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Uncertainty shocks and policymakers' behavior: evidence from the subprime crisis era

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Abstract

Purpose – The purpose of this paper is to examine the effects of the 2007-2009 uncertainty shocks on policymakers' behavior.

Design/methodology/approach – Uncertainty shocks in the US credit, financial and production markets are represented by extraordinary events. As in Bloom (2009), these events are associated with significant economic and political shocks (e.g. Lehman Brothers' collapse). Credit markets uncertainty shocks, which played a crucial role in the aftermath of the house prices collapse in the USA, are first analyzed in a bivariate VAR context, and then, embodied in a simple theoretical framework.

Findings – The empirical evidence suggests that the US credit, financial and production markets have been affected by a relative large number of uncertainty shocks (i.e. rare events). In a Brainard's (1967) uncertainty scenario, it is shown that a bizarre money-liquidity relationship exacerbates the "policymakers' cautiousness-aggressiveness trade-off." In addition, the model suggests that a "double" dose of policy, in presence of a global credit crunch, might be useless.

Originality/value – This paper improves the existing literature in two main directions. First, it provides novel empirical evidence on the unusual dynamics of the US credit market and its effects on the real economic activity during the crisis. Second, in a very simple theoretical framework accounting for parameter uncertainty, it addresses whether a bizarre money-credit relationship affects policymakers' behavior (i.e. cautiousness vs aggressiveness).

Keywords Uncertainty, Financial and credit shocks, Lending activity, Policy effectiveness

Paper type Research paper

1. Introduction

The origin of the 2007-2009 global economic and financial panic can be traced back to a set of incentives that were introduced in the public policy stance to encourage and support a rapid expansion of credit[1]. It is also popularly known that the crisis was mainly driven by waves of successive external shocks over the short space of three years. It started with a drop in house prices in 2007 (caused by a set of naive tightening monetary policies)[2]. It was then strengthened by (i) spikes in food and energy prices in mid-2008; (ii) an unprecedented synchronized drop in international stock market indexes; and (iii) an unusual contraction in the retail, commercial and interbank lending activity in the aftermath of the Lehman's Chapter 11. Finally, it lasted more than expected due to a steep drop in international trade in 2009.

Still, a general and unique consensus on the real causes and mechanisms of the subprime crisis is missing. Differently from early arguments on the nature of this panic, more recent studies argue that the initial amount of subprime mortgages losses (i.e. $250 billion)[3] and the subsequent drop in stock market prices are not solely responsible for the unprecedented and synchronized collapse in the production of major

JEL Classification — E01, E41, E44, E52, E58, E61, G01, G15

industrialized economies (Blanchard, 2008; Cheung and Guichard, 2009; Claessens *et al.*, 2010; Perri and Quadrini, 2013; among others). As mentioned above, the crisis is rooted in a number of factors. While some of these are common to previous crisis (e.g. asset prices bubble, current account deficits), others are new (i.e. increased financial integration, balance sheet linkages, increased information flows, strong credit crunch). In particular, differently from past crises, the subprime crisis was characterized by a larger number of uncertainty shocks (or rare events) in the credit, production and stock markets (Bloom, 2009; Baker *et al.*, 2013; Donadelli, 2015)[4]. In particular, the 2007-2009 economic downturn was largely driven by an extraordinary stop in the retail, commercial and interbank lending activity (see Figures 3-8). We argue that this amplified the adverse effect of an early drop in the US house prices market[5]. This unprecedented scenario largely increased economic policy uncertainty (Bloom, 2009) as well as affected the effectiveness of expansionary policies (Aastveit *et al.*, 2013).

Based on this evidence, a large number of studies have started to examine the impact of uncertainty shocks on financial and real variables. Relatively little research, however have focussed on the effects of uncertainty shocks on policymakers' behavior. An exception is Aastveit *et al.* (2013) who address whether economic uncertainty alters the macroeconomic influence of monetary policy (i.e. policy effectiveness). We complement these studies by looking at the impact of unusual credit market conditions on the effectiveness of a policy in a Brainard's (1967) parameter uncertainty (hereinafter Brainard uncertainty) framework. In particular, in a simple theoretical context, we examine whether uncertainty shocks in the credit markets along with other uncertainty shocks influenced the behavior of the US policymakers (i.e. cautiousness vs aggressiveness). This paper improves the existing literature in two main directions. First, it provides novel empirical evidence on the unusual dynamics of the US credit market. For completeness an updated analysis on the dynamics of the US stock market volatility is developed. In doing so, we provide evidence on the overall amount of uncertainty in the subprime crisis era, which heavily influenced policymakers' actions. Second, it addresses whether unusual money and credit market conditions affect policymakers' decisions in a very simple theoretical framework.

We proceed as follows. First, we identify uncertainty shocks and unusual credit and money market conditions in the USA We study then their effects on industrial production and unemployment rate. On one side, our simple *ex-post* empirical analysis confirms that the 2007-2009 period was characterized by an unprecedented number of rare events in the US stock, credit and money markets. Our novel analysis, suggest that the usual "quantitative easing policy-liquidity relationship" broke in the aftermath of the subprime crisis (see Figures 4 and 5). On the other side, in line with other empirical and theoretical works examining the impact of volatility shocks (Bloom, 2009; Fernàndez-Villaverde *et al.*, 2011; Fernàndez-Villaverde *et al.*, 2012; Donadelli, 2015), we observe that both stock market volatility and credit market extraordinary events (i.e. 1/0 shock indicator) can have a sizable adverse effect on economic activity.

In this unusual environment, central banks do not have precise information about the real monetary transmission mechanism (Brainard, 1967; Blinder, 1997; Sack, 2000; Aastveit *et al.*, 2013). In other words, there is much more uncertainty about model's parameters (e.g. policymakers have no idea on the effects of a quantitative easing policy on output). We stress that, in line with "Brainard Uncertainty Principle," the presence of a relative large number of uncertainty shocks in the US credit, money and stock markets should bring policymakers (i.e. FED) to be extremely cautious. As discussed in Sack (2000), the Brainard's (1967) conservatism principle is also supported by data. Therefore,

parameter uncertainty and "cautiousness" can be useful to explain the behavior of the FED. However, as suggested by our empirical analysis, the standard benefits of a quantitative easing policy were affected by unusual credit market conditions. We stress that this partially offset the real benefits of the expansionary monetary policy. We add this extra phenomenon (i.e. credit crunch) in a two-country Brainard's uncertainty framework. In other words, we assume that the target (e.g. output) depends linearly on the domestic and foreign "money policy" as well as on an additional domestic and foreign instrument capturing "liquidity." On one side, as discussed in Brainard (1967), these additional instruments should bring the FED to be much more cautious. On the other side, the sign of the parameter attached to the credit component – driven by an extraordinary credit market scenario – might induce policymakers to be more aggressive. It turns out than an unusual credit market conditions exacerbate the "cautiousness-effectiveness trade-off." In other words, a bizarre money-liquidity relationship may affect the benefits of a quantitative easing policy. Overall, in this scenario, policymakers remain uncertain about a large number of parameter values. This might induce them to think about unconditional monetary policies.

The rest of the paper is organized as follows. Section 2 reviews the literature. Section 3 provides relevant stylized facts and re-examines the impact of "ad hoc" stock market volatility shocks on real economic activity. Section 4 studies credit market conditions in the USA during the crisis. Section 5, in a two country-two instrument version of Brainard, studies the "cautiousness-aggressiveness trade-off." Section 6 concludes and discusses policy implications.

2. Related literature
This paper is related to various strands of the literature. Most broadly, it relates to the literature on the effects of unprecedented financial and real variables' dynamics on real economic activity and political stability. Bloom (2009) first examined the impact of uncertainty shocks on real economic outcomes. By focussing on stock market volatility shocks, he finds that uncertainty tend to increase when economic and political shocks (e.g. 1st Gulf War, Asian Crisis, 9/11 terrorist attacks, Lehman Chapter 11) take place; a stock market volatility shock produces a rapid and statistically significant drop in industrial production and employment. In the spirit of Bloom (2009), Donadelli (2015) identifies uncertainty shocks in the US credit, production and stock markets in the post-Lehman era (i.e. January 2007-December 2011). The author examines then their effects on Asian stock market prices. Post-Lehman results suggest that uncertainty shocks produce a short-run drop in most Asian stock market prices. Following Bloom (2009), the effects of uncertainty shocks have been studied also in a Dynamic Stochastic General Equilibrium context. Fernàndez-Villaverde et al. (2011) study the real effects of real interest rate volatility shocks. They find that an increase in real interest rate volatility has a negative effect on real economic activity (i.e. it produces a drop in output, consumption and investment). In a similar setup, Fernàndez-Villaverde et al. (2012) examine the effects of fiscal volatility shocks (i.e. changes in uncertainty about future fiscal policy) on macroeconomic aggregates. They find that fiscal volatility shocks have sizable adverse effects on economic activity. Similarly, Leduc and Liu (2015) show that uncertainty shocks can be contractionary. They rely on an economy with frictions and flexible-prices.

Second, our paper relates to the literature on the implications of economic policy uncertainty. On the one side, this literature examines the impact of economic policy uncertainty on financial and real variables. Pastor and Veronesi (2013) find that shocks on political news tend to cause an increase in the equity risk premium. Other

works, have examined the impact of policy uncertainty on domestic economic outcomes (see e.g. Gomes *et al.*, 2012).

Johannsen (2013) observes that the adverse effects of fiscal policy uncertainty are very large if there are close to zero interest rates. This literature includes also recent empirical works examining the dynamics of the co-movement between equity market returns and changes in economic policy uncertainty (Antonakakis *et al.*, 2013; Donadelli and Persha, 2014).

Recently, Gauvin *et al.* (2014) examine whether macroeconomic policy uncertainty in advanced economies spills over to emerging markets via capital flows. They find that increased EU policy uncertainty pushes portfolio equity inflows into emerging markets. On the other side, it focuses on the effects of economic policy uncertainty on fiscal and monetary authorities' behavior. Early works, in a structural context, observe that political instability may be able to predict crisis (Bussière and Mulder, 1999). Therefore, policymakers must account for this extra source of risk. Most recently, Aastveit *et al.* (2013) examine whether economic uncertainty alters monetary policy effectiveness. They find that real economic activity, in presence of relatively high level of economic policy uncertainty, is less affected by standard monetary policy shocks. In other words, policy uncertainty tends to undermine policymakers' credibility.

Our paper is also connected to the recent literature aimed at examining the impact of changes in the US credit market conditions on real economic activity during the subprime crisis. This literature assumes that large changes in credit market conditions played a crucial role in the aftermath of the Lehman collapse, and represent central driver of cross-country business cycle fluctuations (Demyanyk and van Hemert, 2008; Baum *et al.*, 2009; Ivashina and Scharfstein, 2009; Claessens *et al.*, 2010; Perri and Quadrini, 2013).

