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Monetary policy and stock prices: theory and evidence

by Stefano Neri



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MONETARY POLICY AND STOCK PRICES: THEORY AND EVIDENCE

by Stefano Neri*

Abstract

The objective of this paper is to evaluate the effects of monetary policy shocks on stock market indices in the G-7 countries and Spain using the methodology of structural VARs. A model is estimated for each country and the effects of monetary policy shocks are evaluated by means of impulse responses. A contractionary shock has a negative and temporary effect on stock market indices. There is evidence of a significant cross-country heterogeneity in the persistence, magnitude and timing of the responses. A limited participation model with households trading in stocks is set up and the responses of stock prices to a monetary policy shock under different rules are evaluated. The model is able to account for the empirical response of stock prices to monetary policy shocks under different policy rules.

JEL classification: C32; E52; G12.

Keywords: monetary policy; stock prices; structural VAR; limited participation model.

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1. Introduction¹

From 1995 to 2000 financial markets experienced a sustained increase in stock prices in many countries. Stock market indices increased by 270 per cent in Spain, 200 per cent in France, Italy, Germany, and the US, more than 100 per cent in the UK and Canada and only 10 per cent in Japan. A sudden inversion of the trend was recorded in March 2000. After the March peak, at the end of February 2001 indices had dropped by roughly 25 per cent in Spain, 20 per cent in Germany, France, Italy and the US and by almost 30 per cent in Canada and Japan. Stock market indices continued to decrease throughout 2001 and 2002.

Against this background, it is not surprising that the relationship between monetary policy and asset prices, in general, has recently known renewed interest among researchers and policy-makers. Both academics and policy-makers have debated whether monetary policy should respond to developments in financial markets (Bernanke and Gertler, 2000 and Rigobon and Sack, 2001), the extent to which they might have been caused by monetary policy (Rapach, 2001) and, particularly during the last two years, the role of stock market wealth in the transmission mechanism of monetary policy. For example, in life cycle/permanent income models, changes in stock prices can affect households' consumption choices because these assets are an important component of households' wealth. Movements in interest rates can affect stock prices and consequently households' wealth: this effect can provide an additional channel, besides the traditional interest rate and credit ones, through which monetary policy can affect output and inflation.² The

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²There is little evidence on the contribution of the wealth channel to the monetary transmission

effects of changes in stock prices on households' financial wealth are likely to be larger in those countries where stock ownership is greater among households. With respect to the relationship between financial wealth and consumption, empirical analyses have shown that the effects of changes in stock prices on consumption are not large. Boone, Giorno and Richardson (1998) estimate that a 10 per cent fall in stock market prices reduces consumption by 0.45 to 0.75 per cent in the US after one year. Similar results are obtained for Canada and the UK (0.45), while for the other G-7 countries the estimated elasticities are smaller on average (less than 0.2).³ These findings suggest that the effects of changes in stock prices on aggregate demand and output should be small. However, they may well be far from negligible in the light of the tremendous decline in stock prices in the last two years. By focusing on the effects of monetary policy on stock market indices, this paper may help to give a rough assessment of the relevance of the "stock market" channel for the monetary transmission mechanism. For a given amount of stock holdings in households' portfolios, the finding of a small effect of monetary policy on stock prices would imply that the "stock market" channel is not a dominant source of transmission of monetary policy shocks in the economy.

For all these reasons it is important, especially for central banks, to understand whether and how monetary policy can influence stock market prices. In this paper we rely on structural VARs to identify monetary shocks and evaluate their effects on stock market indices in the G-7 countries and Spain. Structural VARs have been used extensively in the literature to analyze of the effects of monetary policy in many countries. A recent example is Kim (1999), who proposes a common specification to identify monetary policy shocks in the G-7 countries. Although the monetary authorities of these countries have different operating procedures, the proposed model fits well and does not present any mechanism. The analysis of Lettau, Ludvigson and Steindel (2001) for the US is the only exception, although the authors focus on the effects of changes in total wealth on consumption. The main finding is that the wealth channel is not a dominant source of monetary policy transmission to consumption. The reason for this result is that monetary policy shocks, measured by innovations in the federal funds rate, have transitory effects on asset prices.

