The Reaction Function of The Federal Reserve Post 2008 Financial Crisis

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Abstract

This paper uses vector autoregressive analysis to show a change to the Federal Reserve's reaction function post 2008. The model's prediction for the stance of Fed policy show that a Taylor Rule identification structure for the Federal Funds Rate no longer holds. Stress to financial markets during the crisis has meant that additional consideration of financial conditions is needed to accurately reflect Fed decision making since the Great Recession.

1 Introduction

The Federal Reserve has a dual mandate: maintaining stable inflation and maximum employment. Since this mandate was declared in 1977, the Fed has used its primary policy tool, the federal funds rate (FF), to try to best achieve these goals. In 2008, a collapse in the housing market triggered a crisis in the US financial crisis which spread to the rest of the world. The Fed reacted to the severity of the crisis by sharply cutting interest rates to zero, where they have remained since.

Economists analyzing the Fed's policy response have found that the Taylor Rule, which is based on inflation and unemployment deviation from their target, is a good predictor of monetary policy. However, when one uses that framework to analyze the response of the Fed to the 2008 crisis, one finds that the speed and severity of the monetary accommodation is not fully explained. This paper posits that the dislocation experienced by financial markets at the outset of the crisis caused financial conditions to become of central importance to the Fed insofar as they reflected the extent of impairment of transmission channels of monetary policy to the real economy. As such, this paper believes that in order to effectively understand Fed policy post 2008, a measure of financial conditions must be included in its reaction function.

This paper will use vector autoregressive analysis of the relationship between key economic variables to shed light on the Fed's reaction function pre and post Great Recession. The analysis will first examine a framework that solely considers the three variables of the Taylor Rule in predicting monetary policy. The paper finds that while this rule is effective for the pre-crisis period, it fails to predict Fed policy at the zero lower bound after 2008.

However, when financial variables are included, an unconstrained estimation finds that the FF should have gone negative after 2008 to provide adequate accommodation to the US economy. This result is not captured by a VAR model that does not include financial conditions. The difficulty of imposing negative rates led the Fed to turn to unconventional measures of easing such as forward guidance and quantitative easing. As the FF loses its information content on monetary policy at the zero lower bound, this paper compares its predictions to an unconstrained Shadow Interest Rate that includes measures of unconventional policy (Wu and Xia, 2014).

This paper establishes that when financial conditions are included in the VAR model, the prediction of the Fed's monetary policy stance improves significantly. However, it also shows that between 2008 and 2012, the Fed should have engaged in even more quantitative easing than was the case and having done so, should have started tightening earlier by 2013. The results also suggest that to compensate for an overtly tight policy during the first part of the recession, the Fed has had to maintain QE for a longer period of time after 2013 to provide the same cumulative easing effect on the US economy for the entire 2008-2015 period.

The paper proceeds as follows: Section 2 discusses the relevant economic literature. Section 3 lays out the econometric framework of analysis. Section 4 describes the data. Section 5 presents the main results and Section 6 concludes.

2 Literature Review

Vector Autoregression

The vector autoregression (VAR) framework was pioneered by Sims (1980) in response to fundamental flaws in previous techniques of econometric analysis. "A VAR is a n-equation, n-variable linear model in which each variable is in turn explained by its own lagged values, plus current and past values of the remaining $n-1$ variables." (Stock and Watson, 2001) The technique allows for the model to capture rich relationships and dynamics between variables over a model comprised of many simultaneous univariate equations.

Stock and Watson (2001) "Vector Autoregressions" uses a small model VAR with three variables in order to describe the relationships between key macroeconomic indicators in the US. Stock and Watson's paper is a survey article of different VAR forms: reduced, recursive and structural. They use inflation, the unemployment rate and the federal funds rate to assess the power of VARs in various applications of econometric analysis.

Stock and Watson use data from 1960-2001 to analyze their VAR's power at the four key tasks of econometric analysis: data description, forecasting, structural inference and policy analysis. They find that the three variables all have significant predictive power over one another and that the error in forecasts for one variable is largely explained by the other two: "For example, at the 12 quarter horizon, 75% of the error in the forecast of the Federal Funds rates is attributed to the inflation and unemployment shocks in the recursive VAR." (Stock and Watson, 2001) For these reasons, they find that the recursive VAR is an effective tool for US monetary policy description.

Stock and Watson use the VAR for multistep ahead forecasting both out of sample (from 2000 on) and pseudo out-of-sample (1960-2001). For pseudo out-of-sample forecasts, they find that their three variable VAR improves on both a random walk and univariate autoregression in its predictions for the variable movements.

While the VAR gives strong results for these two tasks, Stock and Watson find it lacking in its use for structural inference and policy analysis. Structural inference and policy analysis require using a structural vector autoregression (SVAR) to identify how the variables are related to one another. These identifying assumptions are based on economic theory and "even modest changes in the assumed rule resulted in substantial changes in these impulse responses. In other words, the estimates of structural impulse responses hinge on detailed institutional knowledge of how the Fed set interest rates." (Stock and Watson, 2001) Stock and Watson use a Taylor Rule as their identifying assumption, which will be discussed in greater detail later in this paper.

What Stock and Watson find is that the VAR "shocks" that would be used for structural inference largely just reflect omitted variables from the model. "Because of omitted variables, the VAR mistakenly viewed and labeled these increases in interest rates as monetary shocks, which led to biased impulse responses." (Stock and Watson, 2001) In reality, identifying the monetary rule is near impossible and while Stock and Watson find that the inflation rate, unemployment rate and federal funds rate are the most important variables to consider, there was not a stable rule between them that the Fed followed. Frequent changes in the policy rule meant that the shocks were not real monetary shocks, but just the SVAR falling to the Lucas Critique (Lucas, 1976) of incorrect identifying assumptions.

Taylor Rule

Stock and Watson find that inflation, unemployment and lagged values of the Fed Funds Rate are the most effective way to capture movements in the interest rate. The theory behind this comes from the dual mandate of the Fed: price stability and maximum employment. John Taylor created the Taylor Rule (Taylor, 1993) as a way of summarizing how the Fed responds to deviations from target output and inflation. In their model, Stock and Watson use Okun's Law (Okun, 1963) to replace the output gap with the employment gap. Stock and Watson write their Taylor Rule as:

$$R_t = r^* + 1.5(\overline{\pi}_t - \pi^*) - 1.25(\overline{u}_t - u^*) + lagged\ values\ of\ R,\ \pi,\ u + \epsilon_t$$

This equation forms the interest rate equation in the three variable SVAR. R_t is the interest rate, r^* is the neutral interest rate of the economy, $\overline{u}_t$ is the average unemployment rate over the last year, u^* is the target employment rate or NAIRU, $\overline{\pi}_t$ is the average inflation rate over the last year, π^* is the target inflation rate of 2%, and ϵ_t is the error term.