Relative little research, however, has examined the effects of unprecedented credit/liquidity market conditions on policymakers' behavior (i.e. cautiousness vs aggressiveness) in a Brainard uncertainty framework. We aim to fill this gap. Therefore, our work is also related to Brainard (1967) who first showed that if there is uncertainty about the parameters of the model (e.g. uncertainty about the effects of an increase in the supply of money on output) then central banks should not behave as if the uncertainty does not exist. Differently from Brainard (1967), our static model accounts for an extra component (i.e. instrument) capturing credit/liquidity effects as well as for the effect of foreign policy instruments. Based on "Brainard Uncertainty Principle" this should increase the overall level of uncertainty, and thus, forces monetary authorities to be more cautious. However, our novel *ex-post* empirical analysis suggests that a bizarre money-credit relationship might imply aggressiveness.

3. Empirical evidence: re-examining the US stock market
This section provides first an updated analysis of the dynamics of the US stock market volatility over the last decades. In particular, we compare volatility in the pre- and post-subprime crisis eras. Second, it the spirit of Bloom (2009), we identify stock market volatility shocks and then study their effects on the US real economic activity. Overall, the analysis is aimed at capturing uncertainty shocks and their effects on macro aggregates, two aspects that are crucial for policymakers' strategies (i.e. economic policy uncertainty).

3.1 Data
We use the S&P 500 Composite Price Index and the CBOE SPX Volatility Index (VIX), to capture the US stock market price and volatility, respectively. Both series are

monthly and run from January 1990 to June 2011. It is worth noting that the VIX is often defined as a "fear index" because it spikes during market turmoil or periods of extreme economic policy uncertainty. In particular it has been observed that uncertainty increases as the number of economic and political shocks increase (Bloom, 2009; Antonakakis *et al.*, 2013; Donadelli and Persha, 2014). It turns out that uncertainty shocks in the US markets might increase parameter uncertainty, that is, it affects policymakers' actions. To capture real economic activity dynamics, we use the Industrial Production and Capacity Utilization Index and the Civilian Unemployment Rate. Both series are monthly and run from January 1990 to June 2011, and taken from FRED Economic Data (St. Louis FED).

3.2 Stylized facts

Figure 1 plots the dynamics of the S&P 500 Price Index and VIX. As in Bloom (2009) and Baker *et al.* (2013), we observe that big jumps in the level of stock market volatility are strictly related to significant economic and political shocks (e.g. Cuban missile crisis, the Franklin National Financial crisis, the Black Monday, the Gulf War and the terrorist attacks of 9/11). Needless to say, the Lehman Chapter 11 belongs to this class of shocks. However, it features different characteristics.

Usually, after these shocks, stock market volatility spikes and then quickly falls back. In fact, over previous periods characterized by economic and political shocks, volatility drops back to standard levels within three/four months (see gray vertical bars in Figure 1). In contrast, in the aftermath of the Lehman collapse, volatility lay at an unprecedented upper bound level for more than six months. Not surprisingly, over the post-Lehman sample (i.e. September 2008-March 2009) the average level of volatility is very high (i.e. 47.13). In contrast, in the pre-Lehman era (i.e. January 1990-August 2008) it is equal to 19.10 (see entries in Table I)[6].

3.3 Uncertainty shocks and real economic activity: a review

3.3.1. Methodology. To evaluate the impact of uncertainty shocks on real economic outcomes we estimate a range of bivariate VARs, based on monthly data running from
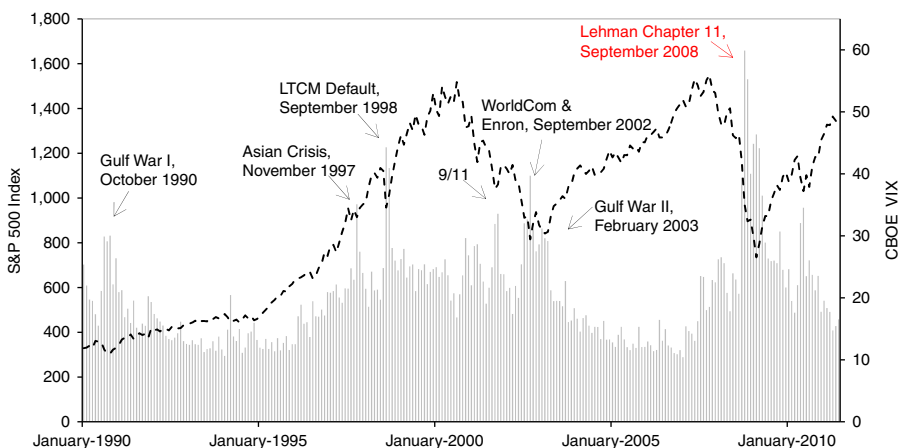

Figure 1.
S&P 500 index (left vertical axis) and monthly US stock market volatility (right vertical axis)

Notes: The dashed line represents the historical quotes of the S&P 500 Index and the vertical bars represent the VIX
Source: Datastream

January 1990 to June 2011. As in Bloom (2009), US stock market uncertainty shocks are represented by "ad hoc" indicators, which take value 1 if an extraordinary event occurs, and 0 otherwise. These extraordinary events are chosen as those with stock market volatility more than 1.65 standard deviations above the Hodrick-Prescott detrended mean of the VIX series. Formally:

$$Stock\ Vol\ Shock\ Index_t = \begin{cases} 1 & if \quad VIX_t > \overline{\mu}_{hp}^{VIX} + 1.65\ Sd^{VIX} \\ 0 & if \quad VIX_t < \overline{\mu}_{hp}^{VIX} + 1.65\ Sd^{VIX} \end{cases} \quad (1)$$

where $\overline{\mu}_{hp}^{VIX}$ is the Hodrick-Prescott detrended mean of the VIX series.

As suggested by Figure 1, some of these shocks occur in one month only and others span multiple months. We find that the Lehman shock spans multiple months. Specifically, the VIX is 1.65 standard deviations above the Hodrick-Prescott detrended mean of the VIX series in eight consecutive months.

We study the effects of uncertainty shocks on real economic fundamentals via a VAR analysis. A standard VAR(p, k) can be written as follows:

$$X_t = A_1 X_{t-1} + \ldots + A_k X_{t-k} + W_t \quad (2)$$

where $W_t \sim WN(0, \Omega)$. The $MA(\infty)$ representation requires $x_t = \sum_{j=0}^{+\infty} c_t W_{t-j}$, which holds under the usual assumptions. In general x_t is a vector $(p \cdot 1)$ and k represents the number of lags. In our bivariate world x_t is a (2.1) vector composed as follows:

$$x_t = [REV_t, Shock_t]$$

where REV_t is a variable representing the US real economic activity and $Shock_t$ represents an "ad hoc" created volatility shock indicator. In our empirical setup, REV_t is represented by industrial production index; civilian unemployment rate. Equation (2) can be re-written as follows:

$$\underbrace{\begin{bmatrix} REV_t \\ Shock_t \end{bmatrix}}_{X_t} = \underbrace{\begin{bmatrix} a_1 & c_1 \\ b_1 & d_1 \end{bmatrix}}_{A_1} \underbrace{\begin{bmatrix} REV_{t-1} \\ Shock_{t-1} \end{bmatrix}}_{X_{t-1}} + \ldots + \underbrace{\begin{bmatrix} a_k & c_k \\ b_k & d_k \end{bmatrix}}_{A_k} \underbrace{\begin{bmatrix} REV_{t-k} \\ Shock_{t-k} \end{bmatrix}}_{Xt-k} + \underbrace{\begin{bmatrix} {}^w REV_t \\ {}^w shock_t \end{bmatrix}}_{W_t}$$

$$(3)$$

Period	Chicago board of options exchange (CBOE): VIX average values
January 1990-June 2011 (full sample)	20.32
January 1990-August 2008 (pre-Lehman)	19.10
September 2008-March 2009 (post-Lehman "6 months")	47.13
April 2009-June 2011 (post-subprime crisis)	23.51
Source: Datastream	

Our VAR estimates are obtained via a robust standard error procedure (i.e. HAC). The number of lags k is chosen according to the BIC selection criterion. To conclude, we use a Cholesky decomposition as identification scheme.

3.3.2. Results. Figure 2 reports the impulse response functions of industrial production and unemployment rate to a stock market volatility shock (i.e. uncertainty shock). We observe that an innovation on the volatility shock indicator – a shock to (1) – affects both the log and the percentage change of the industrial production index as well as the log and the percentage change of the unemployment rate. As expected, the impact on the rate of change of the industrial production index is negative and the impact on the unemployment percentage change is positive[7]. In other words, rare events in stock market volatility have a negative effect on real economic activity.

## 4. Empirical evidence: the US credit market

This section examines changes in credit market dynamics as well as their effects on the real economic activity. First, we report stylized facts on the US credit market conditions during the subprime crisis. We rely on the consumer credit, loans and mortgages and interbank lending markets. We turn then our attention to the impact of consumer credit uncertainty shocks and tightening credit conditions on the industrial production and unemployment rate.

4.1 Data

We use the rate of change of the total consumer credit outstanding amount as proxy for the US retail credit market dynamics. The series is taken from the Federal Reserve and run from January 1960 to May 2011. We remind that this variable usually includes all purchases made via credit cards, lines of credits and loans. To capture the credit crunch, we also use two money aggregates. In particular, we analyze movements in the M2 Money Stock aggregate and Institutional Money Funds (i.e. M3). While the former captures quantitative easing policies, the latter measures the true value of liquidity in the economy. Both series are taken from FRED Economic Data (St. Louis FED). The Net Percentage of Banks Tightening Standards for C&I Loans to Large and Middle-Market Firms, the Net Percentage of Banks Tightening Standards for Commercial Real Estate Loans and the Net Percentage of Domestic Respondents Tightening Standards for Mortgage Prime Loans are then employed to describe the US loans and mortgages lending market activity. These are quarterly series taken form the US Federal Reserve Senior Loan Officer Opinion Survey. Finally, to capture the increase in the cost of credit in the interbank lending market, we use the spread between the three-month US LIBOR and the Three-Month Overnight Index Swap (OIS). For comparison purposes, we also use the EURIBOR-OIS spread. Both series are downloaded from Bloomberg. Data run from December 2001 to July 2011. Finally, to measure real economic activity, we use the industrial production index and the unemployment rate (as in Section 3), and the US Real Gross Domestic Product.

