lags to be 2. Therefore, the more appropriate specification of the reduced-form VAR is:

$$\Delta OilPrice_t = \beta_{10} + \beta_{11}\Delta OilPrice_{t-1} + \beta_{12}\Delta OilPrice_{t-2} + \beta_{13}\Delta TBillRate_{t-1} + \beta_{14}\Delta TBillRate_{t-2} + \beta_{15}\Delta GDP_{t-1} + \beta_{16}\Delta GDP_{t-2} + \varepsilon_{1t} \quad (4)$$

$$\Delta TBillRate_t = \beta_{20} + \beta_{21}\Delta TBillRate_{t-1} + \beta_{22}\Delta TBillRate_{t-2} + \beta_{23}\Delta OilPrice_{t-1} + \beta_{24}\Delta OilPrice_{t-2} + \beta_{25}\Delta GDP_{t-1} + \beta_{26}\Delta GDP_{t-2} + \varepsilon_{2t} \quad (5)$$

$$\Delta GDP_t = \beta_{30} + \beta_{31}\Delta GDP_{t-1} + \beta_{32}\Delta GDP_{t-2} + \beta_{33}\Delta OilPrice_{t-1} + \beta_{34}\Delta OilPrice_{t-2} + \beta_{35}\Delta TBillRate_{t-1} + \beta_{36}\Delta TBillRate_{t-2} + \varepsilon_{3t} \quad (6)$$

Or in matrix form:

$$Y = B' L(Y) + \varepsilon, \text{ and } \varepsilon \sim N(0, \Sigma) \quad (7)$$

where $Y = \begin{bmatrix} \Delta OilPrice \\ \Delta TBillRate \\ \Delta GDP \end{bmatrix}$ at time t, $L(.)$ is the lag operator ($t-1$and $t-2$), B is the matrix of beta coefficients, ε is the vector of residuals, and Σ is the diagonal variance-covariance matrix.

The reduced-form VAR can be directly estimated through single equation regression methods like OLS, however, the lag structure in equations (4) through (6) is unrestricted and therefore uninterpretable without reference to theoretical economic structures.[5] In other words, there is no unique mapping from reduce-form VAR to structural VAR without imposing sufficient number of contemporaneous restrictions on the lag structure to identify the structural coefficients. Suppose that the structural model has 3 equations, one each for the commodity market, capital market and goods market. Let $e_{\text{Commodity}}$, e_{Capital} and $e_{\text{Production}}$ be the structural disturbances or shocks to the commodity market, capital market and goods market output respectively, and ε_t be the residuals in the reduced-form VAR of equations (4) through (6). This structural VAR can be written in matrix form as:

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[5] Cooley and Leroy (1985) criticize the reduced-form VAR on the ground that traditional VAR uses identification restriction based upon a recursive contemporaneous structure known as Choleski decomposition which is statistical, but not necessarily consistent with economic theory. Therefore the estimated shocks are not pure economic shocks but rather linear combinations of the structural disturbances.

$$Y = B' L(Y) + A^{-1}e \text{, and } e \sim N(0, I) \tag{8}$$

where $Y = \begin{bmatrix} \Delta OilPrice \\ \Delta TBillRate \\ \Delta GDP \end{bmatrix}$ at time t, $L(.)$ is the lag operator ($t-1$and $t-2$), B is the matrix of beta coefficients, A is the matrix of identification restrictions that guarantee the unique mapping between reduced-form VAR and structural VAR, e is the vector of disturbances or shocks, and I is the identity matrix. By comparing equation (7) and (8), the following condition is obtained: $\varepsilon = A^{-1}e$ or $A\varepsilon = e$.

In a very special case, the covariance matrix for structural disturbances $e(\Sigma)$ is diagonal with unity on its diagonal and zero elsewhere, $e = \varepsilon$, or

$$e_{Commodity} = \varepsilon_1 \tag{9}$$

$$e_{Capital} = \varepsilon_2 \tag{10}$$

$$e_{Production} = \varepsilon_3 \tag{11}$$

Equations (9) through (11) can be transformed to matrix form:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} = \begin{bmatrix} e_{Commodity} \\ e_{Capital} \\ e_{Production} \end{bmatrix} \tag{12}$$

Now the matrix of identification restriction is formally defined as:

$$A = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{13}$$

This special case of contemporaneous restrictions implies that each real variable ($OilPrice_t$, $TBillRate_t$, and GDP_t) is assigned to its own structural equation (commodity market, capital market and production output) which ensures that the shocks can be given meaningful economic interpretations. For example, if the commodity price is predetermined, only the commodity (oil) producers can respond instantly to aggregate supply shocks $e_{Commodity}$, hence the residual ε_1 of the oil price equation (4). This is consistent with the aggregate supply function, but the model is still overidentified as explained below.

Sims (1986), Bernanke (1986) and Blanchard and Watson (1986) make use of economic theory to impose short-run structural restrictions (shocks only have temporary effects) on the observed values of residuals (ε_1, ε_2 and ε_3) to recover the underlying structural disturbances ($e_{Commodity}$, $e_{Capital}$ and $e_{Production}$).[6] Following their methodology, there are $3\times(3–1)/2=3$ restrictions required for exact-identification in this 3-variable VAR model of equations (4) through (6). The special case of equation (13) has 6 restrictions, therefore it is overidentified. In order to exact-identify this VAR, I will need only 3 restrictions, or equivalently 3 zero in the A matrix of equation (13).