However, the Taylor Rule does not account for interest rates that are constrained by the zero lower bound. After a period of time at the zero bound, the FF loses its information content about the true stance of monetary policy.

Shadow Rate

Cynthia Wu and Fan Dora Xia at the Federal Reserve Bank of Atlanta have used Factor Augmented VAR (FAVAR) to construct a measure of monetary policy that is unconstrained by the zero lower bound. There series continues from the FF when it hits the zero lower bound at the end of 2008 and allows the stance of monetary policy to be negative to reflect unconventional monetary policy measures such as forward guidance and quantitative easing.

Wu and Xia (2014) find that "that the shadow rate calculated by our model exhibits similar dynamic correlations with macro variables of interest in the period since July 2009 as the fed funds rate did in data prior to the Great Recession. This result gives us a tool for measuring the effects of monetary policy at the ZLB, and offers an important insight to the empirical macro literature where people use the effective federal funds rate in vector autoregressive (VAR) models to study the relationship between monetary policy and the macroeconomy... The evident structural break in the effective fed funds rate [at the zero lower bound] prevents researchers from getting meaningful information out of a VAR during and even post the ZLB. In contrast, the continuation of our series allows researchers to update their favorite VAR using the shadow rate for the ZLB period." (Wu and Xia, 2014)

Xia and Wu's Shadow Rate looks at a number of different facets of the US economy in order to gauge their Shadow Rate prediction. They consider the FF as well as measures of forward guidance, the size of the Fed's balance sheet and the length of time that interest rates have been at the zero lower bound. Using all of these, they use the Shadow Rate to "construct a new measure for the monetary policy stance when the effective federal funds rate is bounded below by zero, and employed this measure to study unconventional monetary policy's impact on the real economy." (Wu and Xia, 2014)

It will be important to assess the FF predictions of this paper's different VAR specifications in relation to both the constrained FF and true measures of monetary policy that include unconventional policies. While Xia and Wu's Shadow Rate is not the only one that has been created, it has been widely cited as effective as a measure of the monetary policy stance since 2009 and is consistently updated on the Federal Reserve of Atlanta's website.

3 Methodology

This paper will use recursive vector autoregressions with different specifications to analyze the relationship between key macroeconomic variables in the United States. Using the findings, it will comment on the Federal Reserve's monetary policy reaction function by seeing which set of variables best describe and predict movements in the Federal Funds Rate and the Shadow Interest Rate.

Three Variable VAR

In Stock and Watson's structural vector autoregression, they use the original Taylor Rule as the identifying assumption for the interest rate rule. They let the rest of the coefficients be determined by a Choleski Decomposition. The SVAR equation therefore looks like:

$$\begin{pmatrix} In_t \\ Un_t \\ FF_t \end{pmatrix} = \begin{pmatrix} . & 0 & 0 \\ . & . & 0 \\ -1.5 & 1.25 & 1 \end{pmatrix} * \begin{pmatrix} In_{t-1} \\ Un_{t-1} \\ FF_{t-1} \end{pmatrix} + 3 \; additional \; lags + \begin{pmatrix} u_t^{In} \\ u_t^{Un} \\ u_t^{FF} \end{pmatrix}$$

Where In_t is the inflation rate, Un_t is the unemployment rate and FF_t is the federal funds rate with their lags. A (.) means that the coefficient is estimated from the data using a Choleski Decomposition. u_t is the vector of error terms.

When this paper re-estimates this SVAR, first over the original period and then updating the sample to 2008, the parameters show instability over their sample and do not hold as a rule for Fed policy in setting rates. Using this SVAR finds large monetary policy shocks over the sample that in reality are probably errors in the identifying assumptions.

While the specific identifying assumptions and coefficients of this Taylor Rule do not hold, the economic theory that the Fed primarily bases its Fed Funds Rate on the inflation rate and unemployment rate is sound. Different iterations and coefficients for the rule have been considered, such as that by Yellen (2012). However, over such a long time period with a different macroeconomic paths and different monetary regimes, it would not make sense to consider one fixed interest rate rule for the entire period.

Furthermore, while the Fed considers a wide variety of factors in setting policy, one of the limitations of the VAR technique is that increasing the number of variables or lags significantly increases the number of parameters that need to be estimated. Therefore, it makes sense to continue to use the three variables of Stock and Watson's VAR as a benchmark for analysis of US monetary policy, but not to use their rigid identifying structure. This paper will focus on unstructured recursive VARs to allow the movements in the data over the sample period to identify the relationship between variables.

While theory will not form strict identifying coefficients for the variables, it will inform which variables will be chosen and the ordering of the recursive VAR. When considering Fed policy, the two most important variables to consider are inflation and unemployment. These are the two focuses of the Fed's dual mandate and theoretically inform all of their policy decisions. This three variable VAR should offer a strong description and prediction of their policy moves as the original benchmark VAR against which future specifications can be compared.

With this economic relationship in mind, the first VAR that will be used is a three variable VAR with inflation, unemployment and the federal funds rate as variables. While adding variables will always improve the ability of the model to fit the data, the cost of additional parameters is high. So, this paper focuses on a small model for the economy that captures key relationships and co-movements.

When using a recursive VAR, the variables have to be ordered according to how they causally affect one another in order to orthogonalize the error terms. "In the jargon of VARs, this is equivalent to estimating the reduced form and then computing the Choleski factorization of the reduced form VAR covariance matrix" (Lütkepohl, 2007). Figure 4 shows the relationship between inflation and unemployment, highlighting how lagged inflation causes unemployment but there is little correlation between lagged unemployment and inflation. As these two variables inform the Fed's policy setting, the VAR will be structured:

$$\begin{pmatrix} In_t \\ Un_t \\ FF_t \end{pmatrix} = \begin{pmatrix} . & 0 & 0 \\ . & . & 0 \\ . & . & . \end{pmatrix} * \begin{pmatrix} In_{t-1} \\ Un_{t-1} \\ FF_{t-1} \end{pmatrix} + additional\ lags + \begin{pmatrix} u_t^{In} \\ u_t^{Un} \\ u_t^{FF} \end{pmatrix}$$

Here, Inflation(In), Unemployment (Un) and the Fed Funds Rate (FF) are all allowed to dynamically explain moves one another. 3 or 4 lags will be considered and u measures the error term. Different tests must be conducted to assess the validity and strength of the VAR models being used. Granger causality statistics test whether the lagged value of one variable is useful when predicting another. This is important in determining whether there adding a variable improves the VAR's estimation by effectively predicting the other variables.

