Risk, Uncertainty and Monetary Policy*

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PRELIMINARY

Abstract

We document a strong co-movement between the VIX, a stock market-based indicator of "risk aversion", and monetary policy. Using a structural vector autoregressive framework, we find that a primary component driving this co-movement is risk aversion rather than expected stock market volatility ("uncertainty"). A lax monetary policy decreases risk aversion significantly after about 6 months. Monetary authorities also react to periods of high risk aversion by easing monetary policy. These results are robust to controlling for business cycle movements. We further investigate channels through which monetary policy may affect risk aversion, e.g. through its effects on broad liquidity measures and credit.

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I. Introduction

A popular indicator of risk aversion in financial markets, the VIX index, shows strong co-movements with measures of the monetary policy stance. Figure 1 considers the cross-correlogram between the real interest rate (the Fed funds rate minus inflation), a measure of the monetary policy stance, and the logarithm of end-of-month readings of the VIX index. The VIX contract, traded on the Chicago Board Options Exchange, essentially prices the "risk-neutral" expected stock market variance for the US S&P 500 contract. The correlogram reveals a very strong positive correlation between real interest rates and future VIX levels. While the current VIX is positively associated with future real rates, the relationship turns negative and significant after 13 months: high VIX readings are correlated with expansionary monetary policy in the medium-run future.

The strong interaction between a "fear index" (Whaley (2000)) in the asset markets and monetary policy indicators may have important implications for a number of literatures. First, the recent crisis has refuelled the debate that lax monetary policy can be conducive to financial instability. The Federal Reserve's pattern of providing liquidity to financial markets following market tensions, which became known as the "Greenspan put", has been cited as one of the contributing factors to the build up of a speculative bubble in the run-up to the 2007-09 financial crisis.[1] Whereas some rather informal stories have linked monetary policy to risk-taking in financial markets (Rajan (2006), Adrian and Shin (2008)), it is fair to say that no extant research establishes a firm empirical link between monetary policy and risk aversion in asset markets.[2]

Second, Bloom (2009) and Bloom, Floetotto and Jaimovich (2009) show that heightened "economic uncertainty" decreases employment and output. It is therefore conceivable that the monetary authority responds to uncertainty shocks, in order to affect economic outcomes. However, the VIX index, used by Bloom (2009) to measure uncertainty, can be decomposed into a component that reflects actual expected stock

[1] Investors increasingly believed that when market conditions were to deteriorate, the Fed would step in and inject liquidity until the outlook improved. The perception may have become embedded in asset pricing in the form of higher valuations, narrower credit spreads, and excess risk-taking. See, for example, "Greenspan Put may be Encouraging Complacency," Financial Times, December 8, 2000.

[2] For recent empirical evidence that monetary policy affects the riskiness of loans granted by banks see, for example, Altunbas, Gambacorta and Marquéz-Ibañez (2009), Ioannidou, Ongena and Peydró (2009), Jiménez, Ongena, Peydró and Saurina (2009), and Maddaloni and Peydró (2009).

market volatility (uncertainty) and a residual, the so-called variance premium (see, for example, Carr and Wu (2009)), that reflects risk aversion and other non-linear pricing effects, perhaps even Knightian uncertainty. Establishing which component drives the strong comovements between the monetary policy stance and the VIX is therefore particularly important.[3]

Third, analyzing the relationship between monetary policy and the VIX and its components may help clarify the relationship between monetary policy and the stock market, explored in a large number of empirical papers (Thorbecke (1997), Rigobon and Sack (2004), Bernanke and Kuttner (2005)). The extant studies all find that expansionary (contractionary) monetary policy affects the stock market positively (negatively). Interestingly, Bernanke and Kuttner (2005) ascribe the bulk of the effect to easier monetary policy lowering risk premiums, reflecting both a reduction in economic and financial volatility and an increase in the capacity of financial investors to bear risk. By using the VIX and its two components, we test the effect of monetary policy on stock market risk, but also provide more precise information on the exact channel.

This article characterizes the dynamic links between risk aversion, economic uncertainty and monetary policy in a simple vector-autoregressive (VAR) system. Such analysis faces a number of difficulties. First, because risk aversion and the stance of monetary policy are jointly endogenous variables and display strong contemporaneous correlation (see Figure 1), a structural interpretation of the dynamic effects requires identifying restrictions. Such structural identification is of considerable interest, as there may be causal relationships in either direction. Monetary policy may indeed affect asset prices through its effect on risk aversion, as suggested by the literature on monetary policy news and the stock market, but monetary policy makers may also react to a nervous and uncertain market place by loosening monetary policy. In the literature on the relationship between the stock market and monetary policy, another paper by Rigobon and Sack (2003) finds that the Federal Reserve does systematically respond to stock

[3] Popescu and Smets (2009) analyze the business cycle behavior of measures of perceived uncertainty and financial risk premia in Germany. They find that positive financial risk aversion shocks have a large and persistent negative impact on the economy and are more important in driving business cycles than uncertainty shocks.

prices, for example.[4]

Second, the relationship between risk aversion and monetary policy may also reflect the joint response to an omitted variable, with business cycle variation being a prime candidate. Recessions may be associated with high risk aversion (see Campbell and Cochrane (1999) for a model generating counter-cyclical risk aversion) and at the same time lead to lax monetary policy. Third, there are a number of measurement problems. Disagreement on how to measure risk aversion in financial markets is rife (see Coudert and Gex (2008) for a survey) and measuring the monetary policy stance is the subject of a large literature (see, for example, Bernanke and Mihov (1998a)). In addition, measuring policy shocks correctly is difficult. Models featuring time-varying risk aversion and/or uncertainty, such as Bekaert, Engstrom and Xing (2009), imply an equilibrium contemporaneous link between interest rates and risk aversion and uncertainty, through precautionary savings effects for example. Such relation should not be associated with a policy shock.

To overcome these difficulties, we strive to characterize the data as fully as possible. In Section II, we start with an analysis of the VIX and a measure of the monetary policy stance (the real interest rate) in a bivariate VAR. We show the dynamic effects of the VIX on monetary policy and vice versa, under a variety of identification schemes. One set of identifying restrictions we find natural to impose is long-run money neutrality. We also show robustness to a number of alternative measurements of the monetary policy stance. In section III, we expand the VAR to account for the most obvious omitted variable, a business cycle indicator, and also split the VIX in a pure volatility component and a residual, which should be more closely associated with risk aversion. In the final section, we empirically examine various channels through which monetary policy may affect risk aversion and private sector risk-taking behavior, as suggested by recent research. Specifically, we consider the effects through the balance sheet of financial intermediaries (as proxied by repo growth and the growth rates of broad money aggregates) and through the expansion of credit (using the growth of credit and credit-to-

[4]The two papers by Rigobon and Sack (2003, 2004) use an identification scheme based on the heteroskedasticity of stock market returns. Given that we view economic uncertainty as an important endogenous variable in its own right with links to the real economy and risk premiums, we cannot use such an identification scheme.

GDP ratio). This analysis has important implications for policy discussions about the effectiveness of monetary policy to contain financial market excesses.

Our main findings are as follows. A lax monetary policy decreases risk aversion in the medium run. Monetary policy also reacts to periods of high risk aversion by relaxing monetary policy. These effects are persistent. Moreover, they are robust to controlling for business cycle movements, as well as to alternative measures of monetary policy stance. Uncertainty (stock market volatility) appears entirely exogenous, so that the effect of monetary policy runs primarily through risk aversion. High repo growth has an independent, persistently negative, effect on risk aversion.

II. The VIX and Monetary Policy

We begin our analysis with a bivariate VAR on a measure of risk aversion and a measure of monetary policy, using monthly data for the United States from January 1990 to July 2007. Table 1 lists the variables, their labels and description. Note that we exclude recent data on the crisis, which presents special challenges.

To measure risk aversion, we start by using end-of-month VIX levels. The VIX represents the implied volatility of a hypothetical at-the-money option on the S&P 500 index with a horizon of 30 calendar days (22 trading days). Since 2004, this volatility estimate is based on a weighted average of European-style S&P 500 options that straddle a 30-day maturity and cover a wide range of strikes (see CBOE (2004) for more details). The VIX is often viewed as a measure of risk aversion in the market place, although it obviously also reflects stock market uncertainty. We decompose the VIX information in Section III.

To measure the monetary policy stance, we start by using the real interest rate, i.e. the Fed funds end-of-the-month target rate minus the CPI inflation rate. We then consider alternative measures of the monetary policy stance for robustness; Taylor rule deviations, the nominal Fed funds rate, and the growth of the monetary aggregate M1.

We collect these two variables in the vector $Z_t = [ra_t, mp_t]'$ where ra_t is our proxy for risk aversion, the VIX, and mp_t is a measure of monetary policy stance. Without loss of generality, we ignore constants. Consider the following structural VAR:

$$A\, Z_t = \Phi\, Z_{t-1} + \varepsilon_t \qquad (1)$$

where A is a 2x2 full-rank matrix and $E[\varepsilon_t \varepsilon_t'] = I$. Of main interest are the dynamic responses to the structural shocks ε_t.

Of course, we start by estimating the reduced-form VAR. We re-write (1) as follows:

$$Z_t = B Z_{t-1} + C \varepsilon_t \tag{2}$$

where B denotes $A^{-1} \Phi$ and C denotes A^{-1}. Moreover, let us define Σ to be the variance-covariance matrix of the reduced-form residuals, that is, $\Sigma = E[(C \varepsilon_t) (C \varepsilon_t)'] = C C'$.

While we expressed the equations for first-order VARs, selecting the correct order of the VAR is important. The first-order VAR is useful to illustrate the identification problem: Equation (2) yields 7 coefficients in the matrices B and Σ, but Equation (1) has 8 unknowns. In general, for a VAR of order k with N variables, we have $(k+1)N^2$ parameters to identify and we can estimate $kN^2 + N(N+1)/2$ parameters. Hence, we need $N(N-1)/2$ restrictions to identify the system.