³The authors assume that consumers in the G-7 countries other than the US have the same marginal propensity to consume out of wealth as consumers in the US

puzzling responses of monetary aggregates and prices (the “liquidity” and “price” puzzles sometimes found in the literature).

The main results of this paper are the following. First, contractionary monetary policy shocks, measured by exogenous increases in short-term interest rates, have small, negative and transitory effects on stock market indices. The persistence, the magnitude and the timing of these effects differ significantly from country to country. These results are in line with previous analyses that have relied on an alternative identification of monetary policy shocks. Second, the proposed model is able to replicate, at least from a qualitative point of view, the empirical responses of stock price indices to monetary policy shocks under a variety of monetary policy rules followed by the central bank and calibration of parameters.

The remainder of the paper is organized as follows: section 2 briefly presents some of the existing literature, section 3 describes the structural VAR methodology, section 4 presents the empirical results, section 5 sets up a limited participation model that explicitly takes into account trading in stock markets and section 6 qualitatively validates the model. Section 7 concludes.

2. The existing literature

Surprisingly, notwithstanding the importance of the relationship between stock markets and monetary policy, to the best of our knowledge little empirical or theoretical research has focused on the effects of monetary policy on stock prices. Sellin (2001) provides an extensive survey of the interaction between monetary policy and stock prices by focusing particularly on the literature that analyzes the effects of monetary policy on stock markets.

Chami, Cosimano and Fullerkamp (1999) suggest the existence of a stock market channel of monetary policy besides the traditional interest rate and credit ones. In their view, the inflation induced by a monetary expansion reduces the real value of firms’ assets, thus acting as a tax on the capital stock. This effect differentiates bonds and stocks and gives rise to the “stock market” channel of the monetary transmission mechanism. An expansionary monetary policy generates a decrease in real stock returns and stock prices.

Cooley and Quadrini (1999a) develop a dynamic stochastic general equilibrium model in which financial factors play an important role in the decisions of firms and the transmission mechanism of monetary policy. Given that firms are heterogeneous with respect to the size of their equity, the authors are able to construct a value-weighted stock market index and evaluate its response to monetary policy shocks. A contractionary one per cent monetary shock reduces the stock market index by nearly 0.2 per cent on impact.

Lucas (1982) and Svensson (1985) analyze cash-in-advance models in which households hold money and stocks. The pricing condition of these assets is the standard formula à la Lucas (1978), according to which the price of a stock is given by the discounted sum of future dividend payments. The model considered in this paper delivers a similar pricing condition. However, as will be stressed in section 5, a basic cash-in-advance model is not capable of generating a liquidity effect, that is a decrease in the short-term interest rate following an increase in the supply of money.

As far as concerns the empirical analysis, few works have tried to evaluate the effects of monetary policy on stock markets. All these analyses share the same methodology of structural VARs.

Thorbecke (1997) analyzes how stock returns respond to monetary policy shocks in the U.S. The author finds that an expansionary monetary policy increases ex-post stock returns.⁴ This result can be explained by the positive effect on economic activity and hence on future cash flows and by the reduction in the discount factor at which those flows are discounted.

Rapach (2001) provides another analysis, based on US data, of the effects of money supply shocks and other shocks on real stock prices. These shocks are identified by means of long-run restrictions. The main result is that each identified shock affects real stock prices. Expansionary monetary policy shocks have a positive effect on real stock

⁴In the VAR analysis monetary policy shocks are identified alternatively as innovations in the federal funds rate and nonborrowed reserves. Identification of structural shocks is achieved by means of a Cholesky decomposition as in Christiano, Eichenbaum and Evans (1996a, 1998).

prices, the response of which can be rationalized according to the standard present-value evaluation principle. The positive effect on output increases expected real dividends while the decrease in the interest rate reduces the discount factor at which future dividend payments are evaluated. Another interesting result is that aggregate supply and monetary policy shocks contributed significantly to the surge in stock prices in the second half of the 1990s.