It is necessary to test the stability of the VAR model in order to ensure that it does not have unit roots. Otherwise, the relationship between the variables would not be stable over time and the model would be ineffective.

Stock and Watson finds that four lags is appropriate for their model. However, as this model updates the data sample until 2015, it re-estimates the Bayesian Information Criteria (BIC) and Akaike Information Criteria (AIC) to check the required number of lags. The new model finds that the optimal number of lags is 3, so this paper will consider both VARs with 3 and 4 lags.

After assessing the descriptive properties of the three variable VAR until 2008, the paper will turn to its forecasting ability. Using the sample truncated at September 2008, to reflect when the FF and Shadow Rate first diverge as unconventional policy begins, the model will perform pseudo out-of-sample forecasts and compare its prediction of the Fed Funds Rate with the Federal Reserve's actual policy moves and the Shadow Rate. This is the fundamental question of this paper: whether the same model that effectively describes and predicts Fed policy until 2008 still holds during the period of the Great Recession. If the model loses its predictive power, it will be necessary to change or add variables to better reflect Fed policy considerations.

Four Variable VAR: Adding Financial Conditions

The financial crisis began at the end of 2007 and spread from the subprime housing market through the entire financial sector. The Fed cut the Fed Funds Rate from 5.25% in July 2007 to the zero lower bound by the end of 2008 (Figure 1). This move was not predicted by just falling inflation or rising unemployment. It is likely that the Federal Reserve, which states that it looks at financial markets but does not set rates based on them, used its policy rate to provide additional monetary easing on account of the financial sector meltdown.

In order to address this departure of Fed policy from being predominately informed by inflation and unemployment, I will incorporate the conditions of financial markets into the VAR. There are numerous ways to do this using different variables or indexes. Therefore, a number of different VAR specifications will be considered.

$$\begin{pmatrix} In_t \\ Un_t \\ FCI_t \\ FF_t \end{pmatrix} = \begin{pmatrix} . & 0 & 0 & 0 \\ . & . & 0 & 0 \\ . & . & . & 0 \\ . & . & . & . \end{pmatrix} * \begin{pmatrix} In_{t-1} \\ Un_{t-1} \\ FCI_{t-1} \\ FF_{t-1} \end{pmatrix} + additional\ lags + \begin{pmatrix} u_t^{In} \\ u_t^{Un} \\ u_t^{FCI} \\ u_t^{FF} \end{pmatrix}$$

This equation represents the new, general 4 variable VAR which includes the variables of the Taylor Rule, Inflation (In), Unemployment (Un) and the Fed Funds Rate (FF) but also adds a fourth variable, a measure of financial conditions (FCI).

There are numerous measures of financial market conditions that can be included. Financial stress indicators vary significantly in complexity. Some are straightforward such as the VIX, which is a measure of the implied volatility of the S&P 500. However, the variability of the VIX is too great to meaningfully provide a measure of financial market conditions over the 2008-2015 period.

Bond spreads offer an effective manner of determining market stress. Using the spread between High Yield debt (BB rated) over T-bills, we can see how the market is pricing risk. During times of financial stress, these spreads will increase dramatically as can be seen in Figure 1.

Beyond these straight forward measures, there are also financial conditions indexes that have been created to more accurately reflect financial market stress. Two notable ones are the St Louis Fed Financial Stress Indicator (Figure 1) and the Chicago Fed's National Financial Conditions Index (Figure 1). These use a number of different financial market variables and weightings to construct an indicator for conditions in financial markets. The particular merit of these indexes is that they include not only a bond spreads, but a wide variety of other financial market indicators such as measures of confidence, liquidity and credit.

The St Louis Fed Financial Stress Indicator (SLFSI) "is constructed from seven interest rate series, six yield spreads and five other indicators"(Kliesen et al., 2010). A summary of the factors considered can be seen in Figure 3 . This index adds significantly to just a measure of bond spreads as it contains information both about market risk perception and about liquidity risk. In it, zero is viewed as normal market functioning and values above are interpreted as above-average financial market stress.

The Chicago Fed National Financial Conditions Index (NFCI) (Brave and Butters, 2012), is calculated from an even wider range of financial market data. The three broad sub-areas considered in the index are risk, credit and leverage. This means that not only does the NFCI contain information about risk and liquidity as does the St Louis Fed FSI, but also about bank lending to consumers and mortgage markets. These would both be of key interest to the Fed when setting rates, who would be trying to maximize the efficacy of their policy stance. The bank lending and mortgage markets can be thought of as the multiplier effect of Fed rate changes, and so when in the Financial Crisis banks stopped lending and the mortgage market froze, FF moves would lose their potency as a policy tool. Thus, this index is likely the most reflective of Fed considerations of financial markets during the Great Recession and will offer the best prediction for FF moves.

For all of the new four variable VARs, granger causality statistics, lag tests and stationarity tests will be computed. Each model will be estimated over the pre crisis sample, 1997-2008 and the results compared to the original three variable VAR. Then, the VARs will be used for pseudo out-of-sample forecasting from September 2008 onwards and the results will be compared to one another, to the original VAR and to the FF and Shadow Rate.

Economic interpretation of the different policy predictions given by the VARs will shed light on whether the Fed's monetary policy reaction function has changed through the Great Recession and whether it was due to new consideration of financial market stress.

4 Data

The VARs used in this paper are small models that focus on key macroeconomic and financial variables. The three variable VAR uses the same data series as Stock and Watson, except taken on a monthly rather than quarterly basis to add more detail to the VAR estimation:

Monthly data on Inflation (Consumer Price Index for All Urban Consumers: All Items, Percent Change from Year Ago, Monthly, Seasonally Adjusted), the Unemployment Rate (Civilian Unemployment Rate, Percent, Monthly, Seasonally Adjusted) and the Fed Funds Rate (Effective Federal Funds Rate, Percent, Monthly, Seasonally Adjusted).

Monthly data for the Shadow Interest Rate (Wu and Xia, 2014) is found on the Federal Reserve Bank of Atlanta's website.

The financial variables that are considered for the four variable VAR are the High Yield BB Spreads (BofA Merrill Lynch US High Yield BB Option-Adjusted Spread), The St Louis Fed Financial Stress Index and The Chicago Fed National Financial Conditions Index. All are taking on a monthly basis. The data is found on the Federal Reserve Economic Database (FRED).

The data series are each available for different sample lengths and so effective comparison limits the sample to Jan 1997 - Feb 2015.

5 Results

Multiple different VAR specifications are estimated in this paper. The results of pseudo out-of-sample forecasts for each from the period of 2008-2015 are shown in Figure 5. Before considering and comparing the forecasts, it is important to first address the framework of each of the VARs.