Now I specify the new restrictions as the followings. The first equation (14) of this 3-variable VAR is treated in the same way as equation (9) because it represents the commodity (oil) price and is assumed exogenous, at least contemporaneously. It is an appropriate assumption for an open economy. Bernanke, Gertler, Watson, Sims and Friedman (1997) argue that oil price provides valid exogenous shocks and affects U.S. monetary policy and real economy for two reasons. First, periods dominated by oil price shocks are reasonably easy to identify empirically, and the case for exogeneity of at least the major oil price shocks is strong. Second, oil price shocks are perhaps the leading alternative to monetary policy as the key factor in postwar U.S. recessions.

The second equation (15) represents the money (capital) market. In a typical theoretical model of money market, money demand is assumed to depend contemporaneously on the interest rate, inflation, and income, whereas money supply is set by the central bank after observing the money value, inflation and output. In this parsimonious model, I do not consider the money demand and money supply separately. Instead, the equilibrium interest rate (secondary market rate of 3-month Treasury Bill) is a proxy for the optimal or prevailing cost of capital and depends only on production output in the goods market. This assumption implicitly suggests that commodity prices affect the money market only with a lag. The third equation (16) represents the goods (production output) market. I allow shocks of commodity price and capital cost to have a contemporaneous effect on the production output.

[6] Alternatively, Shapiro and Watson (1988) and Blanchard and Quah (1989) consider the shocks having permanent effects.

$$e_{Commodity} = \varepsilon_1 \tag{14}$$

$$e_{Capital} = \varepsilon_2 + a_1\varepsilon_3 \tag{15}$$

$$e_{Production} = a_2\varepsilon_1 + a_3\varepsilon_2 + \varepsilon_2 \tag{16}$$

The restrictions of equations (14) through (16) can be written in matrix form:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & a_1 \\ a_2 & a_3 & 1 \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} = \begin{bmatrix} e_{Commodity} \\ e_{Capital} \\ e_{Production} \end{bmatrix} \tag{17}$$

where a_1, a_2 and a_3 are free-parameters in the sense that they are not restricted to be zero and their values are estimated from the data. The matrix of identification restrictions is defined as the equation (18), and there are 3 zeros in the matrix suggesting 3 restrictions for exact-identification.

$$A = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & a_1 \\ a_2 & a_3 & 1 \end{bmatrix} \tag{18}$$

Having specified the new restriction matrix A, I can estimate the 3-variable VAR and use the impulse-response functions to do further statistical inference. However, in order to study the impact of mortgage securitization and the moral hazard problem between banks and MBS investors on the U.S. economy and specifically the U.S. housing market, I will need to add three more variables to this 3-variable model and construct a 5-variable Structural VAR. ThesE variables are proxies for the activities of housing market and mortgage securitization, and the banks' incentive to screen and monitor the mortgages that are being originated and securitized. The first variable is housing market risk, the second variable is securitization rate, and the third variable is the aggregate ownership of securitized mortgages by all commercial banks (shortened as $Bank_t$ in the VAR). Housing market risk or house price risk is the quarterly standard deviation of the returns of an equally-weighted residential REIT portfolio.[7] Mortgage-backed security or MBS is the financial instrument created by the securitization process, and actively traded among financial institutions including investment banks, insurance companies and hedge funds. The holding of MBS by commercial banks is sometime referenced as the "skin in the game" by market practitioners and academic researchers.

The results of Akaike information criterion (AIC), Schwarz-Bayesian information criterion (BIC), and Hannan-Quinn information criterion (HQIC) suggest the optimal lag length to be 1. The specification of this 6-variable reduced-form VAR is:

$$OilPrice_t = \beta_{10} + \beta_{11} OilPrice_{t-1} + \beta_{12} Securitization_{t-1} + \beta_{13} TBillRate_{t-1} + \beta_{14} HouseRisk_{t-1} + \beta_{15} GDP_{t-1} + \beta_{16} Bank_{t-1} + \varepsilon_{1t} \quad (19)$$

$$TBillRate_t = \beta_{20} + \beta_{21} TBillRate_{t-1} + \beta_{22} OilPrice_{t-1} + \beta_{23} Securitization_{t-1} + \beta_{24} HouseRisk_{t-1} + \beta_{25} GDP_{t-1} + \beta_{26} Bank_{t-1} + \varepsilon_{3t} \quad (20)$$

$$Bank_t = \beta_{30} + \beta_{31} Bank_{t-1} + \beta_{32} OilPrice_{t-1} + \beta_{33} Securitization_{t-1} + \beta_{34} TBillRate_{t-1} + \beta_{35} HouseRisk_{t-1} + \beta_{36} GDP_{t-1} + \varepsilon_{5t} \quad (21)$$

$$HouseRisk_t = \beta_{40} + \beta_{41} HouseRisk_{t-1} + \beta_{42} OilPrice_{t-1} + \beta_{43} Securitization_{t-1} + \beta_{44} TBillRate_{t-1} + \beta_{45} GDP_{t-1} + \beta_{46} Bank_{t-1} + \varepsilon_{4t} \quad (22)$$

$$Securitization_t = \beta_{50} + \beta_{51} Securitization_{t-1} + \beta_{52} OilPrice_{t-1} + \beta_{53} TBillRate_{t-1} + \beta_{54} HouseRisk_{t-1} + \beta_{55} GDP_{t-1} + \beta_{56} Bank_{t-1} + \varepsilon_{2t} \quad (23)$$

$$GDP_t = \beta_{60} + \beta_{61} GDP_{t-1} + \beta_{62} OilPrice_{t-1} + \beta_{63} Securitization_{t-1} + \beta_{64} TBillRate_{t-1} + \beta_{65} HouseRisk_{t-1} + \beta_{66} Bank_{t-1} + \varepsilon_{5t} \quad (24)$$