4.2 Stylized facts

4.2.1. Consumer credit vs money market. Figure 3 reports the variations of the US total consumer credit outstanding amount for the last 50 years. It is worth noting that the total consumer credit decreased by 8.5 percent (on annual basis) in November 2009. In the same month, revolving and non-revolving credit fell at an annual rate of 18.5 and 3.0 percent, respectively. Note also that the series displays 24 out of 34 negative monthly variations over the period August 2008-May 2011 (see red area in Figure 3).
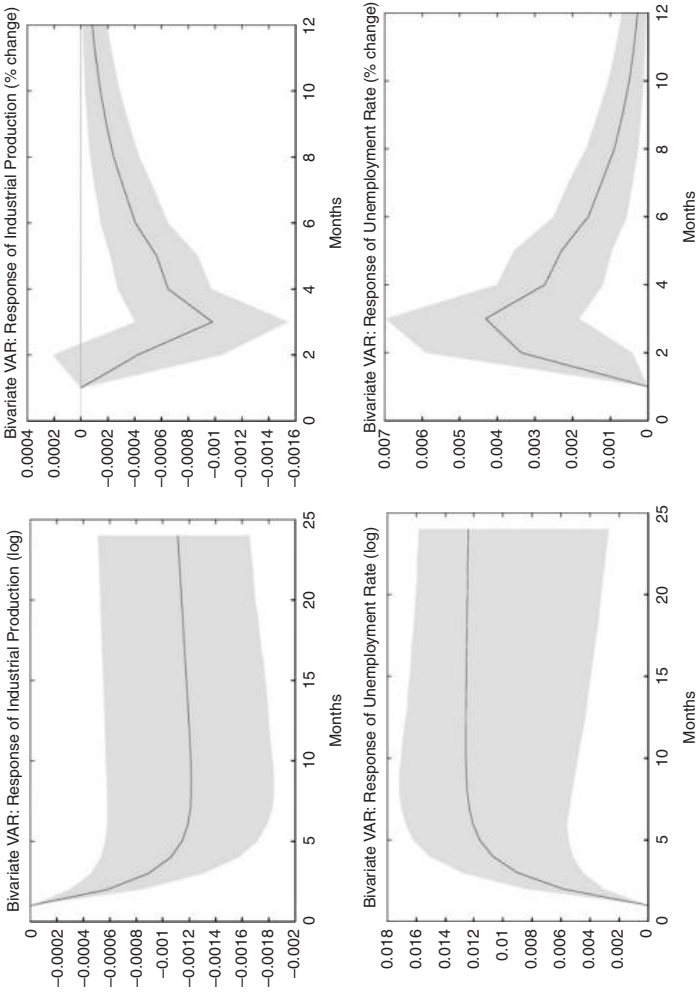
Notes: Impulse responses to stock market volatility shock one standard deviation in size, identified as
the 1/0 uncertainty shock indicators, ordered last in a Cholesky decomposition. The shaded area and
the black line represent 90 percent confidence band and point estimate, respectively. The bivariate
VAR is estimated including a constant. The BIC is used to select the number of lags. Standard errors
are computed using the Newey and West (1987) HAC procedure. Data are monthly and run from
1990:1 M to 2011:6 M
Source: FRED Economic Data (St. Louis FED) and Datastream

Figure 2.
The impact of
stock market
volatility shocks
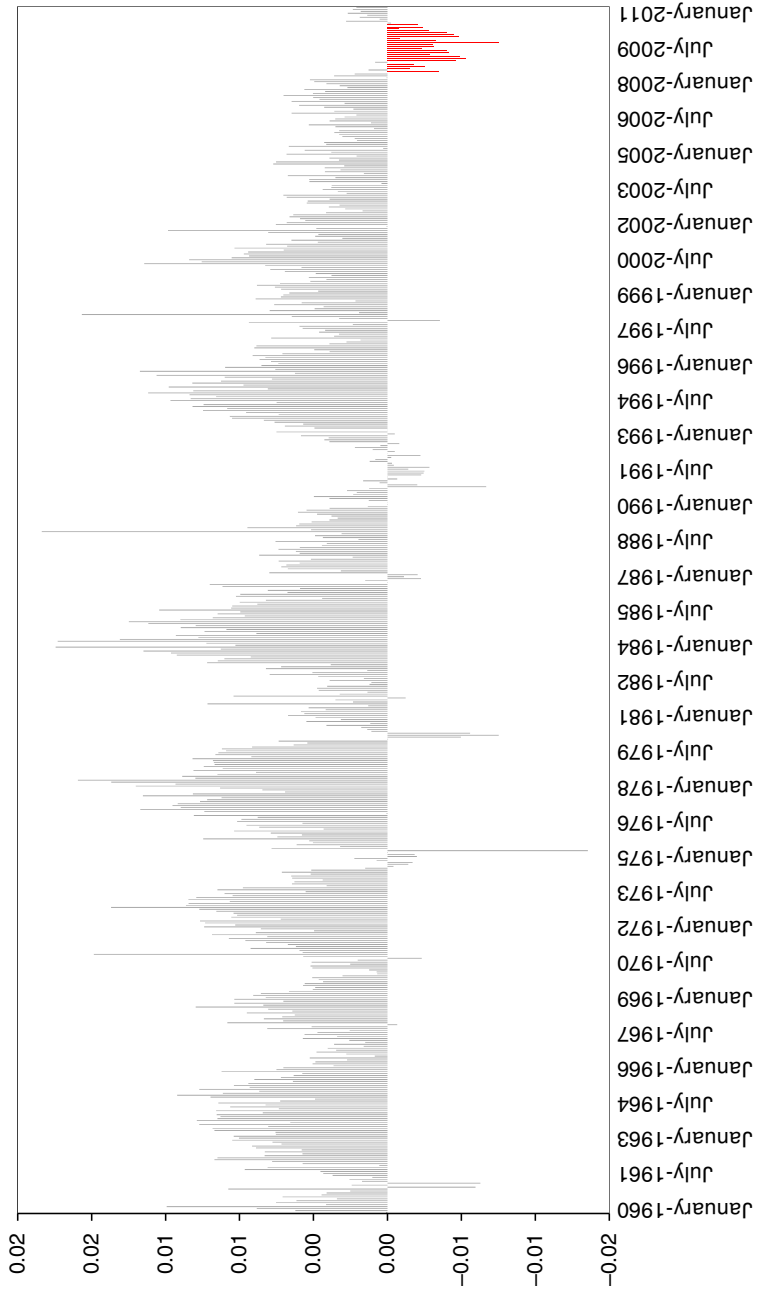
Figure 3.
Total
consumer credit
(percent changes)

It is largely accepted that good credit market conditions stimulate aggregate demand. Therefore, on historical basis, the correlation between changes in total consumer credit and changes in production is positive. Undergraduate macroeconomics books also suggest that an increase in the quantity of money in circulation should produce an increase in the aggregate demand (i.e. production) in the short-run. Table II reports the correlation coefficients between changes in total consumer credit, M2 money stock and industrial production (measured over different sub-periods). As expected, correlation coefficients between consumer credit and industrial production, money stock and industrial production, money stock and consumer credit are strictly positive over the full period January 1960-May 2011. Correlation coefficients remain strictly positive and close to one also over the period January 1960-May 2007. However, an analysis over the crisis period gives rise to counterintuitive results. In contrast to what suggested either by economic theory or by past empirical regularities, correlation coefficients between consumer credit and industrial production, and between money stock and industrial production are strictly negative over the pre-Lehman period (i.e. June 2007-September 2008), −0.71 and −0.78, respectively. We find also negative correlation coefficients between consumer credit and M2 over the following sub-periods: post-Lehman (September 2008-December 2009), post-crisis (January 2010-May 2011) and post-subprime (June 2007-May 2011).

This is also clear from Figure 4, which reports the cumulative rate of change of the consumer credit and M2 in the aftermath of the Lehman Chapter 11. On cumulative monthly basis, the consumer credit outstanding amount falls by 5.61 percent. This results from 24 consecutive negative changes. In contrast, the M2 money stock cumulatively increased by 14.72 percent. We stress that this differs from a standard scenario in which to an increase in the money stock level corresponds an increase in credit availability.

Further evidence on the presence of a credit crunch are provided by the dynamics of the institutional money funds (i.e. M3)[8]:

M3 is the best description of how quickly the Fed is creating new money and credit (Ron Paul).

In other words, M3 tracks what wealthy people are doing with their bucks. Figure 5 reports the rate of change of the M2 and institutional money funds series over the

| Period	Correlation: consumer credit and industrial production	Correlation: consumer credit and M2 money stock	Correlation: industrial prod. and M2 money stock
January 1960-May 2011 (full sample)	0.9507	0.9870	0.9399
January 1960-May 2007 (pre-crisis)	0.9614	0.9872	0.9720
June 2007-December 2009 (crisis)	0.1431	−0.0528	−0.9708
June 2007-September 2008 (pre-Lehman)	−0.7073	0.9882	−0.7827
September 2008-December 2009 (post-Lehman)	0.6699	−0.8180	−0.9350
January 2010-May 2011 (post-crisis)	−0.3014	−0.0208	0.9382
June 2007-May 2011 (post-subprime)	0.2226	−0.6107	−0.7315
Source: Federal Reserve and FRED Economic Data (St. Louis FED)			

Table II.
Consumer credit, industrial production and money stock: correlation values

Figure 4.
Consumer credit
and money stock
during the crisis
(on cumulative basis)
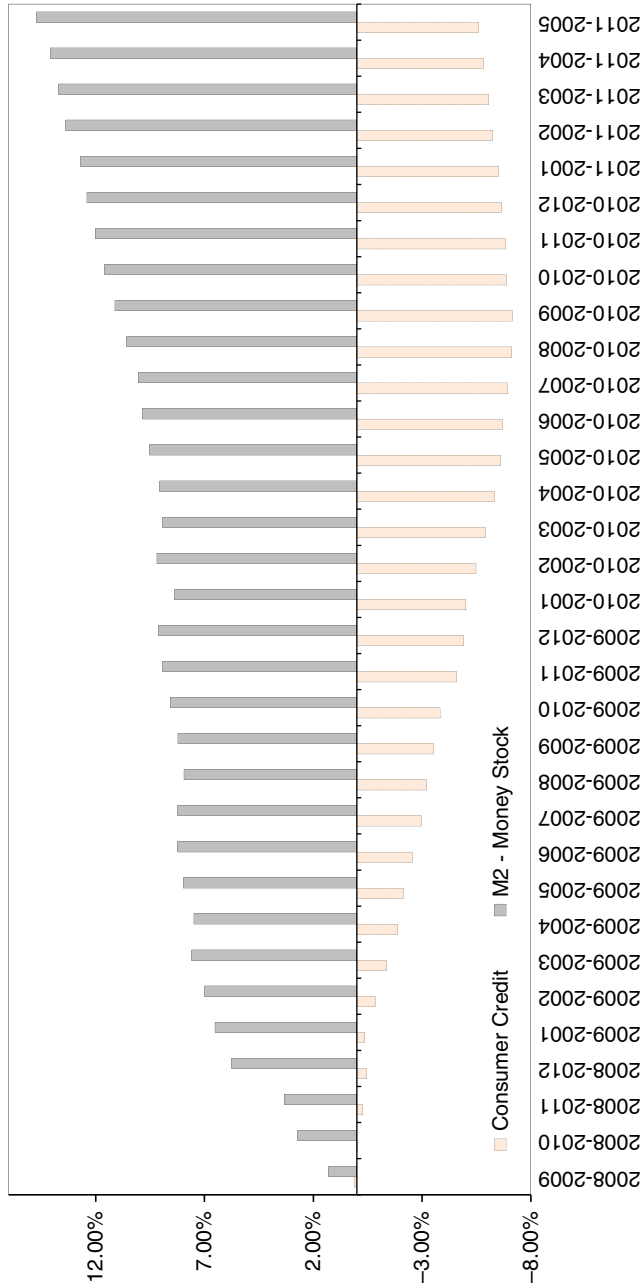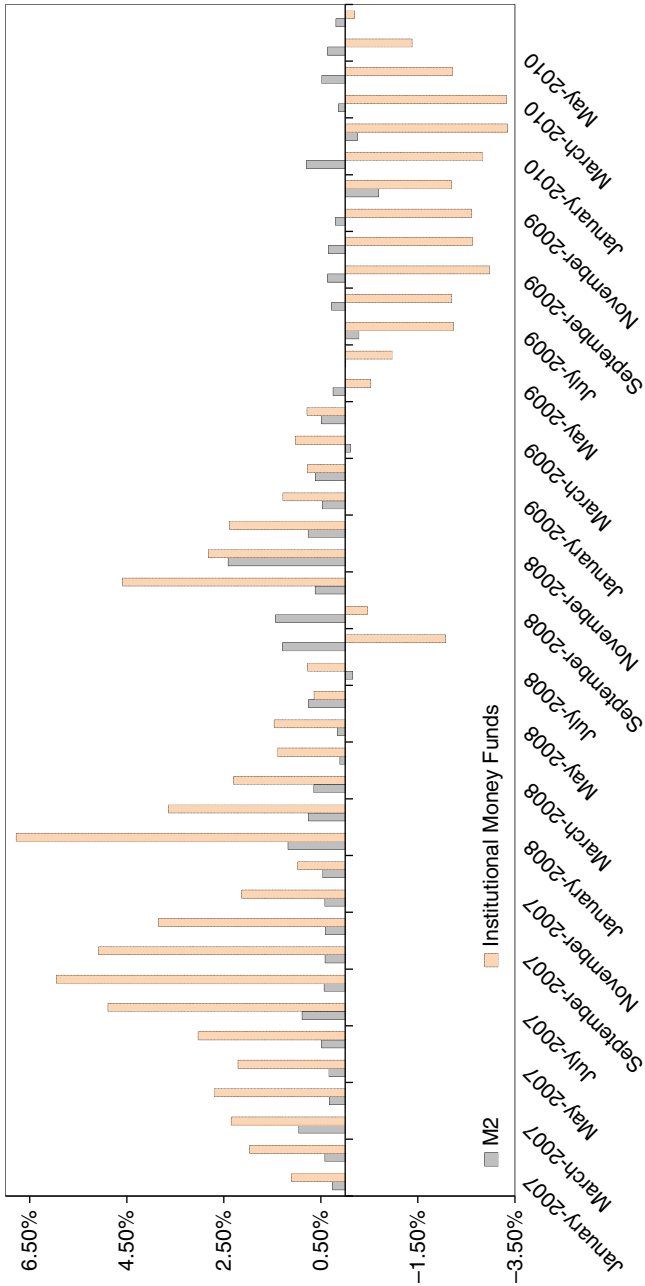
Source: FRED Economic Data (St. Louis FED)