Three Variable VAR Results

The three variable VAR using the original variables of Stock and Watson (2001) meets the stability criteria of having all eigenvalues less than one. Granger causality tests show that at the 10% level, all of the variables predictively cause the other two (Figure 7). The information criteria show that 3 lags are optimal under AIC and 2 are optimal under BIC. The estimation will be more robust with too many rather than too few lags, so the model uses the VAR with 3 lags.

The three variable VAR is estimated until September 2008 and then recursively predicts the FF until the start of 2015. Figure 5 shows that this model clearly misses the Fed's policy of cutting rates to the zero lower bound and keeping them there until 2015. Instead, the model prescribes for rates to be lowered to 0.8% in October of 2009 and then to slowly to be increased to almost 1.5% by March of 2015. This policy prediction would provide a far less expansionary monetary policy than the Fed's own policy, with a significant difference between the forecasted interest rate and both the FF and the Shadow Rate.

Four Variable VAR Results

All four of the key VARs that included financial conditions variables met the stability conditions, each having all eigenvalues less that one. The AIC and BIC show that for the VARs including the BB Spread and St Louis Fed FSI, the optimal lag length is 6. For the VAR including the Chicago Fed FCI, the optimal lag length is 5.

In each of the four variable VAR specifications post 2008 crisis, the financial conditions indicator variable granger causes the Shadow Rate (as the Fed Funds Rate loses its information content) at the 1% level for the St Louis FSI (Figure 11) and Chicago FCI (Figure 13) and at the 5% level for the BB Spread (Figure 9). This notably contrasts to pre 2008, where the financial variables do not granger cause the FF at any significant level (Figures 8, 10, 12). This result highlights that the financial variables were not a significant part of the Fed's decision making process before the financial crisis, but were part of their reaction function following 2008.

While each of the predictions for the FF is different depending on the financial variable included, they all show a similar trend (Figure 6). All three of the VARs predict that the FF should have gone negative at the end of 2008 or start of 2009 to provide greater monetary accommodation to the US economy. The model also shows that after a period of negative interest rates, the FF should have been increased between 2010 and 2013 to above the zero bound towards settling a level more consistent with predictions for the US neutral interest rate, around 3.7% by Fed estimates.

Specifically, the four variable VAR including the BB spread shows interest rates falling to lows of -0.5% before eventually rising above the zero bound in April of 2010 and eventually settling at a rate of around 3.5% between 2013 and 2015 (Figure 6).

When we use a four variable VAR model that includes the St Louis FSI, the prediction is even more extreme. This model predicts that the interest rate would have fallen to -1.67% by November 2009, an even sharper and deeper cut to the FF than with the model using the BB spread. The model predicts that interest rates would rise to above zero in October of 2010 and then to also find a roughly stable level of around 3.7% over the 2013-2015 period (Figure 6).

Finally, the most extreme prediction come when the Chicago FCI is included in the model.

Interest rates are predicted to have fallen for longer to -2.6% in October 2010, when the prediction including the St Louis FSI was just crossing back above the zero bound. The Chicago FCI prediction only rises above zero in August of 2012 but quickly rises to 5% by March of 2015 (Figure 6).

This improvement in the predictions as the financial variable changes follows an intuitive explanation. The Chicago Fed FCI contains the broadest range of financial indicators that the Fed would be considering: not just risk as in the BB Spread variable, or liquidity and risk as in the St Louis FSI variable, but also lending conditions by banks and mortgage providers that would be key transmission mechanisms through which Fed policy works. With credit channels frozen in 2008, the Fed would be paying the closest attention to the Chicago FCI and the variables it is comprised of.

It is important to note that these predictions have sizable confidence bands for the predictions. In the case of the original Taylor Rule variable VAR, the confidence band includes negative interest rate values. While the 95% confidence interval is a large error margin, this uncertainty does highlight a key potential pitfall of the model. Within the 95% interval, the prediction for the FF with the BB and St Louis FSI could have never gone negative and only gone slightly negative with the Chicago Fed FCI.

Comparison between Predictions

In order to effectively compare the predictions of the paper and assess which offers the best estimation of Fed policy during the Recession, both quantitative and qualitative analysis must be conducted. Looking at the predictions overlaid with the FF and Shadow Rate gives the most comparative image of the results (Figure 6). As as Figure 6 shows, the three variable VAR prediction completely misses the zero lower bound as well as the unconventional policy measures of the Fed that drove the Shadow Rate negative. The prediction including the BB spread improves on this, but still does not predict the level of accommodation that the Fed provided. The estimate of the VAR including the St Louis Fed and Chicago Fed most closely mirror the movements of the Shadow Rate.

This is not to say that their predictions perfectly track the moves in the Shadow Rate or the FF. The intuition of the results is corroborated by the work of Woodford (2012) and Reifschneider and Williams (2000). This paper's FF predictions lie initially below both the actual FF and Shadow Rate, meaning that monetary policy in 2008-2013 was not as accommodative as the model would have prescribed. To compensate, expansionary monetary policy must be continued for longer than predicted to have the same overall monetary effect on the US economy. "When policy is constrained by the effective lower bound, policymakers can achieve superior economic outcomes by committing to keep the federal funds rate lower for longer than would be called for." (Reifschneider and Williams, 2000) (Hakkio and Kahn, 2014)

In other words, the intuition for the Fed keeping rates at the zero lower bound and continuing QE for longer than the VAR model predicts is so that the cumulative deviation of the monetary policy stance below prediction offsets the cumulative deviation of policy above prediction. The significant improvement of the VAR prediction including the Chicago FCI is evident when assessing the mean error predictions of the different models from the actual FF. The model including the Chicago FCI finds the smallest overall prediction error by far (-0.39) over the 2008-2015 period, compared with triple the forecast error for the VAR comprised of only the Taylor Rule variables (-0.93) (Figure 2).

6 Conclusion

This paper shows that the Fed's reaction function changed after the 2008 crisis. The inclusion of a variable for financial conditions into the VAR model in addition to the traditional inflation and unemployment significantly improves our prediction of Fed policy post 2008. We find that the Chicago FCI has the best predictive power because of its breadth and inclusion of measures of market risk, liquidity and credit availability. With this additional variable, our VAR prediction shows that the FF should have fallen to -2.6% by the end of 2010.

A zero bound interest rate meant that the Fed had to resort to unconventional policy to provide the required additional monetary stimulus to the economy. This paper also finds that since the Fed did not react with the speed and intensity prescribed by the model, they have had to keep rates at the zero lower bound for longer. By doing so, they were able to provide the same total accommodation effect on the economy over the entire 2008-2015 period. The cumulative effect is now almost fully realized. Employment figures are improving and the financial system is healing, although inflation still has not picked up. One possible extension to this paper would be to use forward looking expectations for the variables in order to better reflect Fed decision making.