Reduced-form Evidence

Before we explore structural identification, Table 2 reports some reduced-form VAR statistics. Panel A produces three lag-selection criteria: Akaike (AIC), Hannan-Quinn (HQIC) and Schwarz (SBIC). While the Schwarz and HQIC criteria select relatively parsimonious VARs, the AIC criterion selects a VAR with 14 lags. We focus the remainder of the analysis in this section on the 14 lag VAR, for reasons detailed below. Panel B reports Granger causality tests. We find strong Granger causality in either direction, i.e. the monetary policy stance predicts risk aversion and risk aversion predicts the monetary policy stance.[5]

Finally, Panel C reports some specification tests on the residuals of the VAR. These tests (see Johansen (1995)) test for autocorrelation in the residuals of the VAR at lag j (j=1,2,3). The VAR with 14 lags clearly eliminates all serial correlation in the residuals.

We couch our main results in the form of impulse-response functions (IRFs henceforth), estimated in the usual way. We compute 90% bootstrapped confidence intervals based on 1000 replications, and focus our discussion on significant responses.

Figure 2 shows orthogonalized "reduced-form" IRFs, that is, the impulse responses generated by the shock of either variable, using a Cholesky decomposition of the estimate

[5] In the 14 lag VAR, reporting the feedback coefficients is not very informative. In a first-order VAR, contractionary monetary policy predicts higher risk aversion next period; whereas higher risk aversion predicts laxer monetary policy next month. Both coefficients are significant at the 5% level.

of the variance-covariance matrix. We order the impulse variable first and the response variable second, so that the response at lag zero represents the off-diagonal element in the Cholesky factor.

A one standard deviation negative shock to the real rate (equivalent to 25.60 basis points), after an initial increase, lowers LVIX by 0.0209 after 15 months (evaluated at the sample average of the VIX, 18.9033, it is equivalent to 0.3951 percentage points on an annualized basis). The impact reaches a maximum of 0.0295 (0.5576 percentage points) after 32 months. The effect remains (borderline) significant up and till lag 48. A one standard deviation positive shock to LVIX (equivalent to 2.5727 percentage points on an annualized basis) leads to a 12.13 basis points decrease in the real interest rate after 23 months. The decrease reaches a maximum level of 18.26 basis points after 31 months.

Hence, apart from a somewhat puzzling significant negative short-run response of the VIX to real interest rates, our evidence reveals significant responses, suggesting that lax monetary policy can indeed affect risk aversion (that is, increase risk appetite) in the medium run (after one year), and that monetary policy also reacts to periods of high risk aversion by relaxing monetary policy, with a somewhat longer lag.

Structural Evidence

To obtain structural identification, we investigate two types of restrictions. A natural restriction to impose is money neutrality: monetary policy cannot have a long run effect on risk aversion. Bernanke and Mihov (1998b) and King and Watson (1992) marshal empirical evidence in favor of money neutrality, but, of course, not in the context of our particular VAR set-up.

Following Blanchard and Quah (1989), the model with a long-run restriction (LR) involves a long-run response matrix, denoted by D:

$$D \equiv (I - B)^{-1} C \tag{3}$$

It follows that $D D' = (I - B)^{-1} C C' [(I - B)^{-1}]' = (I - B)^{-1} \Sigma [(I - B)^{-1}]'$. Hence, using the estimates of B and Σ from the reduced-form VAR, we obtain D, and thus $A^{-1} = C$. Our assumption of long-run money neutrality in the two-variable system implies that $d_{12} = 0$:[6]

[6] Since the matrix D D' is symmetric, there exists a unique lower triangular matrix D such that D D' equals the symmetric matrix. The matrix D is known as the Cholesky factor of the symmetric matrix. In larger systems, the restrictions need not give rise to a Cholesky representation for a unique solution to be guaranteed. This consideration restricts the set of specifications we report in Section III.

$$\mathrm{D} = \begin{bmatrix} d_{11} & 0 \\ d_{21} & d_{22} \end{bmatrix} \tag{4}$$

Recently, the use of long-run restrictions to identify VARs has come under attack (see, for example, Chari, Kehoe and McGrattan (2008)). However, Christiano, Eichenbaum and Vigfusson (2008) show that many of the problems can be overcome by using long-run information (rather than a parsimonious VAR) to identify the long-run restrictions. Although they advocate using a non-parametrically estimated spectral density matrix, our VAR with 14 lags, the lag-length selected by the Akaike criterion, effectively uses long-run information to identify the restrictions.

As an alternative, we employ identification using a short-run restriction (SR), imposing that monetary policy does not have a short-run effect on risk aversion or, equivalently, $\phi_{12} = 0$:

$$\Phi = \begin{bmatrix} \phi_{11} & 0 \\ \phi_{21} & \phi_{22} \end{bmatrix} \tag{5}$$

This exogeneity assumption on risk aversion is consistent with external habit models, such as Campbell and Cochrane (1999) and Bekaert, Engstrom and Xing (2009), where the state variable driving risk aversion follows a univariate autoregressive process, but its shocks may be correlated with other state variables.

Figure 3 shows the impulses-response functions under the structural restrictions. In the model with the long-run restriction, a one standard deviation negative shock to the real rate (equivalent to 65.43 basis points) lowers LVIX by 0.0808 after 36 months (evaluated at the sample average of the VIX, 18.9033, this is equivalent to 1.5274 percentage points on an annualized basis). The maximum impact is a decrease by 0.1020 (1.9281 percentage points) after 42 months. A one standard deviation positive shock to LVIX (equivalent to 5.2759 percentage points on an annualized basis) leads to a 39.04 basis points decrease in the real rate after 23 months. The maximum impact is 56.52 basis points after 31 months.

In the model with the short-run restriction, a one standard deviation negative shock to the real rate (equivalent to 26.34 basis points) lowers LVIX by 0.0197 after 15 months (evaluated at the sample average of the VIX, 18.9033, this is equivalent to 0.3724 percentage points on an annualized basis). The maximum impact is 0.0283 (0.5350 percentage points) after 26 months. A one standard deviation positive shock to LVIX (equivalent to 2.6351 percentage points on an annualized basis) leads to a 12.92 basis points decrease in the real rate after 23 months. The maximum impact is 17.35 basis points after 31 months. Consequently, the dynamic interactions between risk aversion and monetary policy, uncovered in the reduced-form analysis, are preserved under reasonable structural restrictions. A somewhat puzzling short-lived negative effect of interest rates on risk aversion remains robust as well.

Robustness

We first consider the robustness of our results with respect to three alternative measures of monetary policy stance in Table 3. The first measure we consider is Taylor rule residuals, i.e. the difference between the nominal Fed funds rate and the Taylor rule rate (TR rate). The TR rate is estimated as in Taylor (1993):

$$TR_t = Inf_t + NatRate_t + 0.5*(Inf_t - TargInf) + 0.5*OG_t \quad (6)$$

where Inf is the annual inflation rate, NatRate is "natural" real Fed funds rate (consistent with full employment), which Taylor assumed to be 2%, TargInf is a target inflation rate, also assumed to be 2%, and OG (output gap) is the percentage deviation of real GDP from potential GDP. We assume that the growth of potential GDP is 3% per year. We also consider other measures of the monetary policy stance, namely the nominal Fed funds rate instead of the real rate, and the growth rate of the monetary aggregate M1, which is commonly assumed to be under tight control of the central bank.

The results confirm that a looser monetary policy stance (lower Fed funds rate interest rate relative to the Taylor rule rate, lower Fed funds rate, or higher M1 growth) leads to lower implied volatility. Specifically, a one standard deviation negative shock to the Taylor rule deviation (equivalent to 0.19 percentage points) lowers LVIX by a maximum of 0.2349 (evaluated at the sample average of the VIX, 18.9033, it is equivalent to 4.4404 percentage points on an annualized basis) after 47 months in the structural model with the long-run restriction. A one standard deviation negative shock to the Taylor rule deviations (equivalent to 0.34 percentage points) lowers LVIX by a maximum of 0.0811 (equivalent to 1.5331 percentage points) after 32 months in the structural model with the short-run restriction.

The effects for the Fed funds rate are remarkably similar. A one standard deviation negative shock to the Fed funds rate (equivalent to 85.70 basis points) lowers LVIX by a maximum of 0.0937 (equivalent to 1.7712 percentage points on an annualized basis) after 22 months in the structural model with the long-run restriction. A one standard deviation negative shock to the Fed funds rate (equivalent to 16.42 basis points) lowers LVIX by a maximum of 0.0213 (equivalent to 0.4026 percentage points) after 20 months in the structural model with the short-run restriction.

A one standard deviation positive shock to the M1 growth (equivalent to 1.5539 percentage points) lowers LVIX by a maximum of 0.0754 (equivalent to 1.4253 percentage points on an annualized basis) after 6 months in the structural model with the long-run restriction and has no statistically significant impact in the structural model with the short-run restriction. So, while the results are weaker for the money growth measure, we find robust causal reactions between monetary policy and the VIX.

Analogously, the medium-term negative effect risk aversion has on the monetary policy stance is mostly preserved using the Taylor rule residuals, but is a bit weaker and significant for shorter horizons when the Fed funds rate is used. There is no significance using M1 growth. The response of monetary policy to implied volatility may just reflect a reaction of both variables to economic conditions, a hypothesis we formally check in Section III.

Next, we consider the robustness of our results to the lag-length specification in the VAR. The 14-lag VAR may be over-parameterized; consequently, we reduce the lag length to 9 lags. By reducing the lag length to 9 lags, we obtain a saturation ratio of slightly over 10. The saturation ratio is the total number of observations divided by total number of parameters estimated. Second, we estimate a VAR with 1 lag, as selected by the Schwarz criterion (SBIC). In both instances, our results (not reported) are quite similar to the results reported in Table 3.