The paper which is closest to our is Lastrapes's (1998). The author analyzes the response of asset prices - long-term bond yields and real stock price indices - to monetary policy shocks in eight industrialized countries. The identification of monetary policy shocks is achieved by means of long-run restrictions under the assumption that money supply shocks do not permanently affect interest rates, real output, real stock prices and real money. The main finding is that real stock prices respond positively and significantly to unexpected increases in the supply of money.

3. The structural VAR analysis

In this section we present our proposed identification of the structural VARs. These models, which have been extensively used in the analysis of monetary policy, are useful for many reasons: they have the advantage of imposing a minimal set of restrictions, usually coming from economic theory, so that it is possible to simulate the dynamic responses of the variables of interest to policy shocks and to evaluate the relative importance of the different shocks.

We will assume that the economy we analyze can be described by a structural dynamic vector equation:

$$A(L)y_t + c = v_t \tag{1}$$

where y_t is a vector of N economic variables, v_t is a vector of structural shocks that can be given, at least in some cases, an economic interpretation, c is a vector of constants and $A(L)$ is an autoregressive polynomial of order p . The variables in y_t are in order: a world commodity price index, the nominal exchange rate, industrial production, the consumer

price index, a short-term interest rate, a monetary aggregate and the stock market index.⁵ All the variables, with only exception of the interest rate, are expressed in logarithms.

The structural shocks are assumed to be serially uncorrelated and mutually independent. The reduced form of the VAR is given by the following system of equations:

$$y_t = c + B(L)y_t + u_t \quad (2)$$

where u_t is the vector of residuals. These are related to the structural shocks by the following relationship:

$$v_t = A_0 u_t \quad (3)$$

We are interested in recovering the coefficients that contemporaneously link the variables of the y_t vector, that is the non-zero elements of the A_0 matrix in (3). There are several ways of identifying these coefficients; all the different strategies need to impose enough restrictions to do so. A simple way of achieving this is to orthogonalize the reduced form variance covariance matrix of the VAR residuals, Σ , using a Cholesky decomposition: this is equivalent to assuming a recursive structure of the model (1). More complex strategies use both short-run and long-run restrictions as in Galì (1992) and restrictions on the signs of impulse responses as in Uhlig (1999), or restrictions on the signs and cross-correlations of impulse responses as in Canova and De Nicoló (2002). In this paper we rely on a non-recursive structure of the A_0 matrix, thus imposing restrictions only on the contemporaneous relationship among the VAR variables. As a result, the long-run behaviour of the models is left completely unrestricted. Given an estimate of Σ , the coefficients of the matrix A_0 can be estimated by maximum likelihood. Since Σ

⁵We used the nominal exchange rate with the US dollar for Japan, Germany, U.K and Canada and the nominal exchange rate with the Deutsche mark for France, Italy and Spain. With respect to the choice of the monetary aggregate, M2 was used for all the countries with the exception of Germany, for which M3 was used. Stock market indices are: Standard and & Poor 500 (US), Tokyo NSE (Japan), FAZ general (Germany), FTSE all share (UK), CAC 40 (France), MIB (Italy), Toronto Composite index (Canada) and IBEX (Spain). All the data come from the International Financial Statistics (IMF), Main Economic Indicators (OECD), BIS (Bank for International Settlements) and Datastream.

has $n(n + 1)/2$ different elements, a maximum number of $n(n - 1)/2$ coefficients can be estimated, after having normalized the diagonal coefficients of A_0 to 1. The proposed identification scheme is the following:

$$\begin{bmatrix} v_{cp} \\ v_{exc} \\ v_y \\ v_p \\ v_{ms} \\ v_{md} \\ v_s \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & 1 & 0 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 & a_{56} & 0 \\ 0 & 0 & a_{63} & a_{64} & a_{65} & 1 & 0 \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & a_{76} & 1 \end{bmatrix} \begin{bmatrix} u_{cp} \\ u_{exc} \\ u_y \\ u_p \\ u_r \\ u_m \\ u_s \end{bmatrix}$$

where the vector on the left-hand side contains the structural shocks and the vector on the right-hand side the reduced-form innovations. It is important to underline that among structural shocks, only money supply v_{ms} and, to a smaller extent, money demand shocks v_{md} have a clear economic interpretation: the others are loosely identified. The VARs are over-identified by one restriction, with the only exception of the US model in which the exchange rate is not introduced. The money supply and the money demand equations have the following representation in terms of contemporaneous relationships among the residuals of the VAR equations:

$$u_r + a_{51}u_{cp} + a_{52}u_{exc} + a_{53}u_y + a_{54}u_p + a_{56}u_m = v_{ms} \quad (4)$$

$$u_m + a_{63}u_y + a_{64}u_p + a_{65}u_r = v_{md} \quad (5)$$

We expect to find respectively a positively-sloped money supply (4) and negatively-sloped money demand relationship (5) in the (m, r) space.