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Appendix

Table 1: Summary statistics

Variable	**Mean**	**Std. Dev.**
Fed Funds Rate	2.573	2.363
Shadow Rate	2.097	2.94
Inflation	2.286	1.213
Unemployment Rate	6.06	1.782
Inflation	2.286	1.213
High Yield BB Spread	3.846	1.988
Chicago Fed FCI	-0.352	0.594
St Louis Fed FCI	-0.036	1.069
N	219	

Table 2: Mean Error Between VAR Predictions and the Fed Funds Rate

Variable	**Mean**	**Std. Dev.**
VAR with Taylor Variables Mean Error	-0.931	0.325
VAR with BB Spread Mean Error	-2.17	1.581
VAR with St Louis Fed FSI Mean Error	-2.056	2.343
VAR with Chicago Fed FCI Mean Error	-0.398	2.697
N	80	

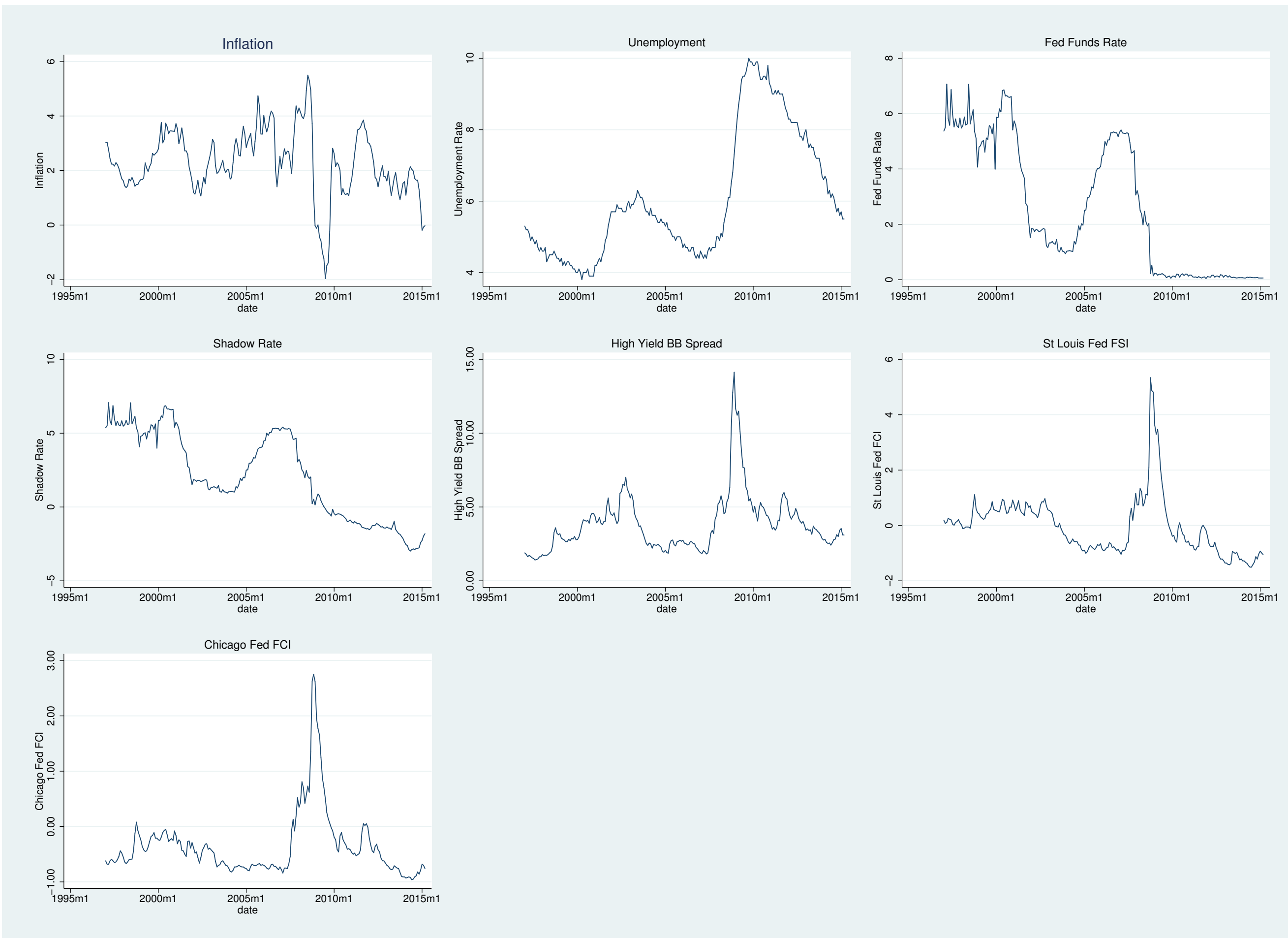

Figure 1: Data Summary

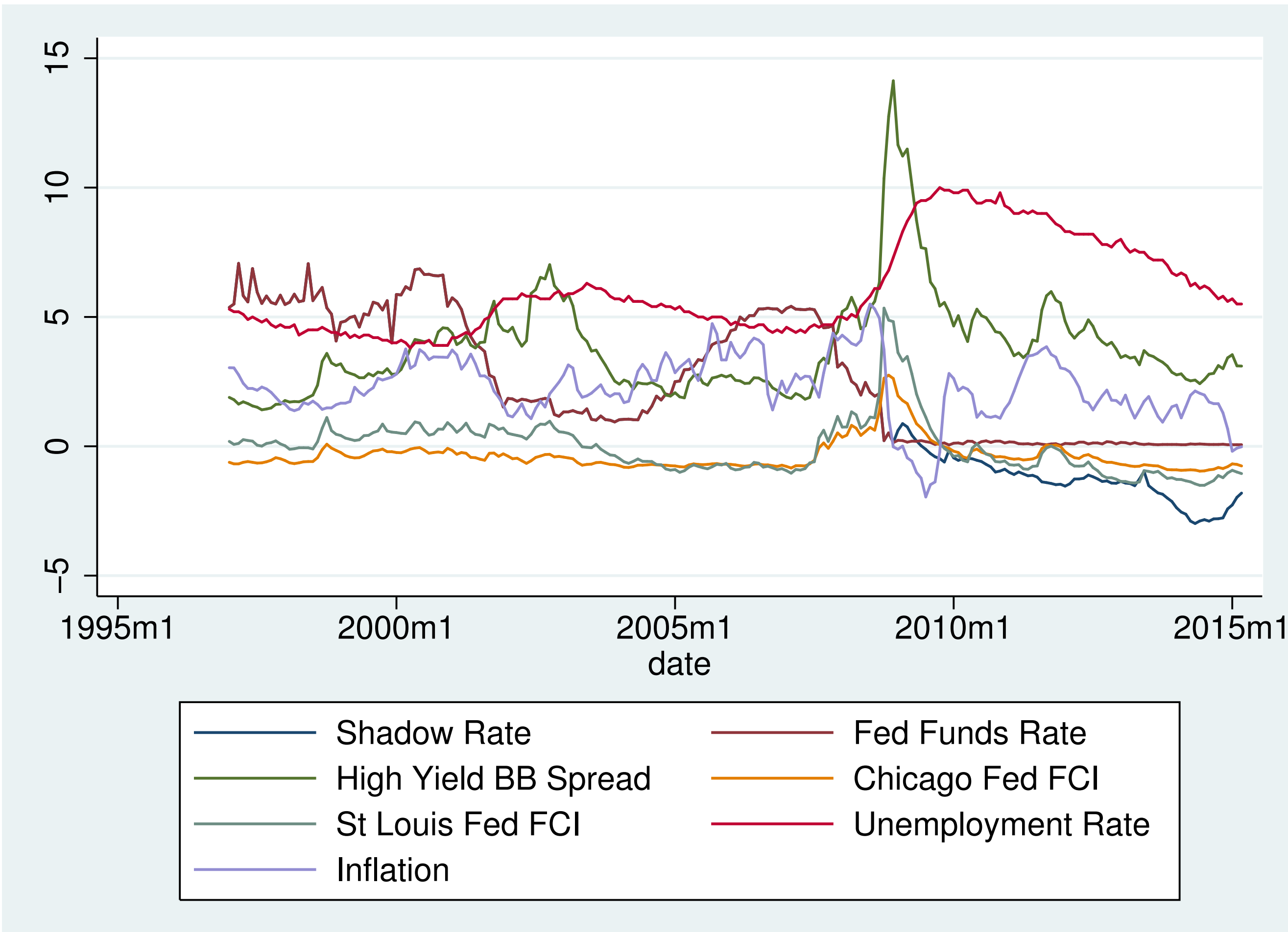

Figure 2: Data

List of Data Series Used to Construct the St. Louis Fed Financial Stress Index (STLFSI)

STLFSI Key		
	Label in Chart	Series
Interest Rates	FedFund	Effective federal funds rate
	Treas2y	2-year Treasury
	Treas10y	10-year Treasury
	Treas30y	30-year Treasury
	BAA	Baa-rated corporate
	Mlynch_HighYld_MasterII	Merrill Lynch High-Yield Corporate Master II Index
	Mlynch_BBBAA	Merrill Lynch Asset-Backed Master BBB-rated
Yield Spreads	YieldCurve_10yr3mo	Yield curve: 10-year Treasury minus 3-month Treasury