Figure 5.
M2 money stock and
institutional money
funds (M3)

post-crisis period. In the aftermath of the Lehman collapse the rate of change of M3 is negative for 14 consecutive months. Therefore, in contrast to M1 and M2 money stock measures, M3 followed a declining path during the crisis suggesting that the Fed was unable to create a "liquid environment."
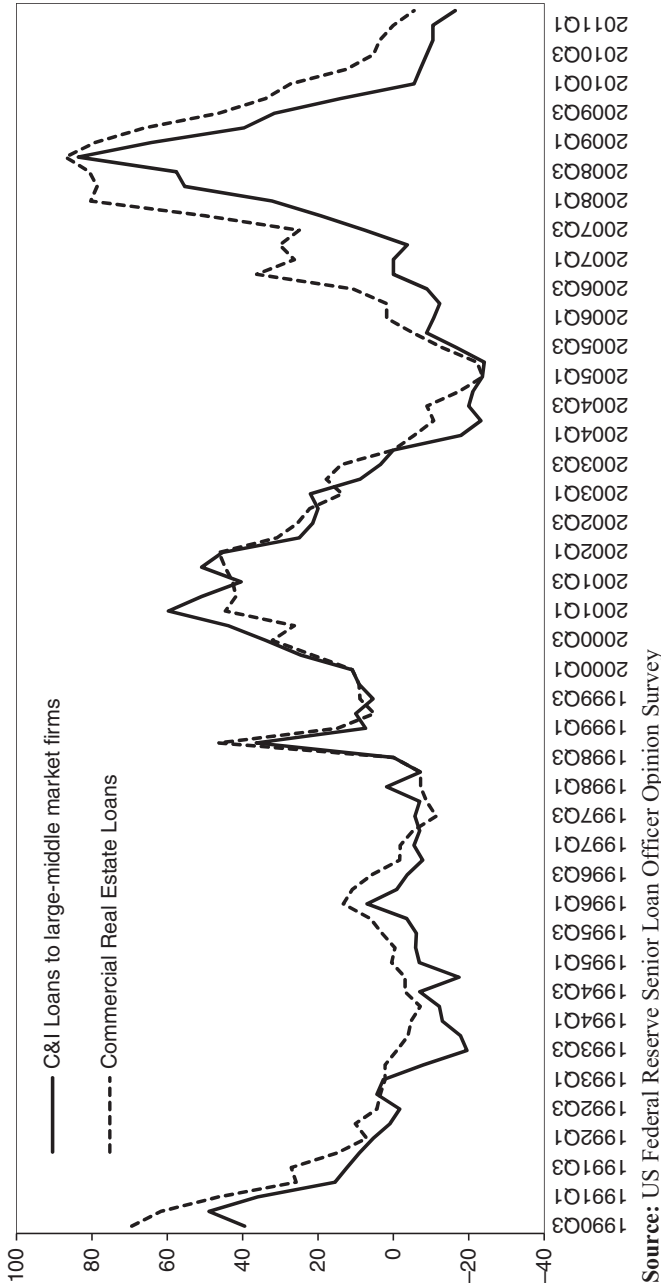
4.2.2. The US loans and mortgages markets. Figure 6 plots the net percentage of banks tightening standards for C&I loans to large and middle-market firms, and the net percentage of banks tightening standards for commercial real estate loans. Figure 7 reports the net percentage of domestic respondents tightening standards for mortgage prime loans. These series account for changes in commercial loans to firms, commercial real estate loans and mortgages availability, respectively. An increase in one of this series denotes tightening credit conditions. The pick reached by the series in the aftermath of the Lehman collapse represents the worst credit scenario since the 1990s, both for commercial and industrial to large-middle-market firms, and for commercial real estate loans. Based on dynamics in Figures 6 and 7, we can draw the following conclusions. First, the conditions of the commercial and industrial loans, and commercial real estate loans worsened during the crisis (i.e. from the third quarter of 2007 to the fourth quarter of 2008). Second, the mortgages prime loans market displays an unprecedented drop in the last two quarters of 2008.

4.2.3. The interbank lending market. The crisis became more severe in the late summer of 2007 when the interbank interest rates (LIBOR-OIS spread) rose dramatically. The LIBOR-OIS spread accounts for the amount of perceived credit risk in the interbank lending market. Normally, when the central banks lower their reference interest rates, both the LIBOR and the OIS rates decline with it. However, when banks are unsure of the creditworthiness of other banks, they charge higher interest rates to compensate them for the greater risk. Therefore, the LIBOR-OIS spread represents a measure of financial stress. Since loans might be LIBOR-indexed, a high spreads affect the real economic benefits of a quantitative easing policy.

Figure 8 reports the dynamics of the LIBOR-OIS and EURIOBOR-OIS spreads over the period 2001-2011[9]. Both spreads spiked more than once during the crisis. In the pre-crisis era the average spread was around ten basis points (bps). As of September 2007, the Bank of England announced emergency funding to rescue the Northern Rock. This produced a steep increase in the spread, which jumped to 85 bps. On March 17, 2008, the collapse of Bear Stearns led to an 83 bps spread, a 19 bps increase from the previous trading day. In the aftermath of the Lehman Brothers' collapse, the implementation of the TARP, produced an unprecedented increase in the spread, which jumped to 365 bps (as of October 10, 2008). As a consequence, the interbank lending activity both in the USA and Europe collapsed. In other words, banks with excess funds stopped to lend to banks needing funds. In this scenario, banks tend to hold a larger amount of cash to avoid credit risk. Therefore, banks lend less both to other banks and consumers generating a global liquidity drop, which lowers aggregate demand[10].

4.3 On the effects of credit shocks
4.3.1. Methodology. As in Section 3, we estimate the impact of changes in credit market conditions via a bivariate VAR. Therefore, via the model defined in Equation (3), we analyze the effects of consumer credit uncertainty shocks (i.e. credit shock index) on real economic activity; the effects of tightening credit market conditions on real economic activity. In line with Section 3, the industrial production index and civilian

Source: US Federal Reserve Senior Loan Officer Opinion Survey

Figure 6.
Net percentage of
banks tightening
standards for C&I
loans to large and
middle-market firms
and net percentage
of banks tightening
standards for
commercial real
estate loans

592
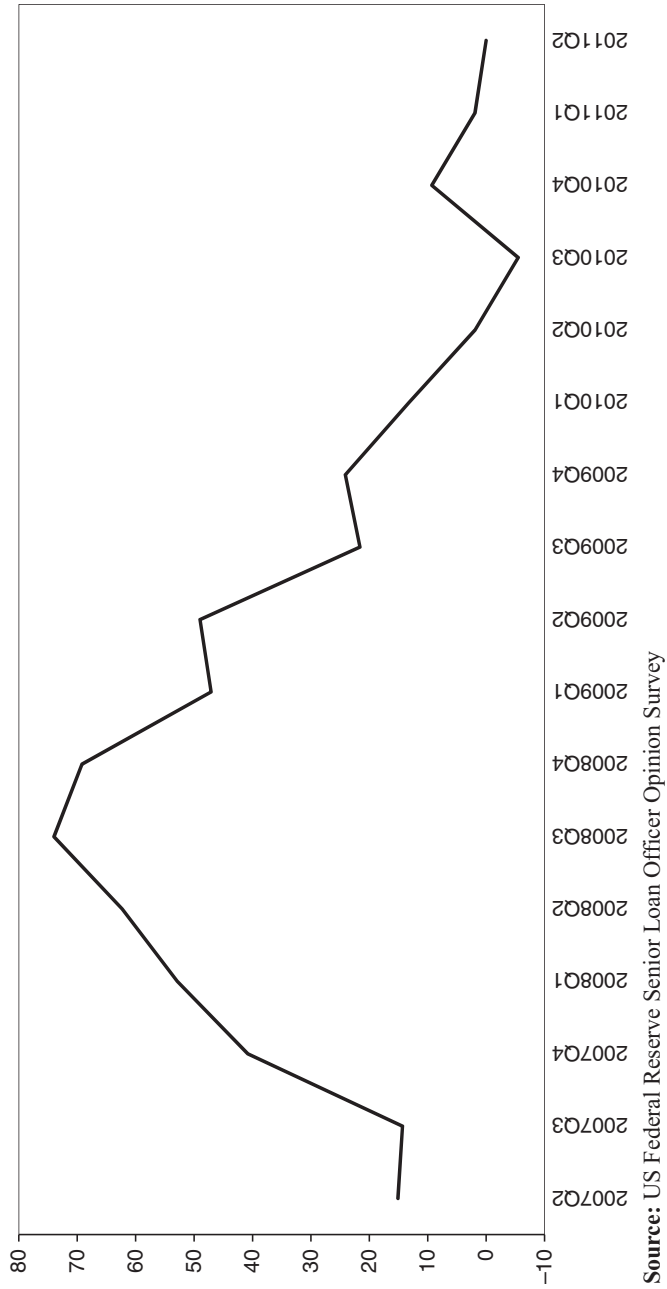
Figure 7.
US net percentage of
domestic
respondents
tightening standards
for mortgage prime
loans