III. Risk, Uncertainty and Monetary Policy

In this section, we analyze a four-variable VAR. First, we add a business cycle indicator. It is conceivable that the intriguing links between our measure of risk aversion and monetary policy simply reflect monetary policy and risk aversion jointly reacting to business cycle conditions. For example, news indicating weaker than expected growth in the economy may make a cut in the Fed funds target rate more likely, but at the same time cause people to be effectively more risk averse, for example because a larger number of households feel more constrained in their consumption relative to "habit," or because people fear a more uncertain future. To analyze business cycle effects, we use the log of jobless claims as a recession indicator, bc_t.

Second, we split the VIX into a measure of stock market or economic uncertainty, uc_t, and a residual that should be more closely associated with risk aversion, ra_t. While we used the VIX index as a measure of risk aversion, it is also an index of stock market volatility (economic uncertainty). The recent finance literature emphasizes its two different components, true economic uncertainty (the physical conditional variance of the stock market) and the remainder, which is called the variance premium (see, e.g., Carr and Wu (2009))[7] and usually computed as the difference between the squared VIX and an estimate of the conditional variance. Recent finance models attribute this difference either to non-Gaussian components in fundamentals and (stochastic) risk aversion (see, for instance, Bekaert and Engstrom (2009), Bollerslev, Tauchen and Zhou (2009), Drechsler and Yaron (2009)) or Knightian uncertainty (see Drechsler (2009)). The fact that the variance premium is nearly always positive suggests that these non-linear features of the data are important. In the context of an external habit model, Bekaert, Engstrom and Xing (2009) recently show how "risk aversion" and economic uncertainty may have different effects on asset prices, and these differences may be important to acknowledge in monetary policy transmission.

To decompose the VIX index into its two components, we borrow a measure of the conditional variance of stock returns from Bekaert and Engstrom (2009), who project monthly realized variances (computed using squared 5-minute returns) on a set of instruments. We call the logarithm of this variance estimate "uncertainty" (uc_t). The logarithm of the difference between the squared VIX and this conditional variance is our improved risk aversion measure (ra_t), although it may also capture Knightian uncertainty and other nonlinearities.

[7] In the technical finance literature, the variance premium is actually the negative of the construct that we use. However, increased risk aversion makes the variance premium more negative, and we want our variable to act as a risk aversion indicator.

Consequently, we now analyze a four-variable system, with $Z_t = [ra_t, mp_t, bc_t, uc_t]'$. This may provide important inputs to a rapidly growing macroeconomic literature on news-driven business cycles. Beaudry and Portier (2006), for example, present empirical evidence suggesting that business cycle fluctuations may be driven to a large extent by changes in stock market expectations, which anticipate total factor productivity movements. Bloom (2009) also shows that "economic uncertainty" has real effects, in particular it generates a sharp drop in employment and output, which rebounds in the medium term, and a mild long-run overshoot. He explains these facts in the context of a production model where uncertainty increases the region of inaction in hiring and investment decisions of firms facing non-convex adjustment costs. In his empirical work, Bloom uses the VIX index to create an index of "exogenous" volatility shocks. However, as the VIX reflects both uncertainty and risk aversion, it is conceivable that it is the risk aversion component of the VIX index that generates the real effects, not the economic uncertainty component. Moreover, these shocks may be simply correlated with business cycles, as predicted by external habit models, for example.[8] In a recent Economist article, Blanchard (2009) describes the VIX index as an indicator of Knightian uncertainty, arguing that such uncertainty may prolong the current crisis. In both cases, the implication is that monetary policy may want to respond strongly to uncertainty shocks, in Bloom's case to economic uncertainty shocks, in Blanchard's case to what we call risk aversion shocks.

Reduced-form Evidence

Table 4 reports some basic VAR statistics. The selection criteria, reported in Panel A, now select much shorter VAR orders, with the Akaike criterion only selecting a third-order VAR. When we estimate that VAR, there is some evidence of remaining serial correlation at the second lag (see Panel C). Panel B reports Granger causality tests for the three-lag VAR. We continue to find strong overall Granger causality in the risk aversion and real interest rate equations. However, while for risk aversion the strong predictive power appears to be still driven by monetary policy, risk aversion no longer significantly predicts the real rate. Uncertainty and jobless rates do predict the monetary policy stance.

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[8] To be fair, Bloom (2009) attempts to identify exogenous shocks to the VIX, which are less likely to be of a cyclical nature.

Granger causality is not significantly present in either the jobless rate equation or the uncertainty equation. While the p-values for the various variables and the overall p-values are relatively low in the jobless equation (with risk aversion predicting or anticipating jobless rates significantly at the 5% level), uncertainty is really only related to past uncertainty.

Figure 4 reports the orthogonalized reduced-form impulse responses for the four-variable VAR. As in the previous section, we use a Cholesky ordering with the impulse variable ordered first and the response variable ordered second. A one standard deviation negative shock to the real rate (equivalent to 32.75 basis points) lowers risk aversion by 0.5940 after 4 months. The impact reaches a maximum of 1.3019 after 15 months and remains significant up and till lag 33. A one standard deviation negative shock to the real rate has an immediate positive effect on uncertainty (an increase of 0.9015). Such an effect may reflect a precautionary savings channel between the interest rate and uncertainty. The effect becomes statistically insignificant thereafter. A one standard deviation positive shock to the risk aversion (equivalent to 5.3098) has an immediate positive impact on uncertainty (an increase of 5.6849), with the effect becoming statistically insignificant after 2 periods. It has no statistically significant impact on the real rate.

As for the impact of uncertainty shocks, a one standard deviation positive shock to uncertainty (equivalent to 9.5272) lowers the real rate initially. The maximum impact of 158.23 basis points occurs after 7 months, with the impact becoming insignificant further out. A one standard deviation positive shock to uncertainty increases risk aversion significantly in the short-run with a maximum impact of 2.4860 in the initial period.

Reduced-form impulse responses indicate that the real interest rate responds primarily to uncertainty shocks, rather than risk aversion shocks. On the other hand, real rate shocks have a stronger and more persistent effect on risk aversion as compared to uncertainty.

Structural Evidence

To identify a four-variable system, we need 6 restrictions on the VAR. Because long-run money neutrality only delivers 3 (no long-run effect of monetary policy shocks on risk aversion, jobless claims and uncertainty), we must make some potentially unpalatable assumptions. Our strategy is to simply verify a number of alternative identification schemes, and see whether the structural results are robust.

One set of restrictions is to assume that risk aversion is not affected by other factors in the long run. While there are a number of theories (Sharpe (1990), Campbell and Cochrane (1999)) suggesting that risk aversion moves counter-cyclically, if risk aversion is ultimately driven by preferences, there should be no long run effects of other shocks. One can make a similar argument for the effect of the business cycle on uncertainty in the long run. Consequently, the restrictions correspond to the following long-run matrix D:

$$\mathrm{D} = \begin{bmatrix} d_{11} & 0 & 0 & 0 \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} & 0 & d_{33} & d_{34} \\ d_{41} & 0 & 0 & d_{44} \end{bmatrix} \tag{7}$$

It is easy to see that a re-ordered system has the standard Cholesky form, and hence should yield a unique solution (see Blanchard and Quah (1989)).

An alternative identification scheme combines the three long-run money neutrality restrictions, i.e. $d_{12} = d_{32} = d_{42} = 0$, with three short-run restrictions as follows:

$$\Phi = \begin{bmatrix} \phi_{11} & 0 & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & 0 & 0 & \phi_{44} \end{bmatrix} \tag{8}$$

In addition to the exogeneity assumption on risk aversion (ϕ_{12}=0), which we also imposed in the two-variable set-up, we assume that the monetary policy and business cycle variables do not have a short-run effect on uncertainty. This choice is motivated by the Granger causality results as well as the cross-correlations between variables, suggesting uncertainty is a relatively "exogenous" variable.

We report the resulting structural impulse-response functions in Figure 5. In a model with long-run restrictions, a one standard deviation negative shock to the real rate (equivalent to 84.93 basis points) lowers risk aversion by 0.9272 after 8 months. The impact reaches a maximum of 1.1380 after 14 months. In a model with long/short-run restrictions, a one standard deviation negative shock to the real rate (equivalent to 84.93 basis points) lowers risk aversion by 0.8944 after 6 months. The impact reaches a maximum of 1.1503 after 14 months. So, the effect of monetary policy on risk aversion is consistent with the reduced-form results under both identification schemes.

As for the shocks to risk aversion, in a model with long-run restrictions, a one standard deviation positive shock to risk aversion (equivalent to 29.5183) lowers the real rate by 149.24 basis points in period 0, reaching a maximum impact of 153.80 basis points in period 1. In a model with long/short-run restrictions, the impact of a one standard deviation shock (or 27.1669) is negative but not significant. Hence, we find a short-lived structural effect of risk aversion on the subsequent monetary policy stance only in the model with long-run restrictions.

The impact of real rate shocks on uncertainty is not statistically significant. In the other direction, in the model with long-run restrictions, the real rate increases by 58.65 basis points following a shock to uncertainty (equivalent to 11.7781), with the impact reaching a maximum of 63.85 basis points in period 1. There are, however, no significant effects in the model with long/short-run restrictions. Finally, increases in uncertainty predict future increases in risk aversion under both identification schemes (although the response is not statistically significant under the long/short-run identification), which is consistent with the results from the reduced-form impulse responses (Panel F). Risk aversion has no significant effect on uncertainty (Panel E).

Robustness

Our results are largely robust to the specific identification scheme used. In Appendix A, we report a large number of identification schemes that we tried and we summarize the main results. In all cases, we find that monetary policy has a significant effect on risk aversion, with the effect concentrated around 8 to 28 months. We find the reverse effect in 7 out of 10 specifications, but when it occurs, it short-lived. As for uncertainty, the strong and puzzling positive effect on future real interest rates we uncovered in the model with long-run restrictions is not robust: it appears in only one additional specification. Finally, we find that uncertainty does not respond to monetary policy shocks.