Equation (4) can be interpreted as a monetary policy rule that specifies the supply of money as a function of the monetary aggregate, the nominal exchange rate, industrial production, the consumer price index and the commodity price index. Equation (6) represents a money demand equation in which the monetary aggregate depends on the interest rate, the assumed opportunity cost, industrial production, the measure of

economic activity, and the price level. This modelling of the policy block allows us to disentangle monetary policy shocks from money demand shocks and it can be regarded as a general scheme that is applicable to different countries where different operating procedures have been implemented. The commodity price index and the exchange rate in the monetary policy rule (4) are used to capture external shocks that may generate inflationary pressures. These variables help to solve the so-called “price puzzle”, after Sims (1992): the finding that a contractionary monetary policy shock generates an increase in the price level. The assumption that the central bank observes industrial production and the price index is not present in Kim (1999), who justifies it in terms of availability of the information at the time when decisions are taken. Given the monthly frequency of the data we use, we prefer not to make this assumption since we think it is not possible to rule out a priori that contemporaneous information on these variables may be available to policy-makers for setting monetary policy.

The exchange rate index is usually introduced in small open economies’ VARs since it is useful for their monetary authorities to target the exchange rate as well (the countries participating in the EMS are an example). Moreover, for these economies the exchange rate plays an important role in the transmission mechanism of monetary policy. Smets (1997) finds that for Germany, France and Italy monetary policy is better modelled when the exchange rate is taken into account. The introduction of the exchange rate is particularly justified for the European economies and Canada (which depends strongly on the US economy). However, we prefer to adopt the same model for all the countries, with the exception of the US, where the exchange rate is not introduced because the economy is usually considered to be relatively closed.

We have assumed a Cholesky identification of the block containing the commodity price index, the nominal exchange rate, the consumer price index and industrial production. This assumption is commonly made in the VAR literature on monetary policy (see e.g. Christiano, Eichenbaum and Evans (1998) and Bernanke and Mihov (1998)). We differ from Kim and Roubini (2000) in that we do not allow the exchange rate to react to

monetary policy shocks.⁶ With respect to the stock price equation we have chosen to leave it completely unrestricted, by assuming that all variables can have a contemporaneous impact on this variable. The minimum identifying restrictions we have imposed represent a very general framework that is able to explain the dynamics of nominal and real variables in a relative large number of industrial economies.

Our analysis differs substantially from the one used by Lastrapes (1998). First, with respect to the identification scheme, we used restrictions on the short-run relationships among the variables and left their long-run behaviour completely unrestricted. We think that monetary policy shocks are not the only shocks that have transitory effects on real variables: aggregate demand and money demand shocks are other examples. Therefore, the long-run monetary neutrality assumption could not be sufficient to identify monetary policy shocks. Moreover, it is well recognized in the literature on VARs that monetary policy shocks are usually identified as innovations in short-term interest rates, while monetary aggregates are usually driven by money demand shocks (see for example Sims, 1992 and Strongin, 1995). Second, contrary to Lastrapes (1998), in order to correctly identify monetary shocks we introduce the nominal exchange rate since, for some countries, especially small open economies, monetary policy shocks are better identified when the exchange rate is taken into account (see Smets, 1997). Finally, we differ with respect to the choice of the sample period used in estimating the VARs: Lastrapes (1998) used monthly data from 1960 to 1994 while we used more recent data from 1985 to 2000.