Source: US Federal Reserve Senior Loan Officer Opinion Survey
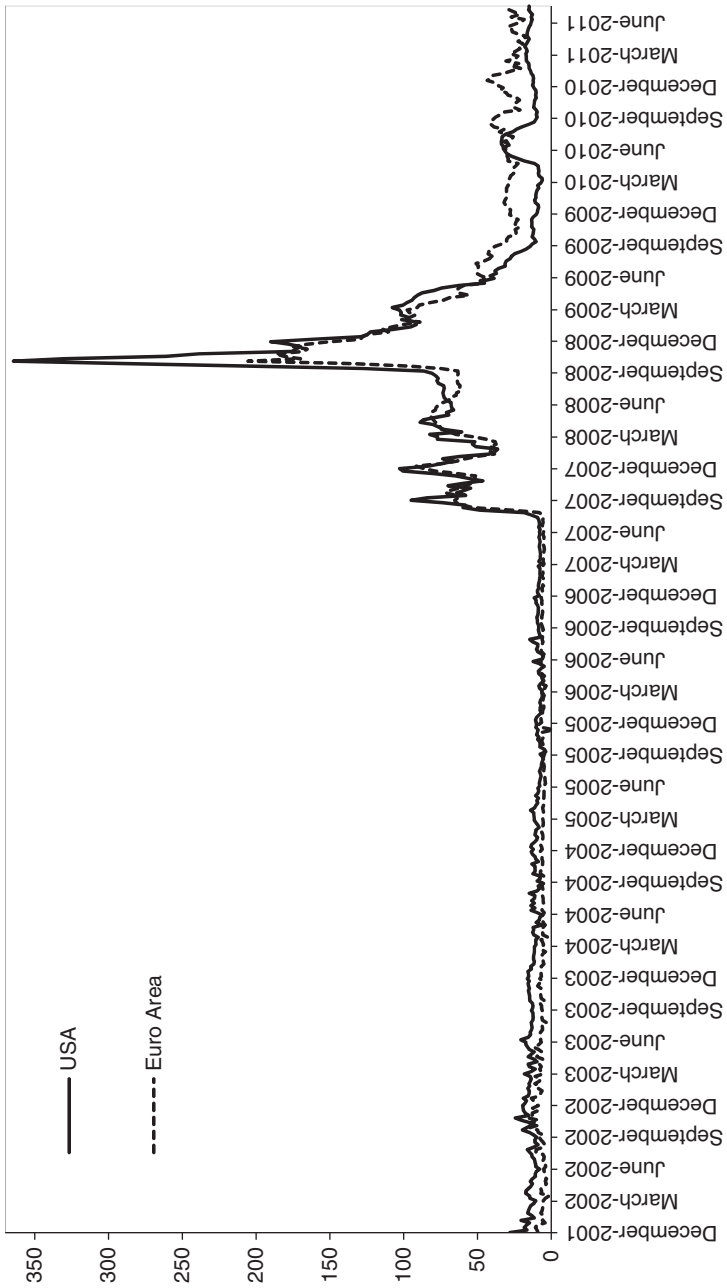
Source: Bloomberg

unemployment rate capture real economic activity, REV_t. Differently, $Shock_t$ is first identified by a novel credit market shock indicator (i.e. credit shock index), and then, by tightening credit market conditions (i.e. shock to the net percentage of domestic respondents tightening standards for C&I loans). To construct our novel credit shock index, we replicate the procedure developed for the construction of the VIX shock indicator. Therefore, the index takes a value of 1 if an extreme event occurs and 0 otherwise. These extreme events are chosen as those with consumer credit growth rate less than 1.65 standard deviations below the Hodrick-Prescott detrended mean of the credit growth rate series. Formally:

$$Credit\ Shock\ Index_t = \begin{cases} 1 & if \quad Credit_t < \mu_{hp}^{Credit} - 1.65\ Sd^{Credit} \\ 0 & if \quad Credit_t < \overline{\mu}_{hp}^{Credit} - 1.65\ Sd^{Credit} \end{cases} \tag{4}$$

where $\overline{\mu}_{hp}^{Credit}$ is the Hodrick-Prescott detrended mean of the consumer credit series.

4.3.2. *Results*. For the full sample (i.e. January 1990-June 2011), we find that the total consumer credit growth rate is 1.65 standard deviations below the Hodrick-Prescott detrended mean in 30 different months. From January 2007 to June 2011 the consumer credit growth rate is below the threshold in 21 out of 30 months. As expected, uncertainty shocks in the consumer credit market tend to take place when financial markets are highly volatile.

Figure 9 reports the impulse response functions of the logs and percentage changes of the industrial production and unemployment rate to a consumer credit shock indicator innovation. Since log series are non-stationary, the industrial production and the unemployment rate responses to credit innovations are protracted (see left panel of Figure 9). The industrial production growth rate rapidly falls within two months (see top-right panel of Figure 9). This response is statistically significant up to three months. We obtain a similar response (with opposite sign) for the unemployment growth rate (see bottom-right panel of Figure 9). Overall, our results suggest that credit market uncertainty shocks can have sizable adverse effects on economic performance.

Figure 10 reports the responses of the real GDP (percentage change) and the unemployment rate (log) to a shock in credit conditions, identified as the innovation in the net percentage of domestic respondents tightening standards for C&I loans. Main results are as follows. First, the US Real GDP growth rate reacts negatively to an innovation in the credit conditions. The negative impact is statistically significant up to 12 quarters after the shock. Second, the response of the unemployment rate is positive and statistically significant up to 14 quarters. This further confirms that tightening credit conditions heavily affect real economic activity.

5. A framework to analyze central banks' behavior in presence of unusual money and credit market conditions

The evidence provided so far shows that the subprime crisis era is characterized by a large number of uncertainty shocks, especially in the credit market, and a high level of economic policy uncertainty. In this scenario, central banks have less information about the structure of the economy they are attempting to control. In particular, there may be an extraordinary high level of uncertainty about the parameter of the model. As largely known, uncertainty makes monetary authorities more conservative in the sense that they prefer to determine the appropriate policy response ignoring
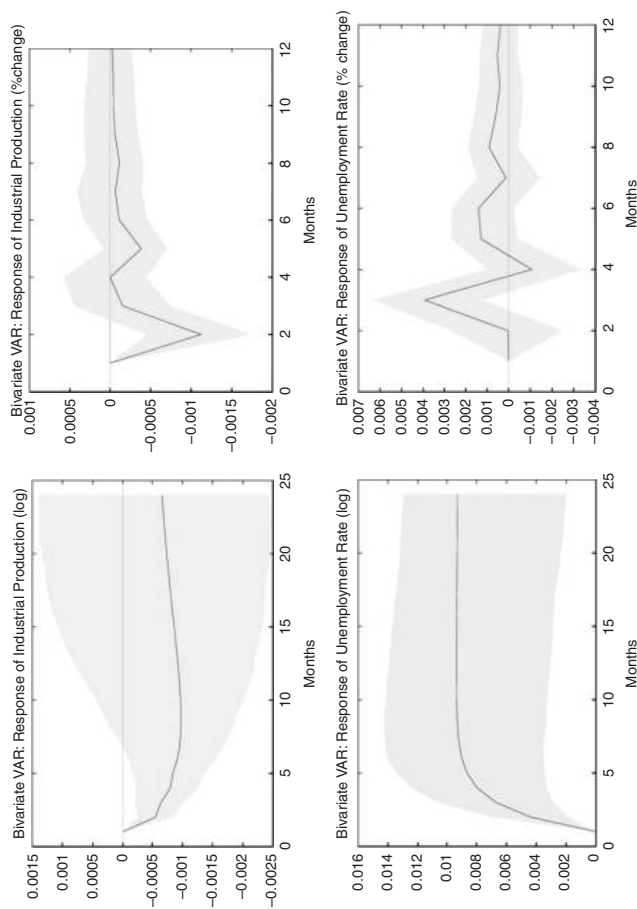
Notes: Impulse responses to consumer credit market (negative) shock one standard deviation
in size, identified as the 1/0 uncertainty shock indicators, ordered last in a Cholesky
decomposition. The shaded area and the black line represent 90 percent confidence band and
point estimate, respectively. The bivariate VAR is estimated including a constant. The BIC is
used to select the number of lags. Standard errors are computed using the Newey and West
(1987) HAC procedure. Data are monthly and run from 1990:1M to 2011:6M
Source: FRED Economic Data (St. Louis FED) and Datastream

Figure 9.
The impact of
consumer credit
uncertainty shocks
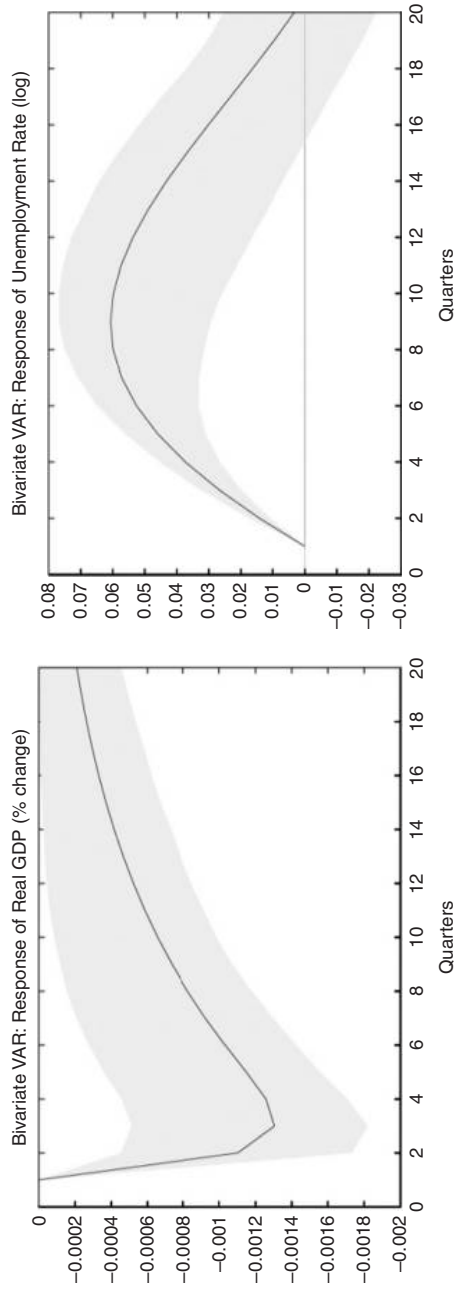
Notes: Impulse responses to a credit conditions shock one standard deviation in size, identified as the innovation in the net percentage of domestic respondents tightening standards for C&I loans, ordered last in a Cholesky decomposition. The shaded area and the black line represent 90 percent confidence band and point estimate, respectively. The bivariate VAR is estimated including a constant. The BIC is used to select the number of lags. Standard errors are computed using the Newey & West (1987) HAC procedure. Data are quarterly and run from 1990:2Q to 2011:1Q. The quarterly series on UNRATE is calculated as quarterly averages of monthly data

Source: FRED Economic Data (St. Louis FED) and Senior Loan Officer Opinion Survey on Bank Lending Practices

Figure 10.
The impact of
tightening credit
conditions

uncertainty, thus, "doing less" (Brainard, 1967). Blinder (1995) argues that the presence of uncertainty can have important implications for policy[11]. For this reason, policymaker should be more cautious. Brainard (1967) develops a model of policy implementation in which the policy maker is uncertain about the impact of the policy instrument on the economy. In a single one target-one policy instrument environment, he shows that optimal policy is a function of both the first and second central moments of the response coefficients. In other words, this type of uncertainty limits movements of the policy instrument away from the level at which policymakers are most certain about its effect. Brainard (1967) claims that, in response to uncertainty about the parameter on a variable, policymakers should attenuate their policy response to movements in that variable. If n instruments are considered (i.e. uncertainty about n parameters), then the implementation of policies requires additional prudence. In this section, we consider two main departures from Brainard's (1967) benchmark model: we abstract from a close economy; and, we account for credit/liquidity market restrictions.