	Corp_CRS	Corporate Baa-rated bond minus 10-year Treasury (corporate credit risk spread)
	HighYield_CRS	Merrill Lynch High-Yield Corporate Master II Index minus 10-year Treasury (high-yield credit risk spread)
	LiborOIS_3mo	3-month London Interbank Offering Rate–Overnight Index Swap spread (3-month LIBOR-OIS spread)
	TED	3-month Treasury-Eurodollar spread (TED spread)
	CPS_3mo	3-month commercial paper minus 3-month Treasury bill (commercial paper spread (3-month))
Other Indicators	EMBI	J.P. Morgan Emerging Markets Bond Index Plus
	VIX	Chicago Board Options Exchange Market Volatility Index (VIX)
	Mlynch_ BMVI_1mo	Merrill Lynch Bond Market Volatility Index (1-month)
	BIR_10yr	10-year nominal Treasury yield minus 10-year Treasury Inflation Protected Security yield (breakeven inflation rate (10-year))
	SP500_FI	S&P 500 Financials Index

Note from: http://research.stlouisfed.org/fred2/series/STLFSI

As of 07/15/2010 the Vanguard Financial Exchange-Traded Fund series has been replaced with the S&P 500 Financials Index. This change was made to facilitate a more timely and automated updating of the FSI. Switching from the Vanguard series to the S&P series produced no meaningful change in the index.