Following the identification method of Sims (1986), Bernanke (1986) and Blanchard and Watson (1986), There are 6×(6–1)/2=15 restrictions required for exact-identification in this 6-variable VAR model of equations (19) through (24). I will specify restrictions in the order of the identification equations. The equation (25) represents the commodity (oil) price and the equation (26) represents the money (capital) market. These two restrictions suggests that oil

[7] House price risk is defined in the previous data section, and see Table 1 for more details. Residential REITs are Compustat firms in GICS 4040 industry, specifically GICS 40402050 sub-industry, engaged in the acquisition, development, ownership, leasing, management and operation of residential mortgages and properties including multifamily homes, apartments, manufactured homes and student housing properties.

price shocks are exogenous and monetary policy is only affected by commodity price and production output. This is based on the results of Bernanke, Gertler, Watson, Sims and Friedman (1997).

$$e_{Commodity} = \varepsilon_1 \tag{25}$$

$$e_{Capital} = a_1\varepsilon_1 + \varepsilon_2 + a_2\varepsilon_6 \tag{26}$$

$$e_{Bank} = a_3\varepsilon_2 + \varepsilon_3 + a_4\varepsilon_4 + a_5\varepsilon_5 \tag{27}$$

$$e_{Housing} = a_6\varepsilon_1 + a_7\varepsilon_3 + \varepsilon_4 + a_8\varepsilon_5 \tag{28}$$

$$e_{Securitization} = a_9\varepsilon_1 + a_{10}\varepsilon_3 + a_{11}\varepsilon_4 + \varepsilon_5 \tag{29}$$

$$e_{Production} = a_{12}\varepsilon_1 + a_{13}\varepsilon_2 + a_{14}\varepsilon_4 + a_{15}\varepsilon_5 + \varepsilon_6 \tag{30}$$

The equation (27) represents the banking market and the change of commercial banks' holdings in mortgage-backed security is assumed to contemporaneously depend on the interest rate, house price risk and securitization activities. This restriction implies that any unexpected rising and falling of construction cost as proxied by the commodity price will only have lagged (not contemporaneous) effect on the securitization market.

The equation (28) is the restriction for the shocks of house price risk. I allow cost of production (commodity price), banks' MBS ownership and securitization activities to have a contemporaneous effect on house price risk. In a typical theoretical model of financial innovation, securitization is assumed to be endogenous and depend on the production cost (commodity price), banks' incentive (MBS ownership) and housing market activities (house price risk). This suggests the restriction in the equation (29) and the interest rate and production output affect the securitization market only with a lag. The restrictions in (28) and (29) imply that the securitization and housing market affect depend on each other contemporaneously in both directions. It is an appropriate assumption for aggregate output (real GDP) is affected by many economic activities including commodity market (oil price), capital market (interest rate), housing market (residential house price risk) and securitization market (residential mortgage securitization rate). The restriction for the goods market is specified in equation (30). The restrictions of equations (25) through (30) can be written in matrix form:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ a_1 & 1 & 0 & 0 & 0 & a_2 \\ 0 & a_3 & 1 & a_4 & a_5 & 0 \\ a_6 & a_7 & a_8 & 1 & a_9 & 0 \\ 0 & a_{10} & a_{11} & a_{12} & 1 & 0 \\ a_{13} & a_{14} & 0 & a_{15} & 0 & 1 \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{bmatrix} = \begin{bmatrix} e_{Commodity} \\ e_{Capital} \\ e_{Bank} \\ e_{Housing} \\ e_{Securitization} \\ e_{Production} \end{bmatrix} \tag{31}$$

where a_1 to a_{15} are free-parameters in the sense that they are not restricted to be zero and their values are estimated from the data. The matrix of identification restrictions is defined as the following, and there are 15 zeros in the matrix suggesting 15 restrictions for exact-identification.

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ a_1 & 1 & 0 & 0 & 0 & a_2 \\ 0 & a_3 & 1 & a_4 & a_5 & 0 \\ a_6 & a_7 & a_8 & 1 & a_9 & 0 \\ 0 & a_{10} & a_{11} & a_{12} & 1 & 0 \\ a_{13} & a_{14} & 0 & a_{15} & 0 & 1 \end{bmatrix} \tag{32}$$

V. RESULTS

The baseline (3-variable) model for studying the behavior of a single representative economy includes three real variables: oil price, 3-month T-bill rate and real GDP. They represent the commodity market (as a proxy for cost of production), money market (as a proxy for cost of capital) and aggregate production output respectively. The data are first-differenced. Statistical tests suggest that first-difference makes the data stationary (See Table IV in the previous Methodology section). After obtained first-differenced time-series data, the first stage is to estimate the reduced-form VAR. The variance-covariance matrix from this reduced-form VAR is used to estimate the structural VAR in the second stage. Two lags are used for this 3-variable VAR model based on the test results of AIC, BIC and HQIC, and the sample period is from the first quarter of 1983 to the fourth quarter of 2009.