5.1 Case I: a benchmark model

For illustration purposes, we first introduce a two-country model with no parameter uncertainty. Countries are interested in maximizing their respective policy functions. Suppose that the policymaker of the domestic country and the policymaker of the foreign country are concerned respectively with the following target variables (y) and (y^*). Assume that (y) and (y^*) depend linearly on P and P^* policy instruments. The impact of the exogenous variables may be summarized in a single variable, u for (y) and z for (y^*). Formally:

$$y = \alpha P + \beta P^* + u$$

$$y^* = \alpha^* P^* + \beta^* P + z \tag{5}$$

For example, Equation (5) describes a policy mechanism in which domestic output y is determined by money stock P through the known coefficient α, and by the indirect foreign policy P^* through the known coefficient β. Similarly, foreign output Y^* is determined by money stock P^* through the know coefficient α^*, and by the indirect domestic policy P through the known coefficient β^*. u and z are i.i.d. error terms with mean zero and variance σ_u^2 and σ_z^2.

Authorities are assumed to have a quadratic loss function (6), which penalizes the deviation of output from a target level:

$$L = E\left[(y - \bar{y})^2\right]$$

$$L^* = E\left[\left(y^* - \bar{y}^*\right)^2\right] \tag{6}$$

Substituting (5) into (6) we can re-write our loss functions as follows:

$$L = E\left[\left(\alpha P + \beta P^* + u - \bar{y}\right)^2\right]$$

$$L^* = E\left[\left(\alpha^* P^* + \beta^* P + z - \bar{y}^*\right)^2\right] \tag{7}$$

In this setup the expectation operator only continues to apply to terms in u and z because α, β, α^*, β^*, P, P^*, $\bar{y}$ and $\bar{y}^*$ are all known by the central banks at the time the

decision is taken[12]. Note also that $E(u^2) = \sigma_u^2$, $E(z^2) = \sigma_z^2$ and $E(u) = 0$, $E(z) = 0$. Then, the expected losses in (7) can be expressed as follows:

$$L = \alpha^2 P^2 + \alpha\beta PP^* - \alpha P\bar{y} + \alpha\beta PP^* + \beta P^{*2} - \beta P^* \bar{y} + \sigma_u^2 - \alpha P\bar{y} - \beta P^* \bar{y} + \bar{y}^2$$

$$L^* = \alpha^{*2} P^{*2} + \alpha^* \beta^* PP^* - \alpha^* P^* \bar{y} + \alpha^* \beta^* PP^* + \beta^{*2} P^2 - \beta^* P\bar{y}$$

$$+ \sigma_z^2 - \alpha^* P^* \bar{y} - \beta^* P\bar{y} + \bar{y}^{*2} \tag{8}$$

The central banks chooses policies P and P^* to minimize the expected loss. Then, optimal policies under certainty equivalence take the following form:

$$P = \frac{\bar{y}}{\alpha} - \frac{\beta}{\alpha} P^*$$

$$P^* = \frac{\bar{y}^*}{\alpha^*} - \frac{\beta^*}{\alpha^*} P$$

Both polices are completely independent of the uncertainty surrounding the error terms u and z[13]. Therefore, central banks have completely ignored uncertainty and set policies such that the output target is met in expectation (i.e. $E(y) = \bar{y}$, $E(y^*) = \bar{y}^*$).

5.2 Case II: a model with "credit policy" and "parameter uncertainty"

We assume now that there is uncertainty about the parameters of the model. Thus, we care about vagueness about the effects of policy changes. In addition, we assume that output is a linear function of both domestic and foreign money- and credit-polices[14]. This implies that authorities can use another instrument to stimulate the economy. Formally, our policy-equations can be written as follows:

$$y = \alpha_1 P_1 + \alpha_2 P_2 + \beta_1 P_1^* + \beta_2 P_2^* + u$$

$$y = \alpha_1^* P_1^* + \alpha_2^* P_2^* + \beta_1^* P_1 + \beta_2^* P_2 + z \tag{9}$$

where the sources of uncertainty are represented by $\{a_1, a_2, \beta_1, \beta_2, \alpha_1^*, \alpha_2^*, \beta_1^*, \beta_2^*\}$ (i.e. the response coefficients of targets (y) and (y^*) to policy actions) and $\{u, z\}$. In this setup, the policymaker is uncertain about the impact of the exogenous variables u and z, and uncertain about the response of y to any given domestic and foreign policy action. In other words, response coefficients uncertainty is introduced by assuming that policymakers view the multiplier as a random variable. Using standard statistical properties, the total variance for our two structural equations (y) and (y^*) takes the following form[15]:

$$\sigma_y^2 = \sigma_{\alpha_1}^2 P_1^2 + \sigma_{\alpha_2}^2 P_2^2 + \sigma_{\beta_1}^2 P_1^{*2} + \sigma_{\beta_2}^2 P_2^{*2} + \sigma_u^2 + 2\rho_{\alpha_1, \alpha_2} \sigma_{\alpha_1} \sigma_{\alpha_2} P_1 P_2$$

$$+ 2\rho_{\alpha_1, \beta_1} \sigma_{\alpha_1} \sigma_{\beta_1} P_1 P_1^* + 2\rho_{\alpha_1, \beta_2} \sigma_{\alpha_1} \sigma_{\beta_2} P_1 P_2^* + 2\rho_{\alpha_2, \beta_1} \sigma_{\alpha_2} \sigma_{\beta_1} P_2 P_1^*$$

$$+ 2\rho_{\alpha_2, \beta_2} \sigma_{\alpha_2} \sigma_{\beta_2} P_2 P_2^* + 2\rho_{\beta_1, \beta_2} \sigma_{\beta_1} \sigma_{\beta_2} P_1^* P_2^*$$

$$\sigma_y^{*2} = \sigma_{\alpha_1^*}^2 P_1^{*2} + \sigma_{\alpha_2^*}^2 P_2^{*2} + \sigma_{\beta_1^*}^2 P_1^2 + \sigma_{\beta_2^*}^2 P_2^2 + \sigma_z^2 + 2\rho_{\alpha_1^*, \alpha_2^*} \sigma_{\alpha_1^*} \sigma_{\alpha_2^*} P_1^* P_2^*$$

$$+ 2\rho_{\alpha_1^*, \beta_1^*} \sigma_{\alpha_1^*} \sigma_{\beta_1^*} P_1^* P_1 + 2\rho_{\alpha_1^*, \beta_2^*} \sigma_{\alpha_1^*} \sigma_{\beta_2^*} P_1^* P_2 + 2\rho_{\alpha_2^*, \beta_1^*} \sigma_{\alpha_2^*} \sigma_{\beta_1^*} P_2^* P_1$$

$$+ 2\rho_{\alpha_2^*, \beta_2^*} \sigma_{\alpha_2^*} \sigma_{\beta_2^*} P_2^* P_2 + 2\rho_{\beta_1^*, \beta_2^*} \sigma_{\beta_1^*} \sigma_{\beta_2^*} P_1 P_2 \tag{10}$$

where the exogenous terms u and z and their respective response coefficients are assumed to be uncorrelated. The policymaker then minimizes the squared deviations of output around the target level, denoted by $\bar{y}$. As in (6), the expected loss functions take the following form:

$$L = E\big[(y-\bar{y})^2\big]$$

$$L^* = E\Big[\big(y^*-\bar{y}^*\big)^2\Big] \tag{11}$$

However, (11) is equivalent to minimizing the variance of y (i.e. σ_y^2) around its mean value. In a certainty equivalent setup, the minimization of the loss function defined in (11) and the minimization of the variance of y are equivalent (i.e. all coefficients are known). This, in turn, implies that $E(y) = \tilde{y} = \bar{y}$. In doing so, the variance of y around $\tilde{y}$ is equal to the variance around $\bar{y}$. In other words, the expected value of y is equal to its target level (i.e. $E(y) = \bar{y}$) With multiplicative uncertainty the choice of optimal values of the instruments should account for the relationship between instrument values and the variance of the goal variable (Brainard, 1967). The central banks' loss functions take the following form:

$$L = E\big[(y-\tilde{y}+\tilde{y}-\bar{y})^2\big] = E\Big[\sigma_y^2+(\tilde{y}-\bar{y})^2\Big]$$

$$L^* = E\Big[\big(y^*-\tilde{y}^*+\tilde{y}^*-\bar{y}^*\big)^2\Big] = E\Big[\sigma_y^{*2}+\big(\tilde{y}^*-\bar{y}^*\big)^2\Big] \tag{12}$$

By substituting (10) in (12) and replacing y and y^* with their estimated counterparts (i.e. $\tilde{y}$ and $\tilde{y}^*$), we get the following optimal policies[16]:

$$P_{1,\,opt} = \frac{\tilde{\alpha}_1}{\big(\tilde{\alpha}_1^2+\sigma_{\tilde{\alpha}_1}^2\big)}\big(\bar{y}-\tilde{\alpha}_2 P_2-\tilde{\beta}_1 P_1^*-\tilde{\beta}_2 P_2^*-\tilde{u}\big)$$

$$-\frac{1}{\big(\tilde{\alpha}_1^2+\sigma_{\tilde{\alpha}_1}^2\big)}\Big(\rho_{\tilde{\alpha}1,\tilde{\alpha}2}\,\sigma_{\tilde{\alpha}1}\,\sigma_{\tilde{\alpha}2}P_2+\rho_{\tilde{\alpha}1,\tilde{\beta}1}\,\sigma_{\tilde{\alpha}1}\,\sigma_{\tilde{\alpha}2}P_1^*+\rho_{\tilde{\alpha}1,\tilde{\beta}2}\,\sigma_{\tilde{\alpha}1}\,\sigma_{\tilde{\beta}2}P_2^*\Big)$$

$$P_{1,opt}^* = \frac{\tilde{\alpha}_1^*}{\big(\tilde{\alpha}_1^{*2}+\sigma_{\tilde{\alpha}_1^*}^2\big)}\Big(\bar{y}^*-\tilde{\alpha}_2^* P_2^*-\tilde{\beta}_1^* P_1-\tilde{\beta}_2^* P_2-\tilde{z}\Big)$$

$$-\frac{1}{\big(\tilde{\alpha}_1^{*2}+\sigma_{\tilde{\alpha}_1^*}^2\big)}\Big(\rho_{\tilde{\alpha}_1^*\tilde{\alpha}_2^*}\sigma_{\tilde{\alpha}_1^*}\sigma_{\tilde{\alpha}_2^*}P_2^*+\rho_{\tilde{\alpha}_1^*\tilde{\beta}_1^*}\sigma_{\tilde{\alpha}_1^*}\sigma_{\tilde{\beta}_1^*}P_1+\rho_{\tilde{\alpha}_1^*\tilde{\beta}_2^*}\sigma_{\tilde{\alpha}_1^*}\sigma_{\tilde{\beta}_2^*}P_2\Big) \tag{13}$$

where $\{\tilde{\alpha}_1, \tilde{\alpha}_2, \tilde{\beta}_1, \tilde{\beta}_2, \tilde{\alpha}_1^*, \tilde{\alpha}_2^*, \tilde{\beta}_1^*, \tilde{\beta}_2^*\}$ represent estimated parameters. Optimal policies differ from the policies that would be pursued in a certainty equivalence world. In a parameter uncertainty framework, policymakers should make use of more information than the expected value of the exogenous variables and response coefficients[17]. For example, the domestic policymaker needs further information about the response coefficient means as well as their variances (e.g. $\tilde{\alpha}_1^2$ and $\sigma_{\alpha1}^2$) even if the response coefficients and the exogenous variables uncorrelated. Finally, note that authorities should also have information on foreign response coefficients means (consistently with an integrated world) and the correlation between parameters (e.g. $\rho_{\tilde{\alpha}_1,\tilde{\alpha}_2}$, $\rho_{\tilde{\alpha}_1,\tilde{\beta}_1}$, $\rho_{\tilde{\alpha}_1,\tilde{\beta}_2}$).