We also check robustness to lag-length. A VAR with 4 lags eliminates all serial correlation in the residuals and still has a saturation ratio of 10 (see Section II, p. 10 for a discussion of the saturation ratio). The results are unaltered. To check for robustness with respect to our business cycle measure, jobless claims, we estimate the model with unemployment rate as a business cycle variable. The estimates are consistent with our previous findings.

We conclude that a lax monetary policy decreases risk aversion significantly, with the effect only being significant after about 6 to 8 months, while high risk aversion decreases the real interest rate. The latter effect's statistical significance is more short-lived, lasting only a few months. So, our previous results extend to the four-variable set-up, i.e. even controlling for business cycle movements, and extracting the risk aversion component out of the VIX. Uncertainty (stock market volatility) appears entirely exogenous, but has a strong positive effect on future real interest rates in the specification with long-run restrictions. This effect is surprising, although it does not seem to be robust. If stock market volatility anticipates business cycle movements, we would expect a negative effect, but of course, we investigate a pure shock to uncertainty, cleansed of business cycle co-movements.

IV. Channels

We have unearthed some intriguing interactions between the component in the VIX index not related to actual stock market volatility, and the stance of monetary policy. If monetary policy indeed affects risk aversion, our results could be important in the current debate about the origins of the 2008-2009 crises. While pinpointing in detail how monetary policy affects risk aversion is beyond the scope of the article, we use this Section to empirically analyze some potential channels, discussed informally in a number of recent articles.

Adrian and Shin (2008) suggest that the link between monetary policy and asset prices runs through the balance sheets of banks and that repo growth rates adequately proxy for the riskiness of bank's balance sheets. Using US data, they find that the growth of outstanding repos forecasts the difference between implied and realized volatility and that rapid growth in repos is associated with loose monetary policy (defined as the Fed funds rate).

To examine the Adrian-Shin story in our structural framework, we use a four-variable VAR as in the previous section but with repo growth replacing the "business cycle" variable. First, we examine whether introduction of this variable eliminates the effect of the real interest rate on risk aversion we uncovered in the previous section. Table 6 summarizes the results. Lax monetary policy is still associated with lower risk aversion after 4 to 6 months (depending on the specification used). This effect is persistent. In the opposite direction, the response of the real rate to a positive risk aversion shock is significantly negative only in the model with long-run restrictions. In Table 7, we investigate the interaction between the real rate and uncertainty, finding the results to be very similar to those obtained in the previous section, with the exception that uncertainty has a positive effect on the real interest rate under both structural specifications.

Second, we analyze the direct link between repo growth and risk aversion. In the model with long-run restrictions, higher repo growth leads to lower risk aversion after 9 months. This effect remains statistically significant until month 30. The direction is similar in the model with long/short-run restrictions, but the effect is not statistically significant. Third, in the model with long-run restrictions, we find that real interest rate is significantly lower following a positive shock to repo growth between months 0 and 23. In sum, our VAR only provides mixed evidence in favour of the Adrian and Shin story, suggesting the monetary policy – risk aversion link does not exclusively run through repo growth.

More generally, commentators have noted a rather large build up of liquidity through money growth at times of crises (see also Adalid and Detken (2007), Alessi and Detken (2009)). We thus use the growth rates of a broad money aggregate as a "channel" variable, replacing the business cycle variable in the four-variable VAR. In particular, we consider the growth rate of M2 net of M1. This part of the money growth is arguably less under control of a central bank and rather reflects activities of the financial sector.[9] It may also reflect savings behavior of individuals, who might flee into safe assets during crisis times.

Using this set-up, we confirm our finding that lower real rates lead to lower risk aversion in all specifications considered (see Table 6). Table 7 shows that the inclusion of the liquidity variable does change the dynamic interactions between uncertainty and monetary policy, with contractionary policy shocks increasing uncertainty. At the same

[9] Recall that we examined the interaction between M1 growth and stock market volatility in Section II.

time, we do not find a statistically significant impact of the growth rate of (M2 - M1) on either risk aversion or uncertainty.

According to Borio and Lowe (2002), medium-term swings in asset prices are associated with a rapid credit expansion. Moreover, they stress that financial imbalances build up in a low inflation environment and that in some cases it is appropriate for monetary policy to respond to these imbalances. Consequently, they suggest a link between credit growth and monetary policy. It is conceivable that periods of high risk appetite coincide with periods of rapid credit expansion, suggesting a channel for the effect of monetary policy on risk aversion.

To investigate the role of credit, we consider two separate four-variable VAR systems, with (private) credit growth and the credit-to-GDP ratio replacing the "business cycle" variable. The significant impact of monetary policy on risk aversion is present again (see Table 6). The interactions between uncertainty and monetary policy are as before (see Table 7). We do not find evidence that credit has a statistically significant effect on risk aversion. Rather, the causality runs in the other direction: a negative shock to risk aversion leads to an increase in both credit growth and the credit-to-GDP ratio. This implies that monetary policy may affect credit growth through its effect on risk appetite. This finding complements recent results in the empirical banking literature (Altunbas, Gambacorta and Marquez-Ibanez (2009), Ioannidou, Ongena and Peydró (2009), Jiménez, Ongena, Peydró and Saurina (2009), Maddaloni and Peydró (2009)) documenting that loose monetary policy increases the riskiness of loans granted by banks. In the presence of agency problems, an environment of abundant liquidity may lead banks to finance projects with negative net present value and to over-lend (Allen and Gale (2007)).

In sum, considering channels through which monetary policy may affect risk aversion confirms that a lax monetary policy has a direct impact on risk aversion. The balance sheets of financial intermediaries seems to be an important transmission channel affecting risk appetite directly, but monetary policy still has an independent effect on risk aversion. Credit does not play a significant role in our set-up. Instead, risk preferences seem to affect credit growth.

V. Conclusions

A number of recent studies point at a potential link between loose monetary policy and excessive risk-taking in financial markets. Rajan (2006) conjectures that in times of ample liquidity supplied by the central bank, investment managers have a tendency to engage in risky, correlated investments. To earn excess returns in a low interest rate environment, their investment strategies may entail risky, tail-risk sensitive and illiquid securities. Moreover, a tendency for herding behaviour emerges due to the particular structure of managerial compensation contracts. Managers are evaluated vis-à-vis their peers and by pursuing strategies similar to others, they can ensure that they do not under perform. This “behavioral” channel of monetary policy transmission can lead to the formation of asset prices bubbles and can threaten financial stability. Given the dramatic crisis witnessed in 2007-2009, Rajan’s story sounds prophetic. Yet, there is no empirical evidence on the links between risk aversion in financial markets and monetary policy.

This article has attempted to provide a first characterization of the dynamic links between risk, uncertainty and monetary policy, using a simple vector-autoregressive framework. We find a robust structural interaction between implied volatility and monetary policy. A primary component driving this interaction is risk aversion rather than uncertainty. Lax monetary policy increases risk appetite in the future, while high risk aversion leads to laxer monetary policy in the future. These results are robust to controlling for business cycle movements. However, when we add uncertainty, only the first effect survives, whereas the monetary policy reaction to risk aversion is only apparent at very short horizons. Uncertainty itself appears to be rather exogenous and does not respond to monetary policy.

We hope that our work will inspire further empirical work and research on the exact theoretical links between monetary policy and risk-taking behavior in asset markets. The policy implications are also potentially very important. Fed chairman Bernanke (see Bernanke (2002)) interprets his work on the effect of monetary policy on the stock market (Bernanke and Kuttner (2005)) as suggesting that monetary policy would not have a sufficiently strong effect on asset markets to pop a “bubble.” However, if monetary policy significantly affects risk appetite in asset markets, it can have rather wide ramifications. If one channel is that it induces excess leverage as in Adrian and Shin

(2008), perhaps monetary policy is potent enough to weed out financial excess. Conversely, in times of crisis and heightened risk aversion, monetary policy can powerfully influence risk aversion in the market place, and therefore affect real outcomes. Blanchard (2009) noted that the economy and financial markets had "nothing to fear but fear itself," suggesting a role for policy to reduce these fears. His conclusion that markets were 'fearful' was exactly inspired by unusually elevated VIX levels.

One disadvantage of our framework is that it does not really test the Rajan (2006) and related stories. Current stories about the potential pernicious effects of lax monetary policy give a prominent role to the length of the policy, and are explicitly asymmetric (they are about policy being too lax, not too contractionary). Such features are really not present in our linear VAR framework. We conduct one preliminary and informal test, investigating whether the duration of a lax policy regime would play a role in the dynamic interactions we observe. To that end, we construct a "duration-adjusted monetary policy" (DUMP for short) variable which takes on the value of $\log(1+c_t+c_t^2)*TRdev_t$, where c_t is the number of periods for which the deviation from the Taylor rule, TRdev, is negative. If the deviation is positive, DUMP is given by the $TRdev_t$ itself. This variable thus puts more weight on those periods in which monetary policy was loose for a prolonged period of time. We estimate the four-variable system composed of risk aversion, DUMP, jobless claims, and uncertainty. We find that, in a model with long-run restrictions, a one standard deviation negative shock to DUMP lowers risk aversion by 1.6684 after 4 months. The impact reaches a maximum of 1.9391 after 9 months. In a model with long/short-run restrictions, a one standard deviation negative shock to duration lowers risk aversion by 1.6789 after 3 months. The impact reaches a maximum of 2.1461 after 9 months.

In sum, monetary policy that is "too low for too long" decreases risk aversion in the stock market. The impact is more immediate and stronger than the one we found using unadjusted indicators of monetary policy stance. While suggestive, we plan to investigate potential asymmetric and duration effects more formally in an explicitly non-linear framework in the near future.