The parameter (β) estimates for the reduced-form 3-variable VAR in equations (4) through (6) are not reported because their economic interpretation is ambiguous without appropriate restrictions.[8] Table VI shows the free-parameters (a) estimates for the identification restrictions of the structural VAR in equations (14) through (16), or equation (18) in matrix form.

[Insert Table V here]

Figure 1 plots the impulse-response functions (IRF) with 95% confidential interval bands.

[Insert Figure 1 here]

Impulse response function (IRF) describes how the economy reacts over time to exogenous impulses, which economists usually call *shocks*, and are often modeled in the context of a VAR. Impulses that are often treated as exogenous from a macroeconomic point of view include changes in government spending, tax rates, and other fiscal policy parameters; changes in the monetary base or other monetary policy parameters; changes in productivity or other technological parameters. In this baseline 3-variable VAR, IRF is the reaction of endogenous macroeconomic variables such as commodity (oil) price, production output (real GDP) and interest rate (3-month Treasury Bill) at the time of the shock and over subsequent quarters in time.

The shock in commodity (oil) price raises the real GDP initially in the first quarter, but reduces the output in the subsequent two quarters, and after the fourth quarter the output returns to normal.[9] The coefficient estimates of the reduced-form VAR in Table VI confirms the relationship because the GDP equation in column (3) has a positive coefficient for the 1-quarter lagged oil price change but a negative coefficient for the 2-quarter lagged oil price change. Interest rate shock has the similar pattern of impact on production output. On the other hand, the commodity price shock has no impact on the interest rate as measured by the 3-month Treasury rate due to the fact that its IRF's 95% confident interval of includes zero. Similarly, shocks in production output as measured by the real GDP do not affect the commodity price change and interest rate change in a significant way. The forecast-error variance decomposition

[8] The evidence presented in Runkle (1987) suggests that it is often difficult to draw strong conclusions about the interrelationship of interest rates, money, prices, and output from unrestricted VARs. They often do not tell much about interesting macroeconomic questions.

[9] Hooker (1996) investigates the Granger-causality between oil price shocks and U.S. GDP changes and shows that a one-time, one-standard deviation increase in oil prices typically led to GDP growth roughly 0.6 percentage points lower in the third and fourth quarters after the shock, returning to its undisturbed rate in a slowly damping cyclical pattern.

(FEVD) is shown in Figure 2. FEVD indicates the amount of information each variable contributes to the other variables in a vector autoregression (VAR) models, or in other words, it determines how much of the forecast error variance of each of the variable can be explained by exogenous shocks to the other variables. The interest rate shock gradually explains most of output's variability. Comparing to the commodity price shock, the interest rate shock is more important for the real GDP.

[Insert Figure 2 here]

To study the impact of mortgage securitization and the moral hazard problem between banks and investors of securitized mortgages on the real economy and U.S. housing market, the 5-variable VAR model adds three new variables relevant to the housing market, mortgage market and incentive to screen and monitor the mortgages that are being originated and securitized: (i) mortgage securitization rate, (ii) house price risk, a measure for the risk in the housing market, (iii) The new variable is the aggregate ownership of securitized mortgages by all commercial banks (shortened as $Bank_t$ in the VAR). Table VI shows the free-parameters (a) estimates for the identification restrictions of the structural VAR in equations (25) through (30), or equation (32) in matrix form.

[Insert Table VI here]

Figure 5 plots the impulse-response functions (IRF) with 95% confidential interval bands.

[Insert Figure 3 here]

These graphs illustrate the reaction of commodity (oil) price, mortgage securitization rate, interest rate (3-month Treasury Bill), housing market risk (residential REITs' price risk), production output (real GDP) and banks' MBS ownership at the time of the shock and over subsequent ten quarters in time. Specifically, positive shocks in the securitization market reduce the housing market risk and increase aggregate production output in a statistically significant way as indicated by the 95% confidential interval bands. The impact to the housing market is long-lasting: it takes about four quarters (one year) for house price risk to return to normal after the initial securitization shock, whereas it takes only about one quarter for output to return to normal. The shock in housing market contemporaneously increases the interest rate and reduces the production output, but the effect is very weak because zero falls inside the 95% confidence interval. Interestingly, the same kind of shock has a long-term effect on the securitization market: the securitization rate increases in response to the rising house price risk and the effect lasts for more than ten quarters. The forecast-error variance decomposition (FEVD) in Figure 4 shows that shocks of securitization market, money market (interest rate) and banking market have significant explanation power over the variation of real GDP. They also gradually explain the variation of housing market.

The shock of banks' ownership of MBS increases the housing market risk for three quarters and reduces the aggregate production output briefly (one quarter). On the other hand, the only shock contemporaneously affects the banks' ownership of MBS is the shock from securitization market.[10] The rising securitization rate suddenly pushes up the banks' holding of mortgage-backed security and this effect disappears in just about one quarter. None of the other macroeconomic shocks in commodity price, interest rate, house price risk and output matters for banks' ownership of MBS. The forecast-error variance decomposition (FEVD) in Figure 4 shows that most variations in securitization market are explained by the shocks of interest rate and house price risk. Shocks of securitization rate and interest rate can explain most of the variability in banks' holdings of mortgage-backed security, whereas the risk of housing market only has insignificant explanatory power for the changes in commercial banks' MBS ownership.