5.3 On the cautiousness-aggressiveness trade-off

The subprime crisis has been characterized by a relatively large number of uncertainty shocks, which led to an unprecedented drop in aggregate production in the major industrialized economies. To avoid a deep recession, policymakers started to implement a sequence of quantitative easing policies. Based on policies in (13), we discussed whether these policies were accurate. Because of parameter uncertainty (e.g. $\sigma^2_{\tilde{\alpha}_1}$, $\sigma^2_{\tilde{\alpha}_1^*} \uparrow$), policymakers should be less aggressive (i.e. $P_1, P_1^* \downarrow$). However, the FED as well as European Central Banks injected a large amount of liquidity into the system during the crisis (see Table III). The choice of this strategy was motivated by two main factors: preserve mortgage market stability; avoid financial institutions bankruptcy. But were banks right? Did they focus on the real amount of liquidity? What authorities can learn from a simple model?

To address these issues, we make use of the model developed in Section 5.2. This allows to examine whether banks need to be aggressive or cautious in presence of many sources of uncertainty. To a very simple theoretical setup with one target-one instrument, it has been added an extra instrument aimed at capturing the shadow effects of credit/liquidity measures. Furthermore, the model account for foreign policies. In this setup, optimal policies depend on a relatively high number of parameters. Because of uncertainty, central banks have no idea about their precise values. Under the scenario depicted by our previous empirical analysis the vagueness around these parameter values is much more larger than in tranquil times. For example, we have observed that the correlation between changes in money supply and credit (i.e. real amount of liquidity in the economy) measures displays a negative value over the subprime crisis period (see Table II ad Figure 4). Roughly, this can be captured by commanding positive values for the "money response coefficients," α_1, β_1, and negative values for the "liquidity response coefficients," α_2, β_2, (or vice versa). While theory suggests that policymaker should be extremely cautious in presence of high uncertainty, the presence of an unprecedented money-credit dynamics and the optimal policies in (13) suggest an aggressive behavior. This might be due to a negative correlation between α_1 and α_2 (or between α_1^* and α_2^*). An unusual sign of the response coefficients suggests also that policy makers should, under certain circumstances, re-design policies. We stress that there is uncertainty also on response coefficients correlation (e.g. $\rho_{\tilde{\alpha}_1,\tilde{\beta}_1}$, $\rho_{\tilde{\alpha}_1,\tilde{\beta}_2}$). We stress that the sign of these correlation coefficients are also key to design policies.

In a scenario characterized by the presence of rare events, where to an expansionary monetary policy corresponds tightening credit conditions, a set of quantitative easing policies might produce undesirable results. The presence of tightening credit conditions

Date	Increase	Decrease (bps)	Level (%)
January 22, 2008	…	75	3.50
January 30, 2008	…	50	3.00
March 18, 2008	…	75	2.25
April 1, 2008	…	25	2.00
October 8, 2008	…	50	1.50
October 29, 2008	…	50	1.00
December 16, 2008	…	75-100	0-0.25
Source: Federal Reserve			

Table III.
Intended federal funds rate, change and level

has simultaneously affected quantitative easing policies and response coefficient uncertainty. Overall, our model gives rise to a "cautiousness-aggressiveness trade-off." On the one side, a sharp increase in the overall variance forces policymakers to be less aggressive (consistently with the theory). On the other side, bizarre policy macroeconomic effects, might force policymakers to be less cautious. More precisely, an unprecedented "money-liquidity relationship" might induce policymakers to be more aggressiveness.

Policymakers, as might be suggested by our model (if specific scenarios show up), were more aggressive rather than cautious, even if there was a high level of parameter uncertainty. However, they underestimated the adverse effects of uncertainty shocks in the credit market (liquidity). Because of policy uncertainty, firms and workers perceived authorities' actions as hesitant and vague. This worsened the crisis.

6. Summary and policy implications

An unprecedented drop in output, consumption, investment and asset prices characterized the subprime crisis in most industrialized economies. During the same period these economies experienced large and synchronized tightening of credit conditions as well as a steep increase in economic policy uncertainty. As results of the unusual credit tightening and the associated lack in liquidity central banks, and in particular the FED, massively injected liquidity into the economy through quantitative easing policies. However, an unusual "money-liquidity relationship," caused by the presence of extraordinary credit market events, partially offset the benefits of the implemented expansionary policies. This paper, in a Brainard uncertainty word, addresses whether monetary authorities' aggressiveness was accurate at the time of the crisis. We focus on a simple two country-two instruments static model with parameter uncertainty and discuss how the nature of monetary policy should change when such uncertainty is accounted for. Our environment suggests that policies are affected by the variance of the response coefficients as well as by the correlation between response coefficients. While a high response coefficient variance induces authorities to be much more cautious, a negative correlation between response coefficients suggests aggressiveness. It turns out that a high level of parameter uncertainty and an unusual "money-liquidity relationship" exacerbate the cautiousness-aggressiveness trade-off. Overall, our simple analysis suggests that in presence of extraordinary money and credit market dynamics policymakers should re-design policies. For example, central banks misdiagnosed the interbank lending market and thereby responded incorrectly by focussing exclusively on liquidity rather than risk. In addition, they provided support for certain financial institutions and creditors, but not for others without a logical and motivated agenda. This worsened the crisis even if there was a large amount of liquidity injected into the market as well as increased the level of economic policy uncertainty. As a result, interest rates reached rapidly the zero lower bound limiting the channel through which authorities stimulate the economy during recession times. Is the time for unconventional monetary policies? Both our empirical and simple theoretical evidence suggest that in presence of extraordinary money-credit market conditions standard expansionary monetary policy might fail (i.e. aggressiveness does not deliver the expected results). Therefore, there is room for alternative/extreme solutions (i.e. unconventional monetary policies), which should take into account the adverse effects of the interbank lending channel and use novel policy instruments. Based on recent research and central bankers' speeches, it seems that we are going into this direction. However, we leave this challenge for future research.

Notes

1. Note that the US Federal Reserve Bank cut Federal funds rate 11 times over the period 2000-2001. Precisely, the effective Fed funds rate moved from 6.50 percent (May 2000) to 1.75 percent (December 2001), source FRED Economic Data (St. Louis FED).

2. Note that from June 2003 to June 2006 Federal Reserve increased the federal funds rate 17 consecutive times (from 1.0 to 5.25 percent).

3. See Greenlaw *et al.* (2008) for additional details.

4. Throughout the paper we use the terms uncertainty shock and rare event interchangeably.

5. See Demyanyk and van Hemert (2008), Baum *et al.* (2009); Ivashina and Scharfstein (2009) and Claessens *et al.* (2010) for a detailed examination of the impact of changes in credit market conditions on the real economic activity during the crisis.

6. Our empirical evidence are in line with Bloom (2009). Differently, our analysis includes post-Lehman data.

7. Note that the log of the industrial production and the log of the unemployment rate responses to stock market volatility indicator innovations are "heavily protracted." This is due to the presence of non-stationary series.

8. The Board of Governors of the Federal Reserve discontinued publishing data on M3 (which incorporates all data on M1 + M2 = M3) on March 23, 2006. M3 also included balances in institutional money funds, repurchase liabilities issued by depository institutions and Eurodollars held by US residents at foreign branches of US banks.

9. See Cassola *et al.* (2013) for an examination of the evolution of the lending activity in the European interbank market during the crisis.

10. Note that the US Nominal Personal Consumption fell by more than 9 percent on annual basis in the last quarter of 2008 (source: Bureau of Economic Analysis).

11. For a detailed discussion on optimal policies under uncertainty, see also Sack (1998), Martin (1999), Shuetrim and Thompson (1999), Giannoni (2002) and Froyen and Guender (2007), among others.

12. In a normal scenario α, β , $\alpha^* \beta^* > 0$. However, evidence from the subprime crisis period suggest different parameters sign.

13. Differently from a one-country world, here the domestic optimal policy depends also on the foreign policy (and viceversa), i.e., the home country chooses the best P given P^* and the foreign country chooses the best P^* given P.

14. Note that our "credit-policy" can be represented also by any type of instrument/policy that played against standard quantitative easing policies during the subprime crises, and thus, partially offset their effects on real economic activity. We can refer to this as the "shadow effect of the credit crunch."

15. Since (10) represents a weighted sum of variables, the variable with the largest weight will have a disproportionally largest weight in the variance of the total.

16. We impose $E(xu) = 0$ and $E(x^*z) = 0$, where x and x^* represent home and foreign parameters in Equation (5.5), respectively. Differently, response coefficients are correlated. Technical details are given in Appendix 2.