4. Estimation results and impulse responses

In this section we present the estimates of the free coefficients of the A_0 matrices and we comment the results from the impulse response analyses. The reduced form VAR in (2) is estimated consistently in levels by means of OLS.⁷ The concentrated log-likelihood

⁶We have experimented alternative identifications in which the exchange rate responded to these shocks without substantial differences in the behaviour of stock prices. Given that we are not interested in accounting for the “exchange rate” puzzle, we have assumed that it does not respond contemporaneously to monetary shocks.

⁷Data are monthly and the sample periods goes from 1985:1 to 2000:12. The selection of the lag number was made by looking at the autocorrelation function of the reduced-form residuals, in order to

is maximized with respect to the free coefficients of the A_0 matrix. The following table reports the over-identifying restriction tests.

TABLE 1
Over-identifying restriction test

	Canada	Germany	France	Italy	Spain	UK	Japan	US
OIR test	0.297	3.645	0.023	2.618	0.012	1.273	0.665	- ^a
p-value	0.585	0.056	0.878	0.105	0.909	0.259	0.414	- ^a

^a The model for the US is exactly identified. See section 3.

Our restrictions are not rejected at conventional 5 per cent significance level for all the countries. The following table reports the (negative) estimated coefficients of the policy block (equations (4) and (5) in section 3) of the A_0 matrix.

TABLE 2
Estimated coefficients of the monetary block of the A_0 matrix

	Canada	Germany	France	Italy	Spain	UK	Japan	US
interest rate equation								
<i>cp</i>	-0.058	-0.032	-0.117	0.044	0.034	-0.110	0.023	0.010
<i>exc</i>	0.172	0.020	0.114	0.047	-0.009	-0.000	0.013	- ^a
<i>y</i>	0.100	0.007	-0.085	-0.012	-0.014	-0.189	0.041	0.077
<i>p</i>	-0.099	-0.039	0.136	0.228	-0.050	0.414	0.083	0.257
<i>m</i>	0.580	0.256	0.213	0.089	0.101	0.598	0.286	0.252
money equation								
<i>y</i>	-0.033	0.114	-0.090	0.043	0.114	0.064	-0.072	-0.014
<i>p</i>	0.212	-0.914	-0.348	0.121	0.934	0.780	-0.127	-0.000 ^b
<i>r</i>	-0.204	-7.340	-0.348	-0.052 ^b	-0.614	-1.314	-2.478	-0.211

^a This coefficient is not present since the exchange rate is not included in the model. See section 3.

^b Not significant at 5 per cent confidence level.

The coefficient that measures the endogenous response of the short-term interest rate to the monetary aggregate has the correct sign in all VARs: following an unexpected increase in money, which may generate inflationary pressures, the monetary authority increases the short-term interest rate as uncorrelated as possible. This strategy led us to choose a different number of lags for the eight VARs.

the interest rate. The commodity price index enters with the correct positive sign in the monetary policy rule of Italy, Spain, Japan and the US. The coefficient on the nominal exchange rate has the correct sign in the policy rule equations of Canada, Germany, France, Italy and Japan: an unexpected depreciation, measured by an increase in the nominal exchange rate, induces the monetary authority to raise interest rates. The price level enters significantly and with the expected positive sign in the interest rate equations of France, Italy, UK, Japan and the US while industrial production has the correct sign in the US, Japan, Germany and Canada. Overall, the signs of these coefficients indicate that monetary authorities move to a contractionary stance when faced with inflationary pressures. In the estimated money demand equations, the interest rate semi-elasticity has the expected sign for all the countries, while this is not the case for output and the price level.

We now analyze the responses of the VAR variables to a contractionary monetary policy shock, measured by an exogenous one per cent increase in the short-term interest rate.⁸ Figure 1 reports the first principal component of the estimated responses of interest rates, monetary aggregates and stock market indices to a contractionary one per cent monetary policy shock for the countries considered.⁹ In all the countries, the initial increase in the interest rate is followed by a contraction of the monetary aggregate. The persistence of this liquidity effect differs from country to country. Almost every model in which policy shocks are identified with innovation in the interest rate shows a liquidity effect in the short run: an expansionary monetary policy shock, for example, is characterized by a decrease in a short-term interest rate and an increase in monetary aggregates (see Gordon and Leeper, 1994).¹⁰ Industrial production and the consumer price index (these responses

⁸Error bands (68 and 95 per cent probability intervals) for the first and second principal components of the impulse responses are computed by means of Monte Carlo integration following Sims and Zha (1999). In this paper the authors show how to compute error bands for over-identified structural VARs.