Figure 3: St Louis Fed Financial Stress Index Components

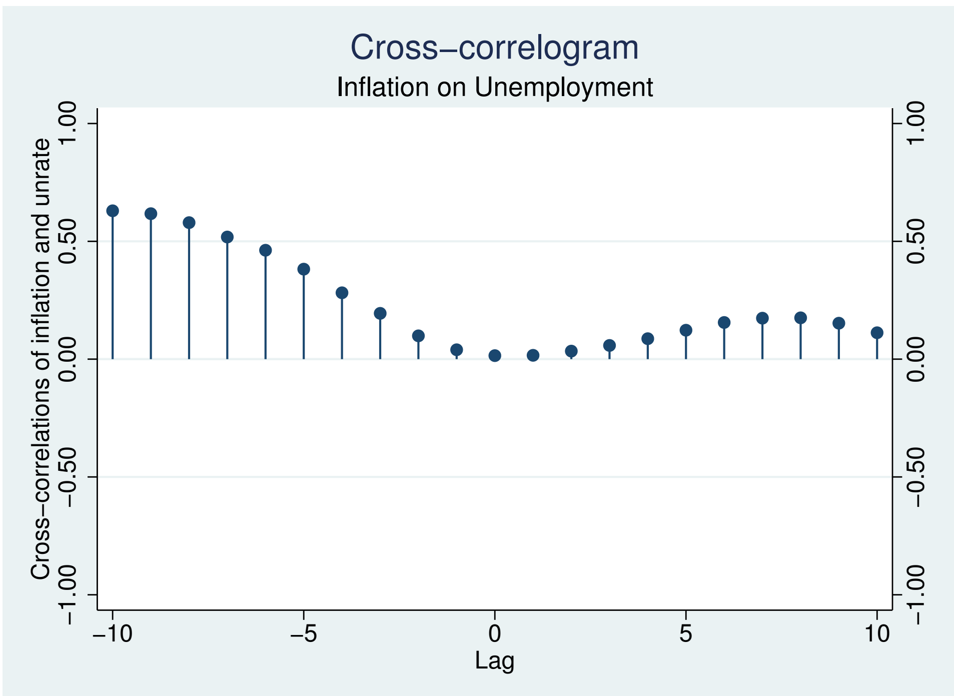

Figure 4: Cross Correlation of Inflation on Unemployment

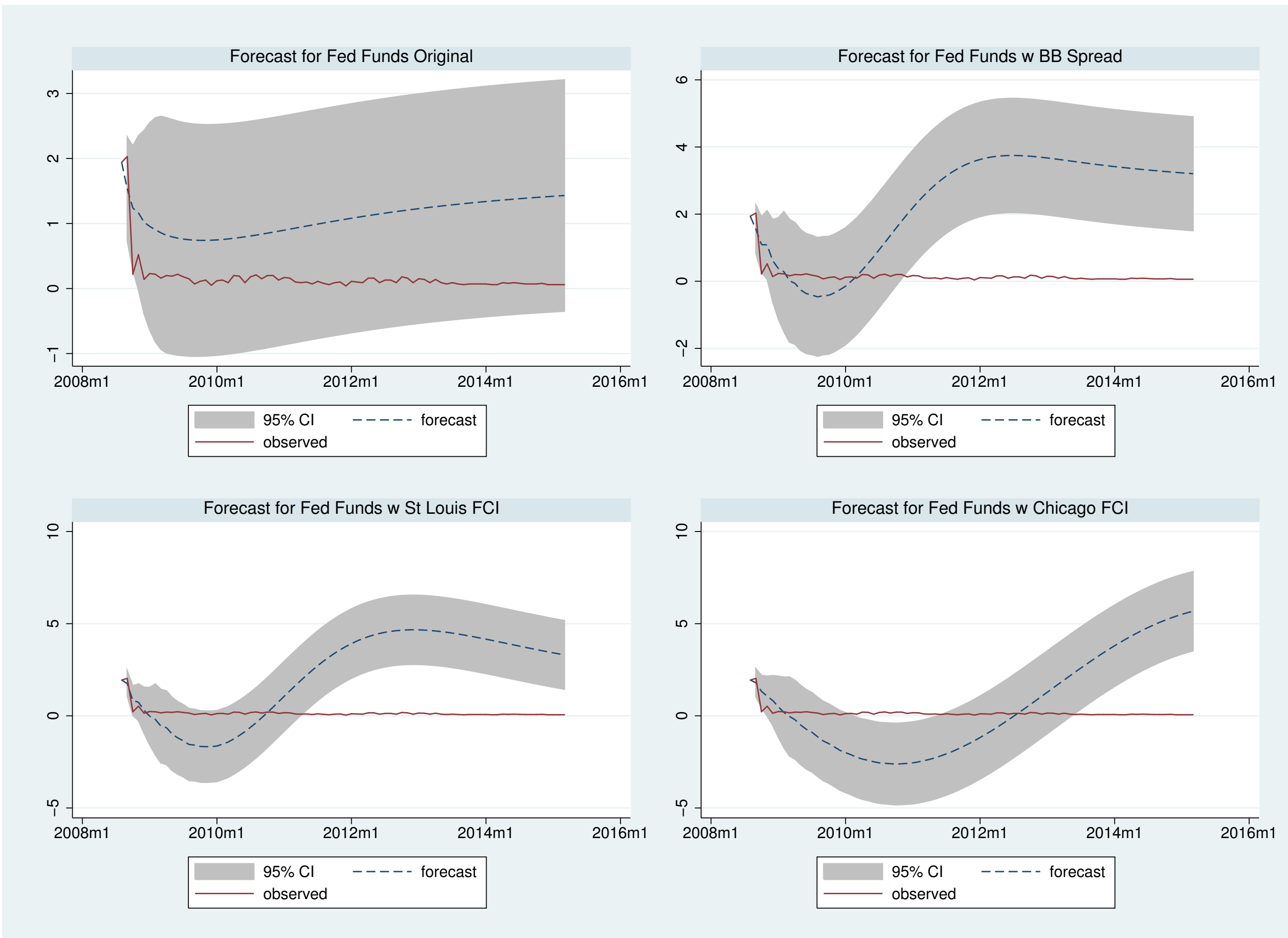

Figure 5: Fed Funds Rate Forecasts for Different VAR Specifications

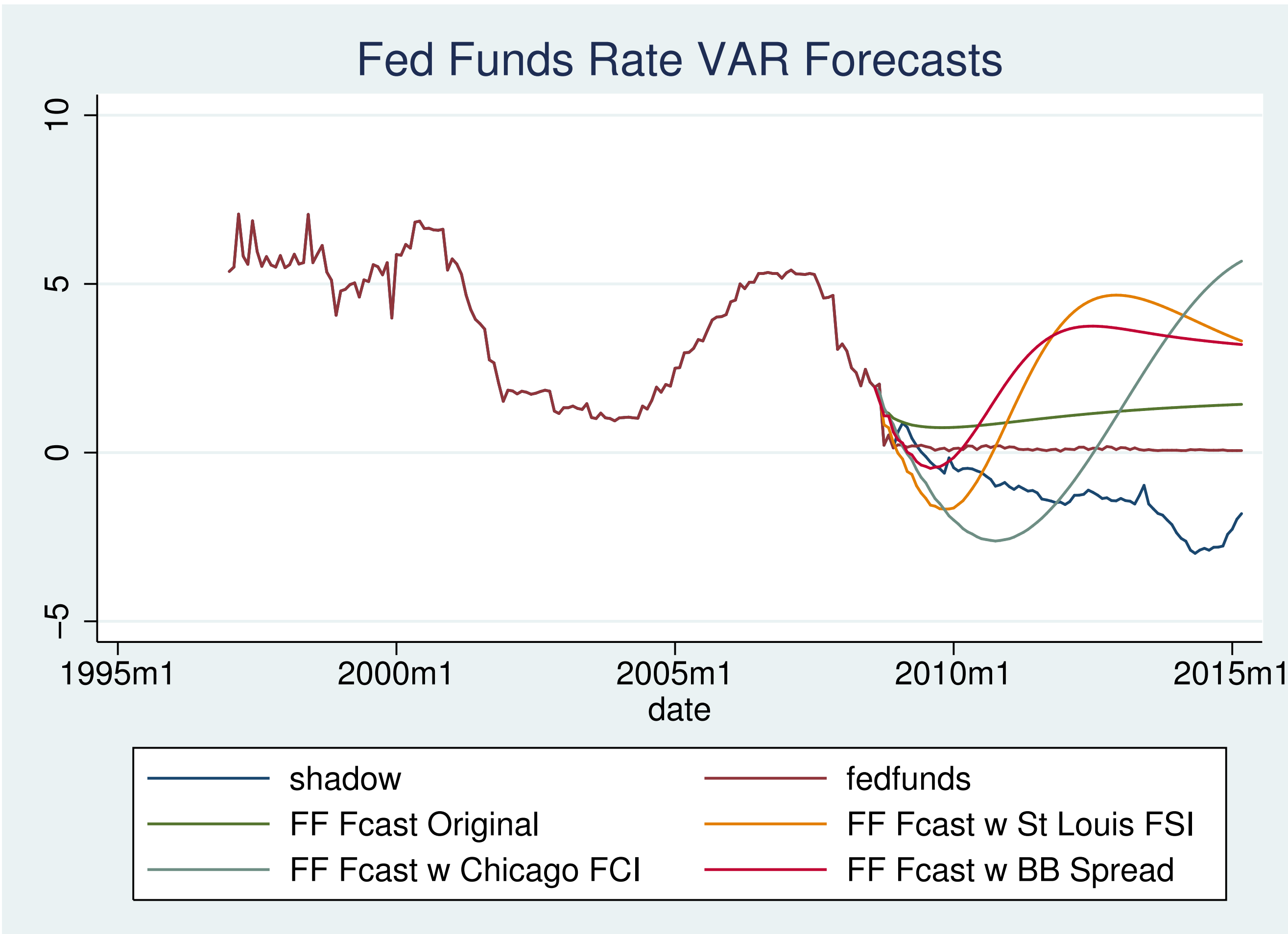

Figure 6: Fed Funds Rate Forecasts

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
inflation	unrate	24.456	5	0.000
inflation	fedfunds	5.5179	5	0.356
inflation	ALL	30.264	10	0.001
unrate	inflation	20.796	5	0.001
unrate	fedfunds	18.913	5	0.002
unrate	ALL	40.24	10	0.000
fedfunds	inflation	8.1837	5	0.146
fedfunds	unrate	13.618	5	0.018
fedfunds	ALL	17.43	10	0.065

Figure 7: Granger Causality Tests for Original Three Variable VAR Pre 2008

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
inflation	unrate	9.6344	6	0.141
inflation	bbspread	5.708	6	0.457
inflation	shadow	6.5559	6	0.364
inflation	ALL	17.163	18	0.512
unrate	inflation	9.6844	6	0.139
unrate	bbspread	11.204	6	0.082
unrate	shadow	15.428	6	0.017
unrate	ALL	40.458	18	0.002
bbspread	inflation	12.838	6	0.046
bbspread	unrate	17.774	6	0.007
bbspread	shadow	1.5515	6	0.956
bbspread	ALL	32.66	18	0.018
shadow	inflation	3.1928	6	0.784
shadow	unrate	24.12	6	0.000
shadow	bbspread	10.857	6	0.093
shadow	ALL	43.284	18	0.001

Figure 8: Granger Causality Tests for Four Variable VAR with BB Spread Pre 2008

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
inflation	unrate	23.358	6	0.001
inflation	bbspread	10.019	6	0.124
inflation	shadow	11.601	6	0.071
inflation	ALL	49.797	18	0.000
unrate	inflation	23.041	6	0.001
unrate	bbspread	16.855	6	0.010
unrate	shadow	19.069	6	0.004
unrate	ALL	72.362	18	0.000
bbspread	inflation	11.165	6	0.083
bbspread	unrate	22.222	6	0.001
bbspread	shadow	12.802	6	0.046
bbspread	ALL	82.091	18	0.000
shadow	inflation	3.3405	6	0.765
shadow	unrate	12.613	6	0.050
shadow	bbspread	7.804	6	0.253
shadow	ALL	28.39	18	0.056

Figure 9: Granger Causality Tests for Four Variable VAR with BB Spread Post 2008

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
inflation	unrate	14.924	6	0.021
inflation	slfci	13.866	6	0.031
inflation	fedfunds	12.968	6	0.044
inflation	ALL	25.99	18	0.100
unrate	inflation	13.25	6	0.039