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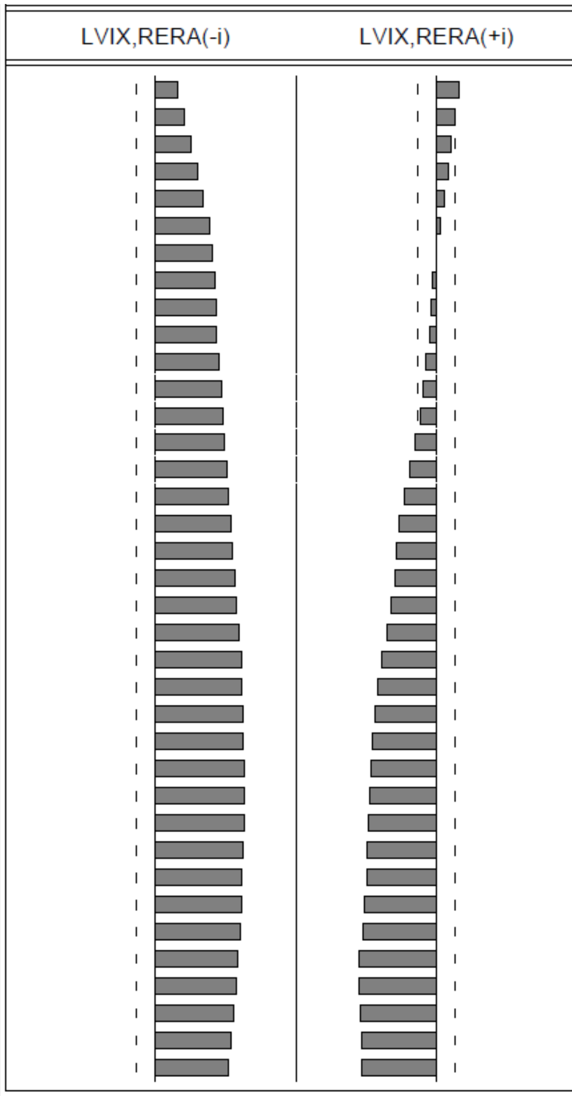
Table 1: Description of variables

Name	Label	Description
Credit growth	CG	Month-on-month growth of loans
Credit-to-GDP ratio	CGDP	Ratio of credit to GDP (intrapolated)
Fed funds rate	FED	Fed funds target rate
Implied volatility S&P500	LVIX	Log of (VIX / $\sqrt{12}$)
Jobless claims	LJOB	Log of jobless claims
M1 money aggregate growth	M1	Month-on-month growth of M1
M2 net of M1 money growth	M2-M1	Month-on-month growth of (M2-M1)
Real interest rate	RERA	FED minus annual CPI inflation rate
Repo growth	GREPO	Monthly growth in repos outstanding
Risk aversion	RA	Log of (squared VIX minus exp(UC))
Taylor Rule deviations	TRULE	FED minus TaylorRuleRate (see p.7)
Uncertainty (conditional variance)	UC	Log of conditional variance

Notes: Monthly frequency, end-of-the-moth data. Source: Thomson Datastream; data on risk aversion and uncertainty are from Bekaert and Engstrom (2009).

Figure 1: Cross-correlogram LVIX RERA



i	lag	lead
0	0.1716	0.1716
1	0.2169	0.1391
2	0.2651	0.1119
3	0.3119	0.0846
4	0.3547	0.0586
5	0.3988	0.0300
6	0.4225	-0.0039
7	0.4401	-0.0283
8	0.4473	-0.0350
9	0.4560	-0.0513
10	0.4684	-0.0759
11	0.4912	-0.0935
12	0.5057	-0.1193
13	0.5150	-0.1628
14	0.5314	-0.2032
15	0.5485	-0.2321
16	0.5634	-0.2719
17	0.5731	-0.2947
18	0.5846	-0.3107
19	0.5979	-0.3344
20	0.6151	-0.3614
21	0.6329	-0.3979
22	0.6438	-0.4308
23	0.6491	-0.4544
24	0.6515	-0.4686
25	0.6598	-0.4800
26	0.6604	-0.4876
27	0.6568	-0.5018
28	0.6524	-0.5128
29	0.6474	-0.5163
30	0.6381	-0.5254
31	0.6251	-0.5465
32	0.6123	-0.5663
33	0.5960	-0.5718
34	0.5761	-0.5616
35	0.5586	-0.5513
36	0.5454	-0.5536

Notes: The first column presents the (lagged) cross-correlogram between the log of the VIX (LVIX) and past values of the real interest rate (RERA). The second column presents the (lead) cross-correlogram between LVIX and future values of RERA. Dashed vertical lines indicate 95% confidence intervals for the cross-correlation. The third column presents the cross-correlation values. The index i indicates the number of months either lagged or led for the real interest rate variable.

Table 2: Bivariate VAR results (LVIX, RERA)

Panel A: Lag-length selection

lag	AIC	HQIC	SBIC
1	-0.1170	-0.0899	-0.0501*
2	-0.1383	-0.0841	-0.0045
3	-0.2496	-0.1683*	-0.0488
4	-0.2686	-0.1603	-0.0010
5	-0.2776	-0.1421	0.0570
6	-0.2691	-0.1066	0.1323
7	-0.2525	-0.0629	0.2158
8	-0.2318	-0.0151	0.3034
9	-0.2469	-0.0031	0.3552
10	-0.2298	0.0411	0.4392
11	-0.2534	0.0445	0.4825
12	-0.2453	0.0797	0.5575
13	-0.4196	-0.0675	0.4501
14	-0.5056*	-0.1265	0.4310
15	-0.4717	-0.0655	0.5318

Panel B: Granger causality

Equation	Excluded	chi2	df	p-value
LVIX	RERA	28.7290	14	0.0110
RERA	LVIX	48.2480	14	0.0000

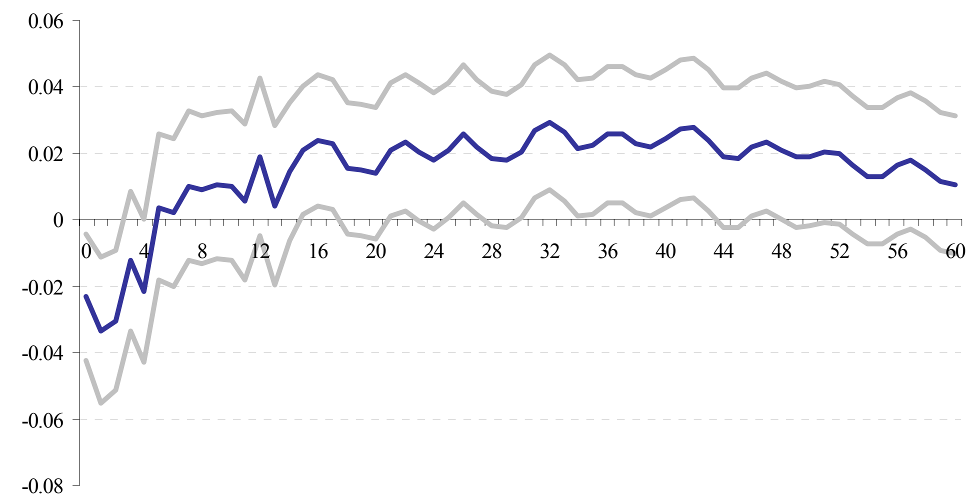
Panel C: Lagrange-multiplier test

lag	chi2	df	p-value
1	1.5554	4	0.8168
2	3.0961	4	0.5419
3	5.4070	4	0.2480

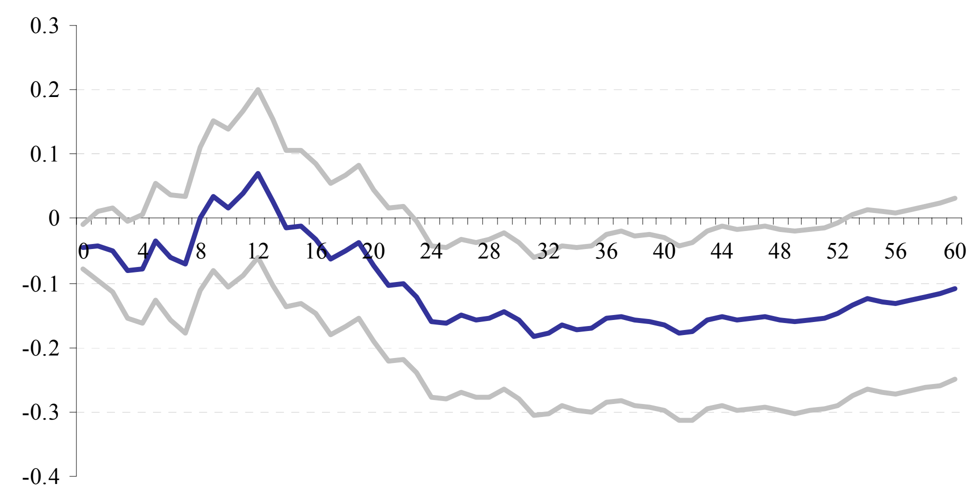
Notes: Bivariate VAR on the log of VIX (LVIX) and the real interest rate (RERA). Panel A presents lag-length selection results based on three criteria: Akaike (AIC), Hannan-Quinn (HQIC) and Schwarz (SBIC). The star indicates the lag chosen. Panel B presents Granger causality results for the model with 14 lags (selected by Akaike). Panel C presents Lagrange-multiplier specification tests for the model with 14 lags (selected by Akaike). The null hypothesis is that there is no autocorrelation at lag order j=1,2,3 and the degrees of freedom are given by the square of the number of equations in the VAR, as the test examines the null hypothesis that the residuals of lag j are not jointly significant in the VAR.