⁹The figure with the second component of the impulse responses is reported in the appendix.

¹⁰The effect of a monetary policy shock on the short-term interest rate is the result of two opposite forces: the liquidity effect, which after a monetary expansion drives down interest rates, and the expected inflation effect, which moves interest rates in the opposite direction. It is widely recognized that, at least in the short run, the liquidity effect of a monetary shock is stronger than the anticipated inflation effect.

are not shown) decrease in all countries, with the responses differing, again, in persistence and magnitude. The price level responds smoothly in all VARs suggesting that prices may be sticky.

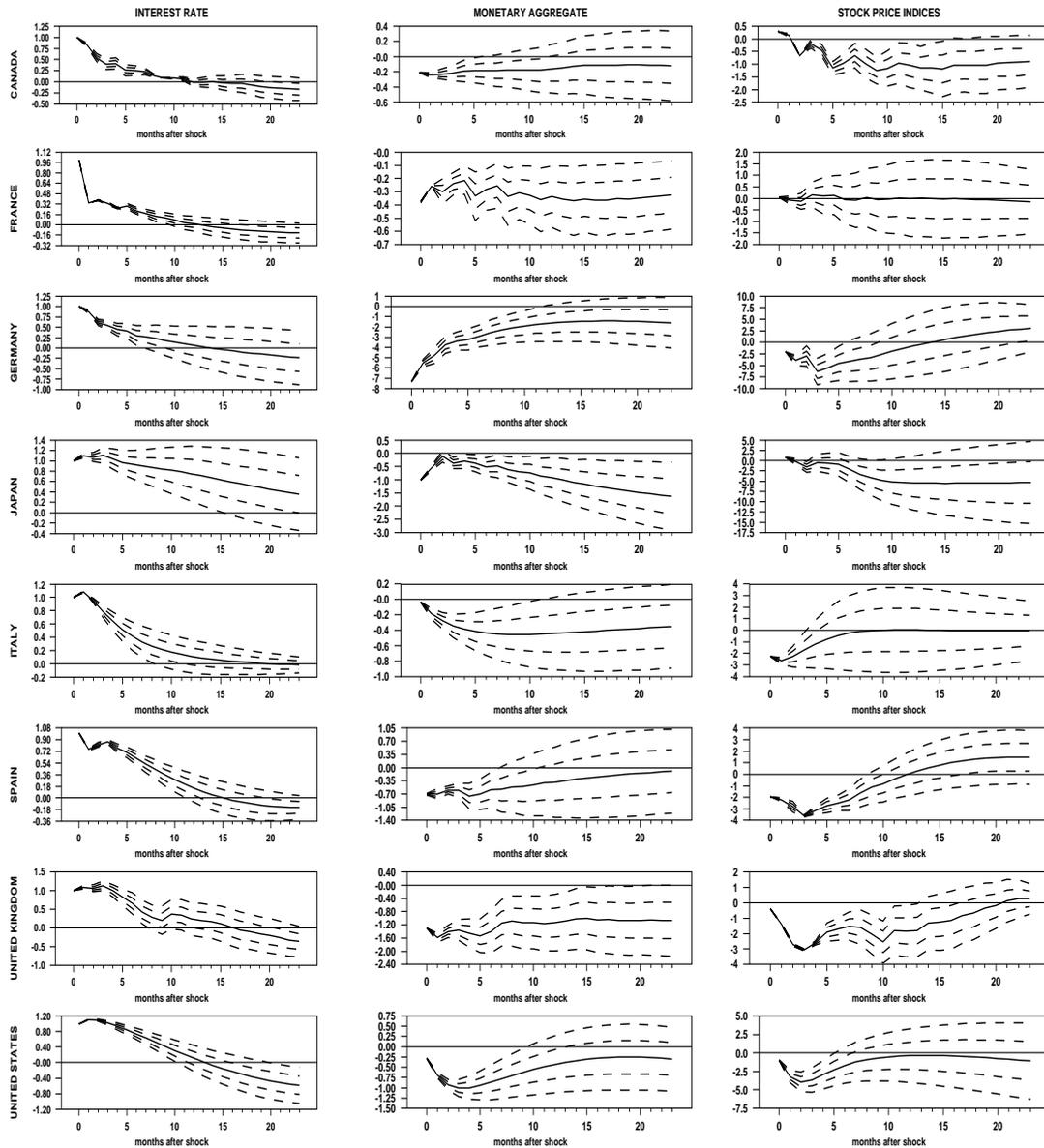


Fig. 1 Contractionary monetary policy shock: first principal component (68 and 95 per cent probability bands)