[Insert Figure 4 here]

In sum, the time-series evidence using structural VAR suggests that residential mortgage securitization does help complete the market by reducing housing market risk and improving production output. The influence of "skin in the game" from the commercial banks' MBS ownership on the securitization activities seems to be insignificant. There are evidences that shocks in banks' holdings of MBS actually increase the risk of residential housing market and makes real GDP decline.

[10] Other IRFs that affect banks' MBS ownership have zero falling inside the 95% confidence interval band.

VI. CONCLUSION

The empirical analysis of this paper indicates that residential mortgage securitization help reduce the housing market risk during the subsequent four quarters after initial shocks of securitization activities. The same shock also improves aggregate production output, but the effect only lasts for about one quarter. Commercial banks' ownership of mortgage-backed security, or the "skin in the game", may not have a significantly positive effect on the degree to which a given change in mortgage securitization activities can influence real output. In fact, the variations of banks' MBS holdings are entirely driven by the aggregate securitization rate of residential mortgages. On the contrary, the reaction of production output and housing market to changes of the "skin in the game", if anything, is negative during the subsequent one quarter and three quarters respectively after initial shocks. Thus, the mortgage securitization boom of the mid-2000s in the U.S. seems to cause the output to go up and housing market risk to go down, supporting the benefits of securitization, as a risk transfer mechanism, securitization benefits the financial market participants by improving market completeness through matching cash flows to investors' need in various states of the nature. However, the negative impact of banks' MBS ownership on real economy and residential housing market might imply that investors have been neglecting the risks associated with investing in Mortgage-Backed Securities.

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Table I. Variable definitions

Variable Name	Definition	Data Sources
Oil	Spot Oil Price: Quarterly price of West Texas Intermediate	FRED, Federal Reserve Bank of St. Louis
Securitization	Quarterly new residential MBS ($)divided by residential mortgage issuance ($)	Flow of Funds, Federal Reserve Board of Governors
Tbill	3-Month Treasury Bill: Quarterly average of secondary Market Rate	FRED, Federal Reserve Bank of St. Louis
Risk	House Price Risk: Quarterly volatility of the residential REIT portfolio return(equally-weighted)	Compustat and CRSP
GDP	Real Gross Domestic Product: Quarterly average	FRED, Federal Reserve Bank of St. Louis
Bank	Quarterly commercial bank's holding of MBS ($) divided by total MBS outstanding ($)	Mortgage Market Statistical Annual, Inside Mortgage Finance Publications

Table II. Summary Statistics

Variable	N	Mean	SD	Min	Max	Median
Oil Price	108	33.81	23.45	11.28	133.93	25.52
Securitization Rate	108	58.22%	15.72%	19.64%	100%	57.23%
3-month T-bill Rate	108	4.59%	2.53%	0.06%	10.32%	4.93%
House Price Risk	108	0.82%	0.75%	0.38%	6.05%	0.6%
Real GDP	108	9837	2310	5866	13326	9584
Bank MBS Holding	108	14.44%	3.46%	6.2%	21.55%	14.7%

Table III. Correlation Matrix

Variable	Oil Price	Securitization Rate	3-month T-bill	House Price Risk	Real GDP
Securitization Rate	0.64				
3-month T-bill	–0.44	–0.72			
House Price Risk	0.43	0.49	–0.42		
Real GDP	0.73	0.69	–0.70	0.36	
Bank MBS Holding	0.36	0.56	–0.75	0.13	0.71

Table IV. Time-series stationarity tests

Unit-root test tests whether a time-series variable is non-stationary using an autoregressive model. A well-known test that is valid in large samples is the augmented Dickey–Fuller test. Another test is the Phillips–Perron test. The null hypothesis is there exists a unit root in the time-series data.

Panel A. Unit-root test on level data:

Variable	Augmented Dickey–Fuller (ADF) Test Statistic	Phillips–Perron (PP) Test Statistic
Oil Price	-1.291 (0.6331)	-0.984 (0.7589)
Securitization Rate	-2.623* (0.0882)	-2.356 (0.1544)
3-month T-bill Rate	-0.647 (0.8600)	-1.370 (0.5966)
House Price Risk	-3.719*** (0.0038)	-3.669*** (-0.0046)
Real GDP	-1.477 (0.5450)	-1.097 (0.7161)
Bank MBS Holding	-1.562 (0.5024)	-1.733 (0.4142)

Mackinnon approximate p-value is shown in the parenthesis with ***, ** and * indicating its statistical significant level of 1%, 5% and 10% respectively.

Panel B. Unit-root test on first-differenced level data (except House Price Risk):

Variable	Augmented Dickey–Fuller (ADF) Test Statistic	Phillips–Perron (PP) Test Statistic
Oil Price	-8.827*** (0.0000)	-8.696*** (0.0000)
Securitization Rate	-12.816*** (0.0000)	-13.576*** (0.0000)
3-month T-bill Rate	-5.591*** (0.0000)	-5.630*** (0.0000)
Real GDP	-5.891*** (0.0000)	-6.001*** (0.0000)
Bank MBS Holding	-8.061*** (0.0000)	-8.058*** (0.0000)

Mackinnon approximate p-value is shown in the parenthesis with ***, ** and * indicating its statistical significant level of 1%, 5% and 10% respectively.