unrate	slfci	17.297	6	0.008
unrate	fedfunds	20.93	6	0.002
unrate	ALL	47.779	18	0.000
slfci	inflation	12.648	6	0.049
slfci	unrate	22.268	6	0.001
slfci	fedfunds	9.2783	6	0.159
slfci	ALL	42.353	18	0.001
fedfunds	inflation	3.8974	6	0.691
fedfunds	unrate	28.669	6	0.000
fedfunds	slfci	24.158	6	0.000
fedfunds	ALL	59.562	18	0.000

Figure 10: Granger Causality Tests for Four Variable VAR with St Louis FSI Pre 2008

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
inflation	unrate	15.492	6	0.017
inflation	slfci	16.04	6	0.014
inflation	shadow	11.64	6	0.071
inflation	ALL	58.479	18	0.000
unrate	inflation	25.114	6	0.000
unrate	slfci	22.413	6	0.001
unrate	shadow	10.472	6	0.106
unrate	ALL	81.105	18	0.000
slfci	inflation	10.249	6	0.115
slfci	unrate	21.506	6	0.001
slfci	shadow	49.752	6	0.000
slfci	ALL	122.92	18	0.000
shadow	inflation	4.5695	6	0.600
shadow	unrate	10.455	6	0.107
shadow	slfci	12.647	6	0.049
shadow	ALL	34.369	18	0.011

Figure 11: Granger Causality Tests for Four Variable VAR with St Louis FSI Post 2008

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
inflation	unrate	7.1889	3	0.066
inflation	cfci	8.3066	3	0.040
inflation	fedfunds	5.8794	3	0.118
inflation	ALL	15.61	9	0.075
unrate	inflation	1.2654	3	0.737
unrate	cfci	8.0184	3	0.046
unrate	fedfunds	14.877	3	0.002
unrate	ALL	33.648	9	0.000
cfci	inflation	1.1317	3	0.769
cfci	unrate	5.7943	3	0.122
cfci	fedfunds	5.3547	3	0.148
cfci	ALL	11.897	9	0.219
fedfunds	inflation	1.8843	3	0.597
fedfunds	unrate	24.073	3	0.000
fedfunds	cfci	9.8233	3	0.020
fedfunds	ALL	40.918	9	0.000

Figure 12: Granger Causality Tests for Four Variable VAR with Chicago FCI Pre 2008

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
inflation	unrate	16.999	6	0.009
inflation	cfci	15.248	6	0.018
inflation	shadow	12.664	6	0.049
inflation	ALL	57.336	18	0.000
unrate	inflation	28.26	6	0.000
unrate	cfci	23.387	6	0.001
unrate	shadow	7.654	6	0.265
unrate	ALL	82.638	18	0.000
cfci	inflation	17.528	6	0.008
cfci	unrate	32.884	6	0.000
cfci	shadow	72.305	6	0.000
cfci	ALL	175.09	18	0.000
shadow	inflation	4.7651	6	0.574
shadow	unrate	10.222	6	0.116
shadow	cfci	19.54	6	0.003
shadow	ALL	42.877	18	0.001

Figure 13: Granger Causality Tests for Four Variable VAR with Chicago FCI Post 2008