A contractionary monetary shock produces a decrease in stock market indices in all

the countries. As the figure shows, the responses differ in terms of magnitude, timing and persistence. With respect to the latter, we find a short-lived response in the US and Germany and a more persistent one in Italy, Canada, the UK, Japan and Spain. Monetary shocks have no significant effects on the stock market in France. Lastrapes (1998) also finds no effects of monetary policy in France and small effects in the U.K. However, our results cannot easily be compared with those of Lastrapes (1998) since his models contain a long-term interest rate instead of a short-term one as in this paper. Rapach (2001) reports for the US a decrease on impact of about 6 per cent in response to a money supply shock that raises the short-term interest rate by one per cent. The following table reports the responses of stock price indices to a one per cent contractionary monetary shock. As far as concerns the maximum (significant) response of stock prices, in the US it reaches nearly 4 per cent (in the fourth month), 1.0 per cent in Canada (twelfth month), 3.1 per cent in the UK (fourth month), 6.3 per cent in Germany (fourth month), 0.1 per cent in France (second month), 2.7 per cent in Italy (second month), Japan 4.6 per cent (twelfth month) and 3.6 per cent in Spain (fourth month).¹¹

TABLE 3
Response of stock price indices to a one per cent contractionary monetary shock

months	Canada	Germany	France	Italy	Spain	UK	Japan	US
2	0.1	-3.9	-0.1*	-2.7	-2.2	-1.4	-1.1	-3.2
4	-0.2	-6.3	0.2*	-1.7	-3.6	-3.1	-2.0*	-3.6
8	-0.7	-3.6*	-0.1*	-0.8	-2.2	-1.5	-4.6	-1.2*
12	-1.0	-1.3*	0.0*	0.1*	-0.4*	-1.8	-6.0*	-0.4*
16	-1.2*	0.7*	0.0*	0.1*	0.8*	-1.3*	-6.0*	-0.4*
20	-1.0*	2.1*	-0.1*	0.0*	1.4*	-0.4*	-5.3*	-0.6*
24	-0.9*	3.0*	-0.1*	0.1*	1.5*	0.3*	-4.4*	-1.1*

* Not significant at 5 per cent confidence level. Significance is tested using the first component of the variance of the impulse responses.

¹¹As for the impulse responses, there is a significant cross-country heterogeneity account in the contributions of monetary shocks to fluctuations in stock markets. It is important to underline that in the very short-run (up to 4 months) more than 70 per cent of the variability of stock market indices is due to shocks originating within these markets. This percentage is still around 50 per cent after 2 years.

Overall, these figures show that the effects of monetary policy shocks on stock prices are not large. It is possible to evaluate the effect of monetary policy shocks on consumption due to changes in stock prices using the elasticities estimated by Boone, Giorno and Richardson (1998) and reported in section 1. With respect to the US and UK, a one per cent increase in the short-term interest rate decreases consumption by around 0.14 per cent after one year. The effects are significantly smaller in Canada, France, Italy, Japan and Germany (around 0.05). It must be noted that the effects of changes in policy interest rates on stock market indices are usually short-lived: they become statistically not significant after 8 to 12 months.

On the basis of the VAR analysis, the following conclusions can be drawn. First, a contractionary monetary policy has a negative and transitory effect on stock market indices, which return to baseline values in the short to medium-run. There is a significant cross-country heterogeneity in the persistence, magnitude and timing of the responses of stock market indices to monetary policy shocks. Second, the effects are, on average, small. With respect to the contributions of monetary policy shocks, a similar heterogeneity is found.