Figure 2: Orthogonalized reduced-form IRFs (LVIX, RERA)

Panel A: Impulse RERA, response LVIX

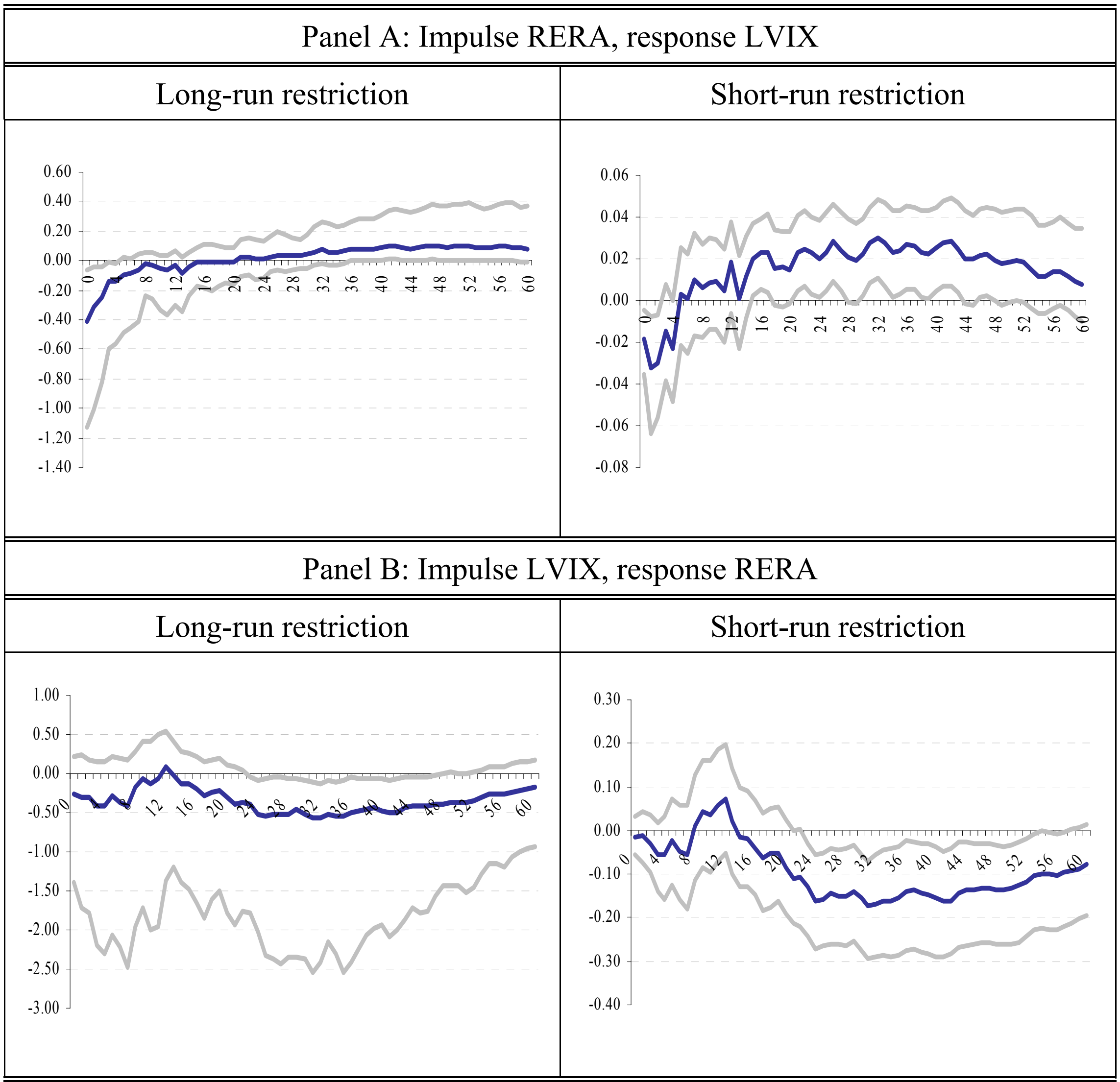


Panel B: Impulse LVIX, response RERA



Notes: Medians (blue lines) and 90% confidence intervals (grey lines) of the estimated orthogonalized IRFs for the model with 14 lags (selected by Akaike). Panel A presents the response of LVIX to a one standard deviation shock to RERA (order of variables in the VAR: RERA LVIX). Panel B presents the response of RERA to a one standard deviation shock to LVIX (order of variables in the VAR: LVIX RERA).

Figure 3: Structural-form IRFs (LVIX, RERA)



Notes: Medians (blue lines) and 90% bootstrapped confidence intervals (grey lines) of the distribution of the estimated structural impulse-response functions for the model with 14 lags (selected by Akaike), based on 1000 replications. Panel A presents the response of LVIX to a one standard deviation shock to RERA. Panel B presents the response of RERA to a one standard deviation shock to LVIX. Panels on the left present results of the model with the long-run restriction, panels on the right present results of the model with the short-run restriction.

Table 3: Robustness to monetary policy measures

MP instrument	Impulse MP, response LVIX		Impulse LVIX, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Real interest rate				
- reduced-form	+	15-17, 21-22, 25-27, 30-43	–	0 - 1, 3, 23 - 52
- structural LR	+	36 - 58	–	23 - 48
- structural SR	+	15 - 53	–	21 - 58
Taylor rule				
- reduced-form	+	5 - 44	–	22 - 26, 40 - 53
- structural LR	+	26 - 60	–	0 - 7, 17 - 54
- structural SR	+	9 - 10, 14 - 53	–	20 - 25, 30 - 32, 37 - 59
Fed funds Rate				
- reduced-form	+	19 - 30	–	3 - 18
- structural LR	+	22 - 29	–	--
- structural SR	+	15 - 37	–	4 - 14
M1 growth				
- reduced-form	–	5 - 32	+	--
- structural LR	–	5 - 34	+	--
- structural SR	–	--	+	--

Notes: Table 3 summarizes results for the real interest rate (RERA) and three alternative measures of the monetary policy stance: Taylor rule deviations (Taylor rule), Fed funds rate, and growth of the monetary aggregate M1. It lists for how many months impulse-response functions (from the reduced-form VAR, and the structural VARs with long-run and short-run restrictions, respectively) were statistically significant within the 90% confidence interval in the direction indicated in the column "sign".

Table 4: Four-variable VAR results (RA, RERA, LJOB, UC)

Panel A: Lag-length selection

lag	AIC	HQIC	SBIC
1	0.0555	0.1639*	0.3231*
2	0.0643	0.2810	0.5995
3	-0.0216*	0.3034	0.7812
4	-0.0088	0.4246	1.0617
5	0.0131	0.5548	1.3511
6	0.1223	0.7723	1.7279
7	0.1942	0.9526	2.0674
8	0.2652	1.1319	2.4060
9	0.2559	1.2310	2.6643
10	0.3212	1.4046	2.9973

Panel B: Granger causality

Equation	Excluded	chi2	df	p-value
RA	RERA	14.4460	3	0.0020
RA	LJOB	1.5888	3	0.6620
RA	UC	5.7468	3	0.1250
RA	ALL	24.8780	9	0.0030
RERA	RA	4.4763	3	0.2140
RERA	LJOB	13.7200	3	0.0030
RERA	UC	9.2123	3	0.0270
RERA	ALL	22.1440	9	0.0080
LJOB	RA	9.1933	3	0.0270
LJOB	RERA	6.4407	3	0.0920
LJOB	UC	5.5901	3	0.1330
LJOB	ALL	12.4980	9	0.1870
UC	RA	0.2420	3	0.9710
UC	RERA	4.6045	3	0.2030
UC	LJOB	0.9810	3	0.8060
UC	ALL	6.8800	9	0.6500

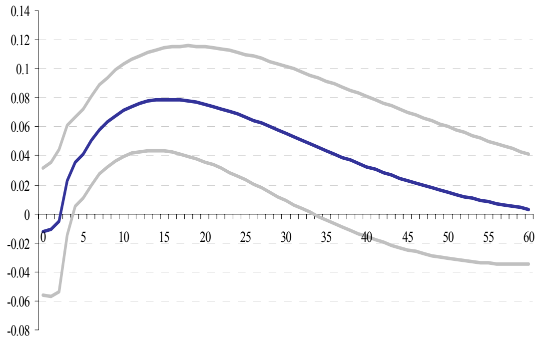
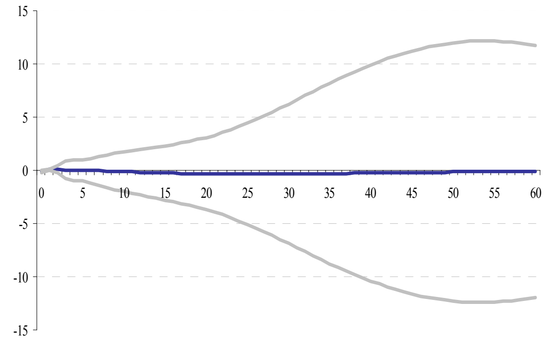
Panel C: Lagrange-multiplier test

lag	chi2	df	p-value
1	22.0339	16	0.1421
2	31.7639	16	0.0107
3	21.4902	16	0.1604

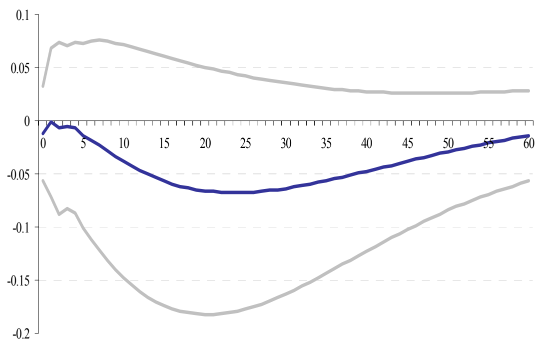
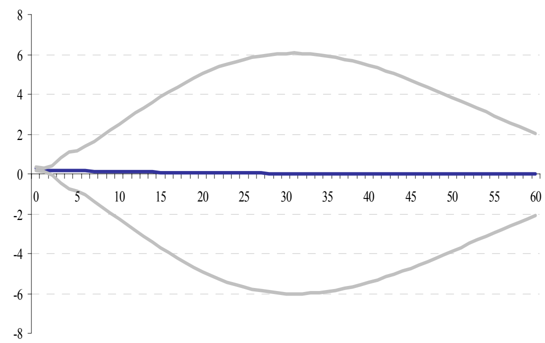
Notes: Four-variable VAR on the log of risk aversion (RA), the real interest rate (RERA), the log of jobless claims (LJOB) and the log of uncertainty (UC). Panel A presents lag-length selection results based on three criteria: Akaike (AIC), Hannan-Quinn (HQIC) and Schwarz (SBIC). The star indicates the lag chosen. Panel B presents Granger causality results for the model with 3 lags (selected by Akaike). Panel C presents Lagrange-multiplier specification tests for the model with 3 lags (selected by Akaike). The null hypothesis is that there is no autocorrelation at lag order j=1,2,3 and the degrees of freedom are given by the square of the number of equations in the VAR, as the test examines the null hypothesis that the residuals of lag j are not jointly significant in the VAR.