Table V. Structural VAR restrictions of baseline model: Macroeconomic system

The restrictions are in the form of a 3 by 3 matrix, thus there are $\frac{3\times(3-1)}{2}$ = 3 restrictions and 3 free-parameters (a_1 to a_3) for exact-identification:

$$A = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & a_1 \\ a_2 & a_3 & 1 \end{bmatrix}$$

The estimates of free-parameters (a_1 to a_3) for the structural VAR restrictions are shown below:

Restriction	(1) ΔOil Price	(2) Δ3-month T-bill	(3) ΔReal GDP
ΔOil Price	1	0	0
Δ3-month T-bill	0	1	0.00507* (1.65)
ΔReal GDP	-2.492*** (-26.13)	-24.55*** (-228.93)	1

t-test is shown in the parenthesis with ***, ** and * indicating its statistical significant level of 1%, 5% and 10% respectively.

Table VI. Structural VAR restrictions of 6-variable VAR model: Macro, mortgage securitization rate, house price risk, and banks' MBS holding

The restrictions are in the form of a 6 by 6 matrix, thus there are $\frac{6\times(6-1)}{2}$ = 15 restrictions and 15 free-parameters (a_1 to a_{15}) for exact-identification:

$$A=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ a_1 & 1 & 0 & 0 & 0 & a_2 \\ 0 & a_3 & 1 & a_4 & a_5 & 0 \\ a_6 & a_7 & a_8 & 1 & a_9 & 0 \\ 0 & a_{10} & a_{11} & a_{12} & 1 & 0 \\ a_{13} & a_{14} & 0 & a_{15} & 0 & 1 \end{bmatrix}$$

The estimates of the free-parameters (a_1 to a_{15}) for the structural VAR restrictions are shown below:

Restriction	(1) ΔOil Price	(2) Δ3-month T-bill	(3) Δ Bank MBS Holding	(4) House Price Risk	(5) ΔSecuritization Rate	(5) ΔReal GDP
ΔOil Price	1	0	0	0	0	0
Δ3-month T-bill	-0.0431 (-0.428)	1	0	0	0	0.00991*** (4.398)
ΔBank MBS Holding	0	-0.950*** (-4.791)	1	-34.46*** (-6.913)	33.67 (1.109)	0
House Price Risk	-0.00759 (-0.0755)	0.0947 (0.648)	-0.0864 (-0.425)	1	-211.8*** (-13.74)	0
ΔSecuritization Rate	0	1.198*** (6.312)	0.993*** (7.110)	34.84*** (7.072)	1	0
ΔReal GDP	-2.073*** (-20.62)	-23.32*** (-119.6)	0	730.9*** (148.0)	0	1

t-test is shown in the parenthesis with ***, ** and * indicating its statistical significant level of 1%, 5% and 10% respectively.

Figure 1. Impulse-Response Function (IRF) of Baseline 3-variable VAR model: Macroeconomic system

The dependent variables of this VAR model are quarterly oil price change, 3-month T-bill change, and real GDP change. The independent variables are the 1-quarter lagged dependent variables. IRF is the reaction of endogenous macroeconomic variables such as commodity (oil) price, production output (real GDP) and interest rate (3-month Treasury Bill) at the time of the shock and over subsequent quarters in time.