17. A similar discussion follows for P_2 and P_2^*.

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Appendix 1. Data

Name of the series	Source	Analyzed sample
CBOE SPX volatility VIX (new) – price index	Datastream	January 1990-June 2011
S&P 500 Composite – price index	Datastream	January 1990-June 2011
Civilian unemployment rate (UNRATE)	FRED Economic Data (St. Louis FED)	January 1990-June 2011 1990:2Q–2011:1Q
Real gross domestic product (GDPC1)	FRED Economic Data (St. Louis FED)	1990:2Q-2011:1Q
M2 Money stock (M2SL)	FRED Economic Data (St. Louis FED)	January 1960-May 2011
Institutional money funds (IMFSL)	FRED Economic Data (St. Louis FED)	January 2007-July 2010
Total consumer credit owned and securitized	Federal Reserve	January 1960-May 2011
Net percentage of banks tightening standards for C&I loans to large and middle-market firms	Federal Reserve Senior Loan Officer Opinion Survey on Bank Lending Practices	1990:2Q-2011:1Q
Net percentage of banks tightening standards for commercial real estate loans	Federal Reserve Senior Loan Officer Opinion Survey on Bank Lending Practices	1990:2Q-2011:1Q
Net percentage of domestic respondents tightening standards for mortgage prime loans	Federal Reserve Senior Loan Officer Opinion Survey on Bank Lending Practices	2007:2Q-2011:1Q
US0003M index – USSOC CMPN currency (LIBOR-OIS Spread)	Bloomberg	December 2001-July 2011
EU0003M index – EUSWEC index (EURIBOR-OIS spread)	Bloomberg	December 2001-July 2011
Industrial production and capacity utilization	Federal Reserve	January 1960-May 2011

Table AI.
Data summary

Appendix 2. Two-country model with "credit policy" and parameter uncertainty

We still adopt our two basic structural equations with n instruments (where $n = 4$):

$$y = \alpha_1 P_1 + \alpha_2 P_2 + \beta_1 P_1^* + \beta_2 P_2^* + u$$

$$y = \alpha_1^* P_1^* + \alpha_2^* P_2^* + \beta_1^* P_1 + \beta_2^* P_2 + z \tag{A1}$$

In this setup, response coefficients are random variables. Therefore, y and y^* are random variables with variances given by:

$$\sigma_y^2 = \sigma_{\alpha_1}^2 P_1^2 + \sigma_{\alpha_2}^2 P_2^2 + \sigma_{\beta_1}^2 P_1^{*2} + \sigma_{\beta_2}^2 P_2^{*2} + \sigma_u^2 + 2\rho_{\alpha_1,\alpha_2} \sigma_{\alpha_1} \sigma_{\alpha_2} P_1 P_2$$
$$+ 2\rho_{\alpha_1,\beta_1} \sigma_{\alpha_1} \sigma_{\beta_1} P_1 P_1^* + 2\rho_{\alpha_1,\beta_2} \sigma_{\alpha_1} \sigma_{\beta_2} P_1 P_2^* + 2\rho_{\alpha_2,\beta_1} \sigma_{\alpha_2} \sigma_{\beta_1} P_2 P_1^*$$
$$+ 2\rho_{\alpha_2,\beta_2} \sigma_{\alpha_2} \sigma_{\beta_2} P_2 P_2^* + 2\rho_{\beta_1,\beta_2} \sigma_{\beta_1} \sigma_{\beta_2} P_1^* P_2^*$$

$$\sigma_y^{*2} = \sigma_{\alpha_1^*}^2 P_1^{*2} + \sigma_{\alpha_2^*}^2 P_2^{*2} + \sigma_{\beta_1^*}^2 P_1^2 + \sigma_{\beta_2^*}^2 P_2^2 + \sigma_z^2 + 2\rho_{\alpha_1^*,\alpha_2^*} \sigma_{\alpha_1^*} \sigma_{\alpha_2^*} P_1^* P_2^*$$
$$+ 2\rho_{\alpha_1^*,\beta_1^*} \sigma_{\alpha_1^*} \sigma_{\beta_1^*} P_1^* P_1 + 2\rho_{\alpha_1^*,\beta_2^*} \sigma_{\alpha_1^*} \sigma_{\beta_2^*} P_1^* P_2 + 2\rho_{\alpha_2^*,\beta_1^*} \sigma_{\alpha_2^*} \sigma_{\beta_1^*} P_2^* P_1$$
$$+ 2\rho_{\alpha_2^*,\beta_2^*} \sigma_{\alpha_2^*} \sigma_{\beta_2^*} P_2^* P_2 + 2\rho_{\beta_1^*,\beta_2^*} \sigma_{\beta_1^*} \sigma_{\beta_2^*} P_1 P_2 \tag{A2}$$

Re-writing the loss functions:

$$L = E\big[(y - \tilde{y} + \tilde{y} - \bar{y})^2\big] = E\Big[\sigma_y^2 + (\tilde{y} - \bar{y})^2\Big]$$

$$L^* = E\Big[(y^* - \tilde{y}^* + \tilde{y}^* - \bar{y}^*)^2\Big] = E\Big[\sigma_y^{*2} + (\tilde{y}^* - \bar{y}^*)^2\Big] \tag{A3}$$

Then, substituting for the estimated values and variance of y and y^*:

$$\begin{aligned}
L = E\Big[&\sigma_{\alpha_1}^2 P_1^2 + \sigma_{\alpha_2}^2 P_2^2 + \sigma_{\beta_1}^2 P_1^{*2} + \sigma_{\beta_2}^2 P_2^{*2} + \sigma_u^2 + 2\rho_{\alpha_1,\alpha_2}\sigma_{\alpha_1}\sigma_{\alpha_2}P_1 P_2 \\
&+ 2\rho_{\alpha_1,\beta_1}\sigma_{\alpha_1}\sigma_{\beta_1}P_1 P_1^* + 2\rho_{\alpha_1,\beta_2}\sigma_{\alpha_1}\sigma_{\beta_2}P_1 P_2^* + 2\rho_{\alpha_2,\beta_1}\sigma_{\alpha_2}\sigma_{\beta_1}P_2 P_1^* \\
&+ 2\rho_{\alpha_2,\beta_2}\sigma_{\alpha_2}\sigma_{\beta_2}P_2 P_2^* + 2\rho_{\beta_1,\beta_2}\sigma_{\beta_1}\sigma_{\beta_2}P_1^* P_2^* \\
&+ \big(\tilde{\alpha}_1 P_1 + \tilde{\alpha}_2 P_2 + \tilde{\beta}_1 P_1^* + \tilde{\beta}_2 P_2^* + \tilde{u} - \bar{y}\big)^2 \Big]
\end{aligned}$$

$$\begin{aligned}
L = E\Big[&\sigma_{\alpha_1^*}^2 P_1^{*2} + \sigma_{\alpha_2^*}^2 P_2^{*2} + \sigma_{\beta_1^*}^2 P_1^2 + \sigma_{\beta_2^*}^2 P_2^2 + \sigma_z^2 \\
&+ 2\rho_{\alpha_1^*,\alpha_2^*}\sigma_{\alpha_1^*}\sigma_{\alpha_2^*}P_1^* P_2^* + 2\rho_{\alpha_1^*,\beta_1^*}\sigma_{\alpha_1^*}\sigma_{\beta_1^*}P_1^* P_1 + 2\rho_{\alpha_1^*,\beta_2^*}\sigma_{\alpha_1^*}\sigma_{\beta_2^*}P_1^* P_2 \\
&+ 2\rho_{\alpha_2^*,\beta_1^*}\sigma_{\alpha_2^*}\sigma_{\beta_1^*}P_2^* P_1 + 2\rho_{\alpha_2^*,\beta_2^*}\sigma_{\alpha_2^*}\sigma_{\beta_2^*}P_2^* P_2 + 2\rho_{\beta_1^*,\beta_2^*}\sigma_{\beta_1^*}\sigma_{\beta_2^*}P_1 P_2 \\
&+ \big(\tilde{\alpha}_1^* P_1^* + \tilde{\alpha}_2^* P_2^* + \tilde{\beta}_1^* P_1 + \tilde{\beta}_2^* P_2 + \tilde{z} - \bar{y}^*\big)^2 \Big]
\end{aligned} \tag{A4}$$

The FOCS:

$$\frac{\partial L}{\partial P_1} = 0$$

$$\begin{aligned}
2\big(\tilde{\alpha}_1 P_1 + \tilde{\alpha}_2 P_2 &+ \tilde{\beta}_1 P_1^* + \tilde{\beta}_2 P_2^* + \tilde{u} - \bar{y}\big)\tilde{\alpha}_1 + 2\sigma_{\alpha 1}^2 P_1 \\
&+ 2\rho_{\alpha 1,\alpha 2}\sigma_{\alpha 1}\sigma_{\alpha 2}P_2 + 2\rho_{\alpha 1,\beta 1}\sigma_{\alpha 1}\sigma_{\beta 1}P_1^* + 2\rho_{\alpha 1,\beta 2}\sigma_{\alpha 1}\sigma_{\beta 2}P_2^* = 0
\end{aligned}$$

$$\frac{\partial L^*}{\partial P_1^*} = 0$$

$$\begin{aligned}
2\big(\tilde{\alpha}_1^* P_1^* + \tilde{\alpha}_2^* P_2^* &+ \tilde{\beta}_1^* P_1 + \tilde{\beta}_2^* P_1 + \tilde{z} - \bar{y}^*\big)\tilde{\alpha}_1^* + 2\sigma_{\alpha 1}^{*2}P_1^* + 2\rho_{\alpha 1,\alpha 2}^*\sigma_{\alpha 1}^*\sigma_{\alpha 2}^*P_2^* \\
&+ 2\rho_{\alpha 1,\beta 1}^*\sigma_{\alpha 1}^*\sigma_{\beta 1}^*P_1 + 2\rho_{\alpha 1,\beta 2}^*\sigma_{\alpha 1}^*\sigma_{\beta 2}P_2 = 0
\end{aligned} \tag{A5}$$

Finally, our optimal responses:

$$\begin{aligned}
P_{1,opt} = &\frac{\tilde{\alpha}_1}{\big(\tilde{\alpha}_1^2 + \sigma_{\tilde{\alpha}_1}^2\big)}\big(\bar{y} - \tilde{\alpha}_2 P_2 - \tilde{\beta}_1 P_1^* - \tilde{\beta}_2 P_2^* - \tilde{u}\big) \\
&- \frac{1}{\big(\tilde{\alpha}_1^2 + \sigma_{\tilde{\alpha}_1}^2\big)}\big(\rho_{\tilde{\alpha}1,\tilde{\alpha}2}\sigma_{\tilde{\alpha}1}\sigma_{\tilde{\alpha}2}P_2 + \rho_{\tilde{\alpha}1,\tilde{\beta}1}\sigma_{\tilde{\alpha}1}\sigma_{\tilde{\alpha}2}P_1^* + \rho_{\tilde{\alpha}1,\tilde{\beta}2}\sigma_{\tilde{\alpha}1}\sigma_{\tilde{\beta}2}P_2^*\big)
\end{aligned} \tag{A6}$$

where:

$$P_{1,opt}^* = \frac{\tilde{\alpha}_1^*}{\left(\tilde{\alpha}_1^{*2} + \sigma_{\tilde{\alpha}_1^*}^2\right)}\left(\bar{y}^* - \tilde{\alpha}_2^* P_2^* - \tilde{\beta}_1^* P_1 - \tilde{\beta}_2^* P_2 - \tilde{z}\right)$$

$$-\frac{1}{\left(\tilde{\alpha}_1^{*2} + \sigma_{\tilde{\alpha}_1^*}^2\right)}\left(\rho_{\tilde{\alpha}_1^* \tilde{\alpha}_2^*}\sigma_{\tilde{\alpha}_1^*}\sigma_{\tilde{\alpha}_2^*} P_2^* + \rho_{\tilde{\alpha}_1^* \tilde{\beta}_1^*}\sigma_{\tilde{\alpha}_1^*}\sigma_{\tilde{\beta}_1^*} P_1 + \rho_{\tilde{\alpha}_1^* \tilde{\beta}_2^*}\sigma_{\tilde{\alpha}_1^*}\sigma_{\tilde{\beta}_2^*} P_2\right) \quad (A7)$$

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