Figure 4: Orthogonalized reduced-form IRFs, RA RERA LJOB UC

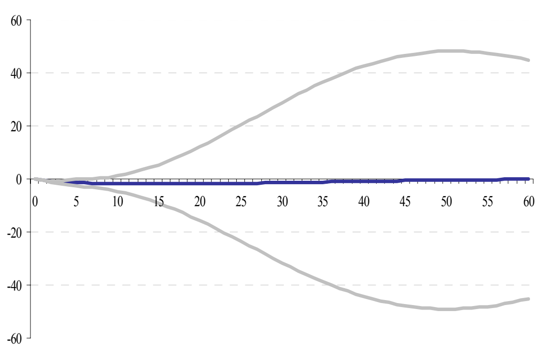
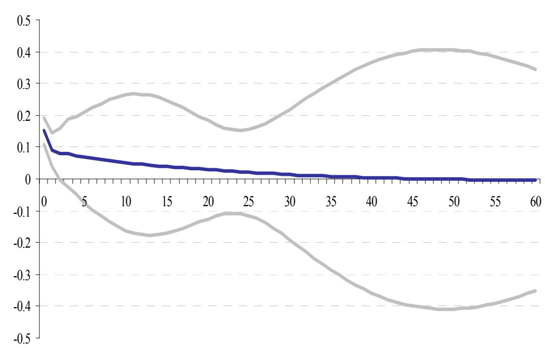
Panel A: Impulse RERA

Response RA	Response UC
	

Panel B: Impulse RA

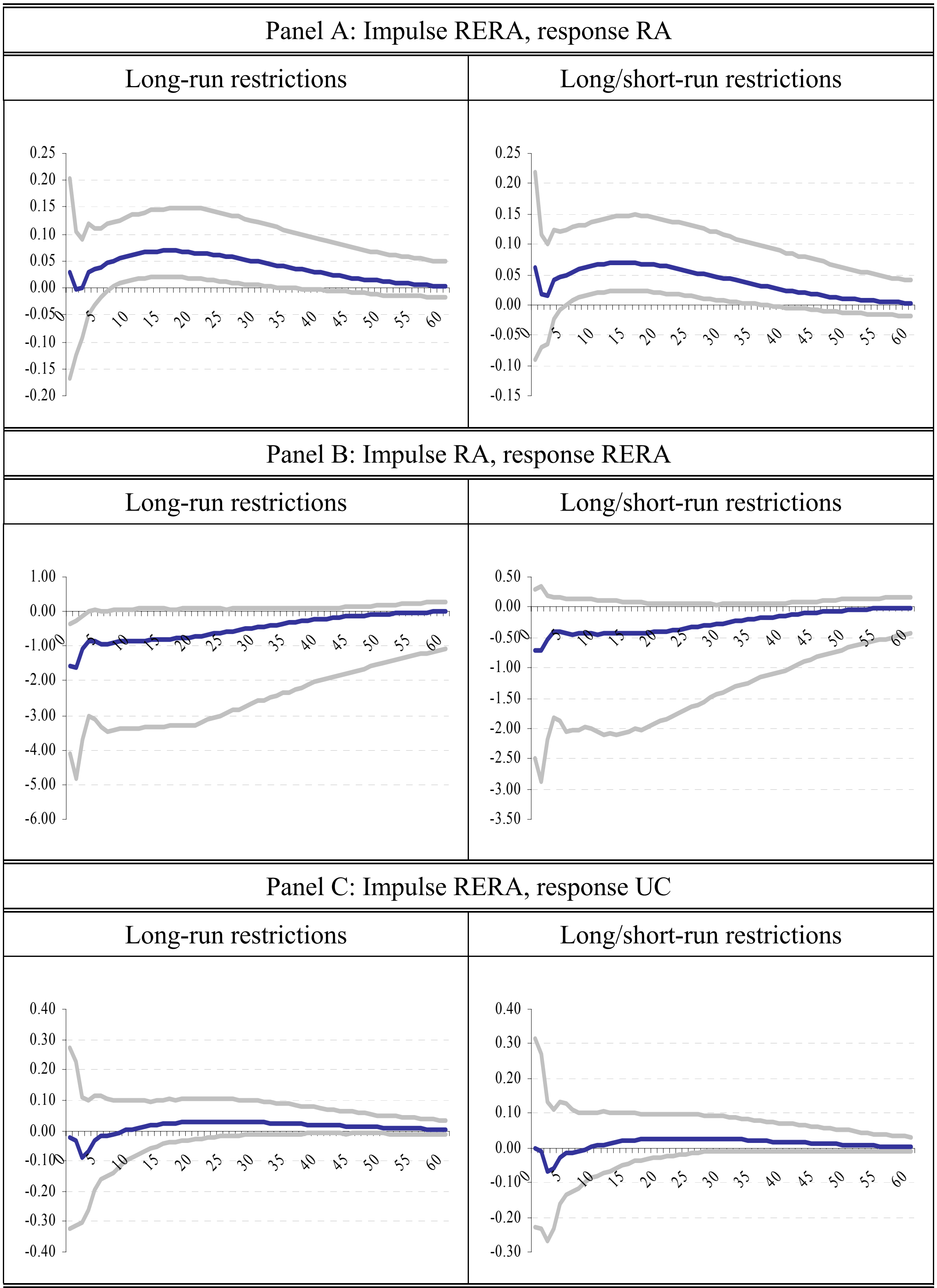
Response RERA	Response UC
	

Panel C: Impulse UC

Response RERA	Response RA
	

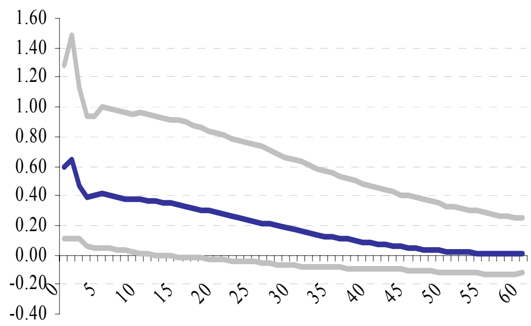
Notes: Medians (blue lines) and 90% confidence intervals (grey lines) of the estimated orthogonalized IRFs for the model with 3 lags (selected by Akaike), with impulse variable ordered first, response variable ordered second. Panel A presents the responses of RA and UC to a one standard deviation shock to RERA. Panel B presents the responses of RERA and UC to a one standard deviation shock to RA. Panel C presents the responses of RERA and RA to a one standard deviation shock to UC.

Figure 5: Structural-form IRFs for the 4-variable VAR (RA, RERA, LJOB, UC)

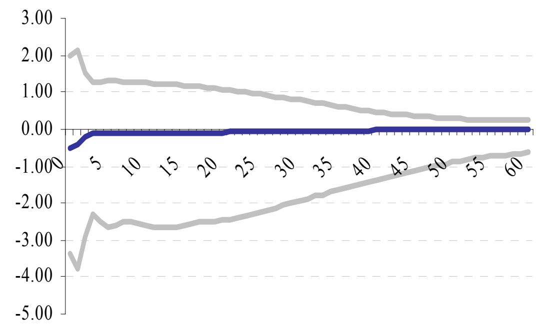


Panel D: Impulse UC, response RERA

Long-run restrictions

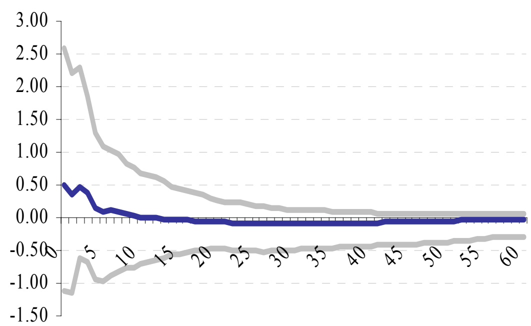


Long/short-run restrictions

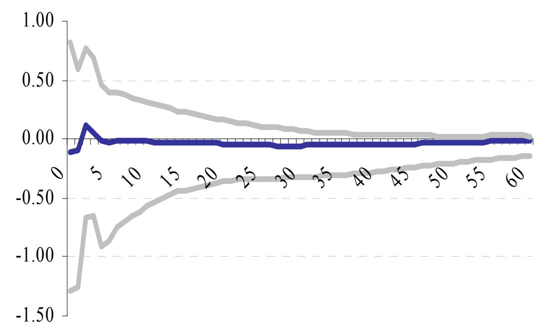


Panel E: Impulse RA, response UC

Long-run restrictions

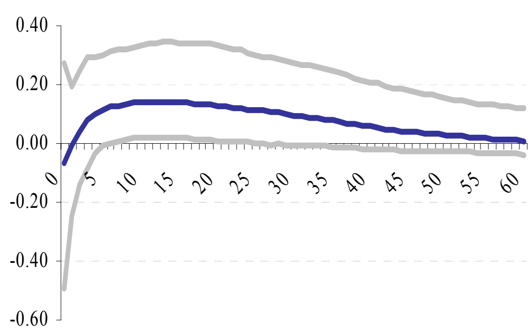


Long/short-run restrictions

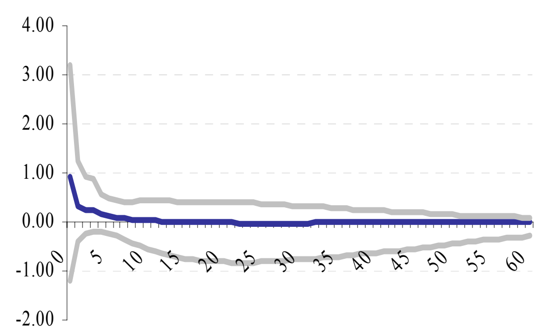


Panel F: Impulse UC, response RA

Long-run restrictions



Long/short-run restrictions



Medians (blue lines) and 90% bootstrapped confidence intervals (grey lines) of the distribution of the estimated structural impulse-response functions for the model with 3 lags (selected by Akaike), based on 1000 replications. Panels on the left present results of the model with long-run restrictions, panels on the right present results of the model with a combination of long- and short-run restrictions.