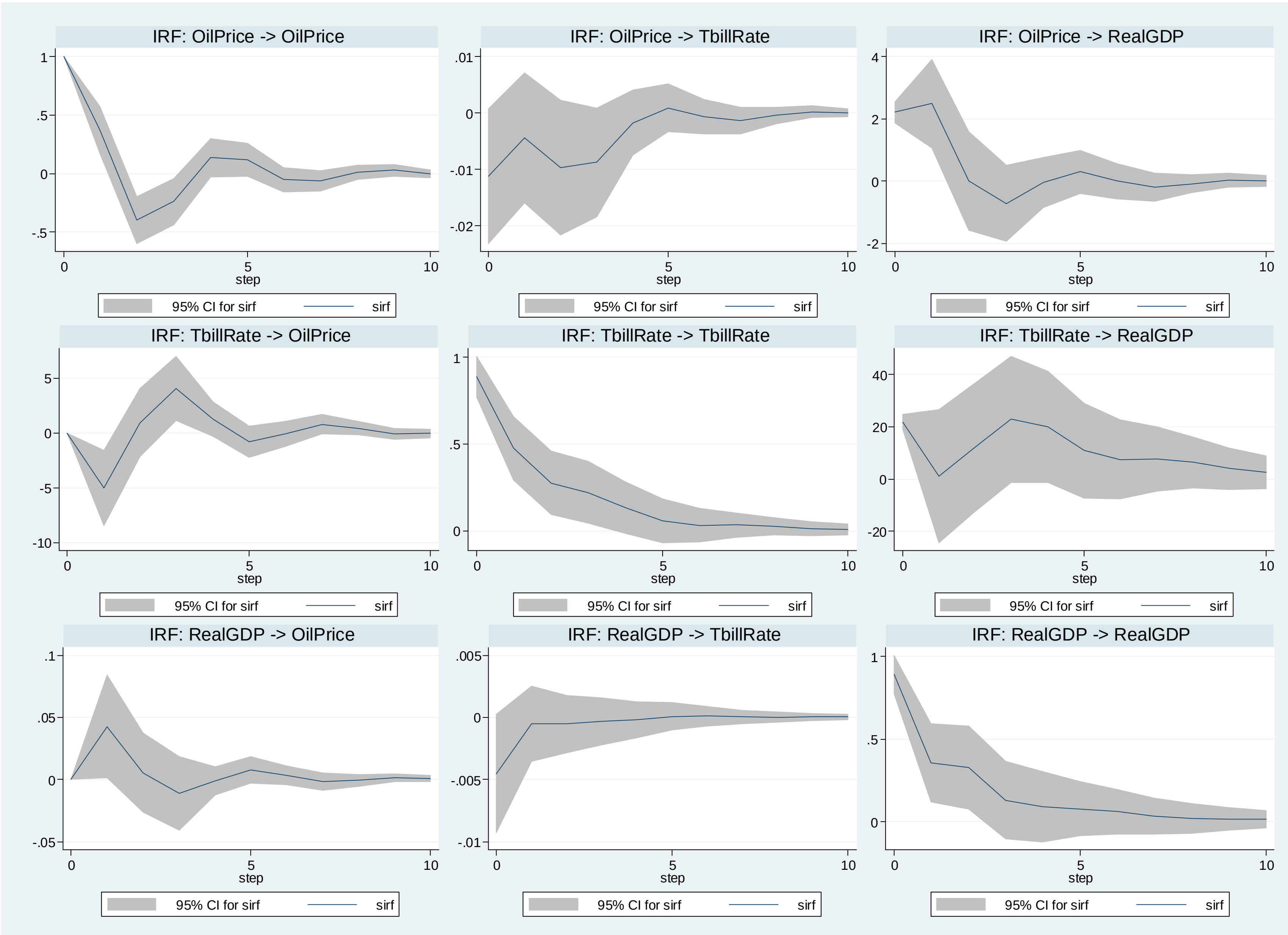

Figure 2. Forecast-Error Variance Decomposition (FEVD) of Baseline 3-variable VAR model: Macroeconomic system

The dependent variables of this VAR model are quarterly oil price change, 3-month T-bill change, and real GDP change. The independent variables are the 1-quarter lagged dependent variables. FEVD indicates the amount of information each variable contributes to the other variables in a vector autoregression (VAR) models, or in other words, it determines how much of the forecast error variance of each of the variable can be explained by exogenous shocks to the other variables.

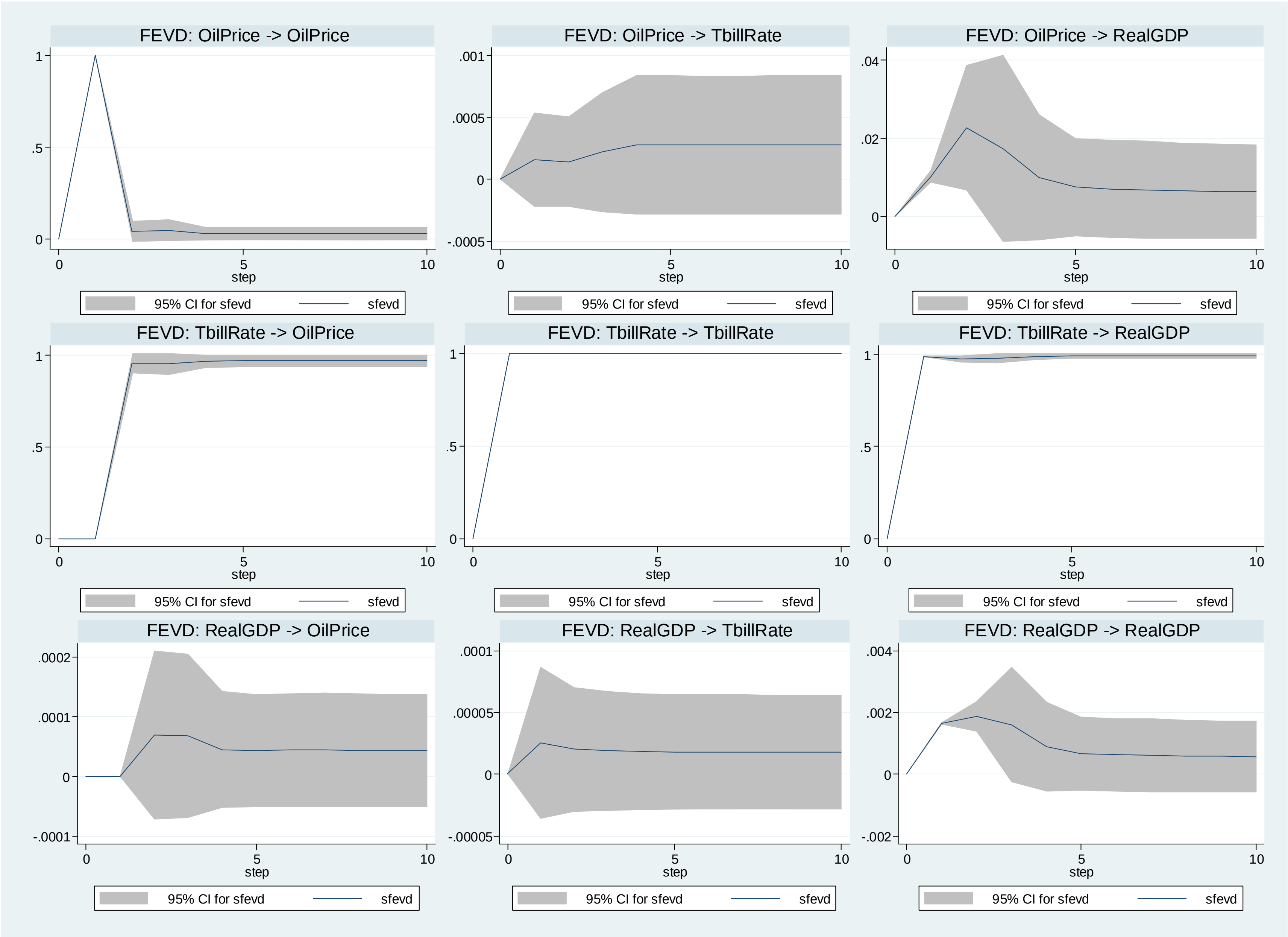

Figure 3. Impulse-Response Function (IRF) of 6-variable VAR model: Macro, mortgage securitization rate, house price risk, and banks' MBS holding