Table 6: Channels, real interest rate – risk aversion pair

Channel	Impulse RERA, response RA		Impulse RA, response RERA	
	sign	significant from-to (month)	sign	significant from-to (month)
Repo growth				
- reduced-form	+	4 – 43	–	--
- structural LR	+	6 – 26	–	0 – 13
- structural LSR	+	5 – 23	–	--
(M2-M1) growth				
- reduced-form	+	7 – 10, 14 – 43	–	22 – 27
- structural LR	+	7 – 35	–	0 – 19
- structural LSR	+	7 – 39	–	--
Credit growth				
- reduced-form	+	3 – 39	–	--
- structural LR	+	9 – 34	–	0 – 22
- structural LSR	+	8 – 35	–	--
Credit/GDP				
- reduced-form	+	3 – 38	–	--
- structural LR	+	9 – 29	–	0 – 19
- structural LSR	+	8 – 27	–	--

Notes: Table 6 summarizes results for the interaction between monetary policy (as represented by the real interest rate) and risk aversion (RA) in the four-variable model RA-MP-Channel-UC. The Table lists the corresponding Channel variable (left column) and for how many months impulse-response functions (from the reduced-form VAR, and the structural VAR with long-run and long/short-run restrictions, respectively) were statistically significant within the 90% confidence interval in the direction indicated in the column "sign".

Table 7: Channels, real interest rate - uncertainty pair

Channel	Impulse RERA, response UC		Impulse UC, response RERA	
	sign	significant from-to (month)	sign	significant from-to (month)
Repo growth				
- reduced-form	+	--	+	--
- structural LR	+	--	+	0 – 6
- structural LSR	+	--	+	0 – 1
(M2-M1) growth				
- reduced-form	+	0 – 1	+	0, 2
- structural LR	+	--	+	0 – 14
- structural LSR	+	26 – 34	+	0 – 23
Credit growth				
- reduced-form	+	--	+	--
- structural LR	+	--	+	0 – 13
- structural LSR	+	--	+	0 – 27
Credit/GDP				
- reduced-form	+	--	+	--
- structural LR	+	--	+	0 – 12
- structural LSR	+	--	+	0 – 22

Notes: Table 7 summarizes results for the interaction between monetary policy (as represented by the real interest rate) and uncertainty (UC) in the four-variable model RA-MP-Channel-UC. The Table lists the corresponding Channel variable (left column) and for how many months impulse-response functions (from the reduced-form VAR, and the structural VARs with long-run and long/short-run restrictions, respectively) were statistically significant within the 90% confidence interval in the direction indicated in the column “sign”.

Appendix

To ensure that our main results in the four-variable model, [RA, RERA, LJOB, UC]', are not sensitive to the identification scheme, we tried a large number of alternative schemes, even some that we do not necessarily view as economically palatable. Imposing restrictions gives rise to a system of non-linear equations, which we solved using both Gauss and Maple software. Our results are always consistent across the softwares, also for those cases for which we cannot prove uniqueness of the solution. Some schemes unfortunately did not yield a solution. Table 8 below provides the identifying restrictions on the left and summarizes main results on the right hand side. For completeness, we first list the long-run model and the long/short-run model we described in the main text. We then present other models we estimated, with long-run money neutrality always imposed.

Table 8: Estimated alternative identifying restrictions

Restrictions	Impulse-response	sign	significant from-to (month)
$\begin{bmatrix} d_{11} & 0 & 0 & 0 \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} & 0 & d_{33} & d_{34} \\ d_{41} & 0 & 0 & d_{44} \end{bmatrix}$	Impulse RERA, response RA	+	7 – 35
	Impulse RA, response RERA	–	0 – 2
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	0 – 11
$\begin{bmatrix} \phi_{11} & 0 & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & 0 & 0 & \phi_{44} \end{bmatrix}$	Impulse RERA, response RA	+	6 – 35
	Impulse RA, response RERA	–	--
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	--
$\begin{bmatrix} d_{11} & 0 & d_{13} & 0 \\ d_{21} & d_{22} & d_{23} & d_{24} \\ 0 & 0 & d_{33} & d_{34} \\ 0 & 0 & d_{43} & d_{44} \end{bmatrix}$	Impulse RERA, response RA	+	7 – 37
	Impulse RA, response RERA	–	0 – 32
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	--
$\begin{bmatrix} d_{11} & 0 & 0 & d_{14} \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} & 0 & d_{33} & d_{34} \\ 0 & 0 & 0 & d_{44} \end{bmatrix}$	Impulse RERA, response RA	+	8 – 35
	Impulse RA, response RERA	–	0 – 7
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	--

Restrictions	Impulse-response	sign	significant from-to (month)
$\begin{bmatrix} d_{11} & 0 & d_{13} & d_{14} \\ d_{21} & d_{22} & d_{23} & 0 \\ 0 & 0 & d_{33} & d_{34} \\ 0 & 0 & d_{43} & d_{44} \end{bmatrix}$	Impulse RERA, response RA	+	7 – 35
	Impulse RA, response RERA	–	0 – 32
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	--
$\begin{bmatrix} d_{11} & 0 & d_{13} & d_{14} \\ d_{21} & d_{22} & 0 & d_{24} \\ d_{31} & 0 & d_{33} & 0 \\ 0 & 0 & d_{43} & d_{44} \end{bmatrix}$	Impulse RERA, response RA	+	7 – 34
	Impulse RA, response RERA	–	--
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	0 – 24
$\begin{bmatrix} d_{11} & 0 & d_{13} & d_{14} \\ d_{21} & d_{22} & 0 & 0 \\ d_{31} & 0 & d_{33} & 0 \\ 0 & d_{42} & d_{43} & d_{44} \end{bmatrix}$	Impulse RERA, response RA	+	8 – 28
	Impulse RA, response RERA	–	0 – 7
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	--
$\begin{bmatrix} \phi_{11} & \phi_{12} & 0 & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & 0 & 0 & \phi_{44} \end{bmatrix}$	Impulse RERA, response RA	+	5 – 31
	Impulse RA, response RERA	–	0 – 1
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	--
$\begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ 0 & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & 0 & 0 & \phi_{44} \end{bmatrix}$	Impulse RERA, response RA	+	6 – 31
	Impulse RA, response RERA	–	--
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	--
$\begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & 0 \\ \phi_{41} & 0 & 0 & \phi_{44} \end{bmatrix}$	Impulse RERA, response RA	+	6 – 30
	Impulse RA, response RERA	–	0 – 9
	Impulse RERA, response UC	+	--
	Impulse UC, response RERA	+	--

Notes: Table 8 summarizes the main results for the interaction between monetary policy (as represented by the real interest rate, RERA), risk aversion (RA) and uncertainty (UC) in the four-variable model RA-RERA-LJOB-UC under various identification schemes. The Table lists the corresponding identification assumption for the structural VAR (left column) and for how many months impulse-response functions were statistically significant within the 90% confidence interval in the direction indicated in the column “sign”.

In Table 9, we list the schemes that did not yield a solution. Models with long-run restrictions are on the left hand side. Models combining the three long-run money neutrality restrictions with three short run restrictions are on the right hand side.

Table 9: Identifying restrictions that did not yield a solution

Long-run schemes (matrix D)	Long/short-run schemes (matrix Φ)
$\begin{bmatrix} d_{11} & 0 & 0 & 0 \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} & 0 & d_{33} & d_{34} \\ 0 & 0 & d_{43} & d_{44} \end{bmatrix}$	$\begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ 0 & 0 & 0 & \phi_{44} \end{bmatrix}$
$\begin{bmatrix} d_{11} & 0 & 0 & 0 \\ d_{21} & d_{22} & d_{23} & d_{24} \\ 0 & 0 & d_{33} & d_{34} \\ d_{41} & 0 & d_{43} & d_{44} \end{bmatrix}$	$\begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ 0 & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & 0 & 0 & \phi_{44} \end{bmatrix}$
$\begin{bmatrix} d_{11} & 0 & d_{13} & 0 \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} & 0 & d_{33} & d_{34} \\ 0 & 0 & 0 & d_{44} \end{bmatrix}$	$\begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & 0 & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & 0 & 0 & \phi_{44} \end{bmatrix}$
$\begin{bmatrix} d_{11} & 0 & d_{13} & d_{14} \\ d_{21} & d_{22} & d_{23} & d_{24} \\ 0 & 0 & d_{33} & 0 \\ d_{41} & 0 & 0 & d_{44} \end{bmatrix}$	$\begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & 0 \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & 0 & 0 & \phi_{44} \end{bmatrix}$
$\begin{bmatrix} d_{11} & 0 & d_{13} & d_{14} \\ 0 & d_{22} & d_{23} & d_{24} \\ 0 & 0 & d_{33} & d_{34} \\ 0 & 0 & d_{43} & d_{44} \end{bmatrix}$	$\begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ 0 & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ 0 & 0 & \phi_{43} & \phi_{44} \end{bmatrix}$