The dependent variables of this VAR model are quarterly oil price change, securitization rate change, 3-month T-bill change, house price risk (quarterly return volatility of the equally-weighted residential REIT portfolio), real GDP change and banks' MBS holding change. The independent variables are the 1-quarter lagged dependent variables.

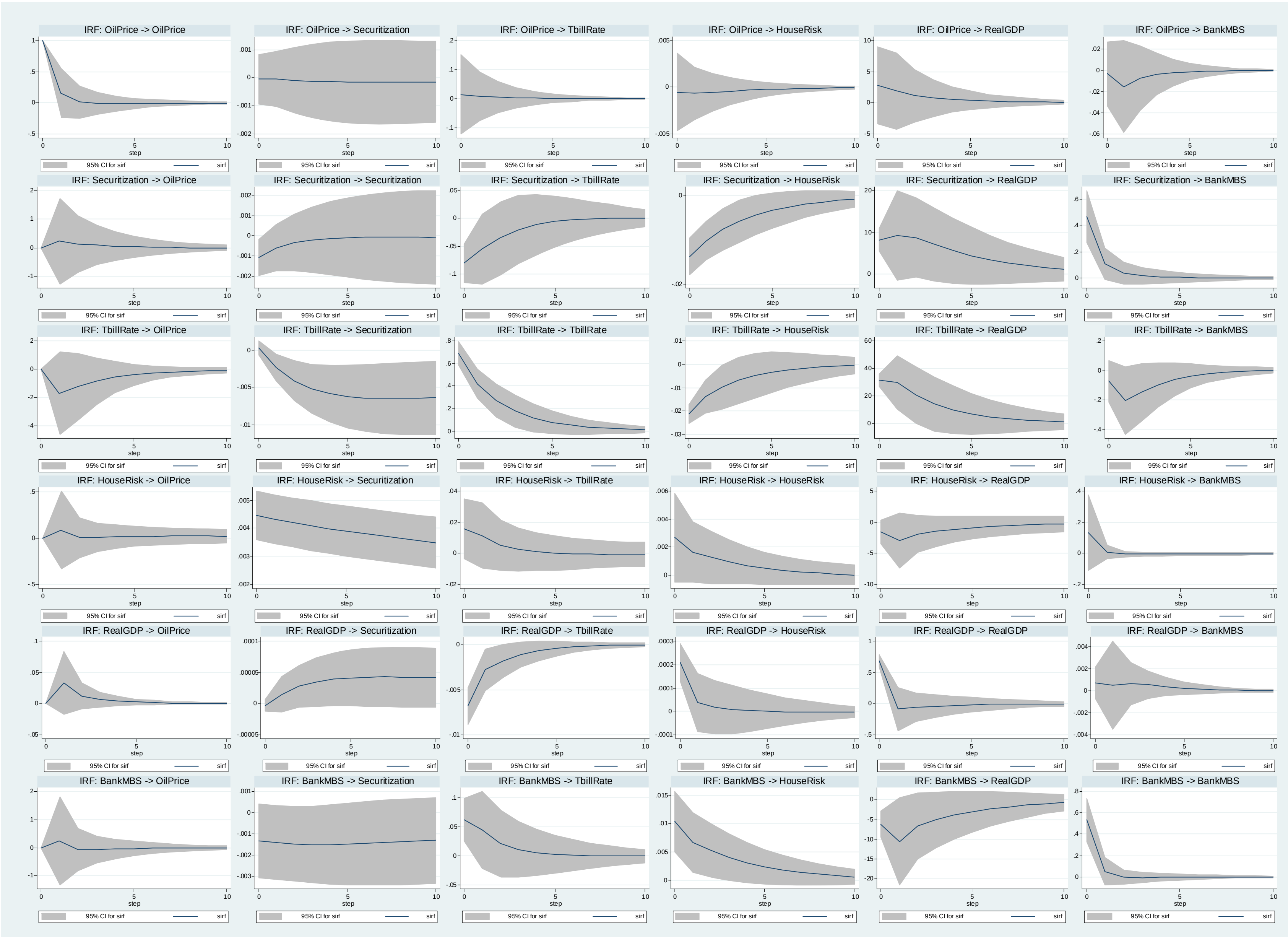

Figure 4. Forecast-Error Variance Decomposition (FEVD) of 6-variable VAR model: Macro, mortgage securitization rate, house price risk, and banks' MBS holding

The dependent variables of this VAR model are quarterly oil price change, securitization rate change, 3-month T-bill change, house price risk (quarterly return volatility of the equally-weighted residential REIT portfolio), real GDP change and banks' MBS holding change. The independent variables are the 1-quarter lagged dependent variables.