5. A limited participation DSGE model

In this section we present a limited participation model based on Christiano, Eichenbaum and Evans (1997), Christiano and Gust (1999) and Christiano and Eichenbaum (1992), which we modify to include trading in the stock market. The model will be used to interpret the empirical findings of the previous section on the effects of monetary shocks on stock prices under different policy rules. The model will be validated using the data in section 6.

The choice of the limited participation model is motivated by the need to replicate the main aspects of the monetary transmission mechanism: a contractionary monetary policy shock generating an increase in the short-term interest rate and a decrease in money, output, inflation and profits. In this class of models an expansionary monetary shock, measured by an exogenous increase in the growth rate of money, generates a liquidity

effect by decreasing the interest rate. By contrast, cash-in-advance models of the type described in Lucas (1982) and Svensson (1985) are not able to generate a liquidity effect after a serially correlated shock to the growth rate of money. The reason is that in this class of models, monetary policy is able to affect interest rates only through expected inflation. Sticky price models of the type considered in Christiano, Eichenbaum and Evans (1997) fail to account for the negative response of profits to a contractionary monetary policy shock. Therefore, this class of models cannot be used to analyze the implications of monetary policy for stock prices, which depends crucially on the behaviour of profits.

We now briefly describe the model. A representative household maximizes the expected discounted flow of instantaneous utilities which are given by:

$$U(C_t, C_t^h, N_t, H_t) = \frac{(C_t - C_t^h)^{1-\gamma}}{1-\gamma} - \psi_0 \frac{(N_t + H_t)^{1+\psi}}{1+\psi} \quad (6)$$

where $1/\psi$ is the elasticity of labour supply N_t and C_t is consumption. The parameters ψ_0 , ψ and γ are all positive. We allow for habit formation in consumption as in Boldrin, Christiano and Fisher (2001): C_t^h summarizes past choices of consumption goods purchases. This feature is introduced in order to replicate the hump-shaped response of consumption to monetary shocks that is found in empirical VAR analyses. According to Boldrin, Christiano and Fisher (2001), allowing for habits in consumption in a standard real business cycle model helps to account for a high equity premium without having to rely on highly risk averse households. We use the following specifications of habits in consumption: $C_t^h = \chi C_{t-1}^h + b C_{t-1}$.¹² The parameter b determines the degree to which consumption is intertemporally substitutable. In solving the model we will assume for simplicity that χ is equal to zero as in Christiano, Eichenbaum and Evans (2001).

A monetary friction is introduced, according to which households only gradually adjust their holdings of cash and deposits. This friction helps to generate an excess of liquidity

¹²Boldrin, Christiano and Fisher (2001) have experimented with more general specifications of the habits function C_t^h without any significant effect on the behaviour of asset prices.

in the economy after a monetary policy shock that drives the interest rate down. We introduce a cost for adjusting the cash that is used by the representative household to purchase consumption goods: this cost is modelled in terms of hours, H_t , spent organizing funds and withdrawing money from bank accounts. We will model H_t as a function of cash holdings Q_t , as in Christiano and Eichenbaum (1992):

$$H_t = d \left\{ \exp \left[c \left(\frac{Q_t}{Q_{t-1}} - \mu_Q \right) \right] + \exp \left[-c \left(\frac{Q_t}{Q_{t-1}} - \mu_Q \right) \right] - 2 \right\} \quad (7)$$

where μ_Q is the steady state gross growth rate of cash holdings.¹³ Both the function H_t and its first derivative, H'_t , equal zero in the steady state. The marginal cost of adjusting cash is an increasing function of the two parameters c and d : the larger the value of these parameters, the larger will be the response of the interest rate to a change in the growth rate of money.

Households face a cash-in-advance constraint on the purchases of consumption goods:

$$P_t C_t \leq W_t N_t + Q_t \quad (8)$$

where P_t is the price of consumption goods, W_t is the wage paid by firms and Q_t is cash holdings. An amount D_t , which is given by $M_t - Q_t$, is transferred to a representative financial intermediary. This receives a money injection X_t ($X_t = M_{t+1} - M_t$) from the central bank and lends the available funds $D_t + X_t$ to firms charging the interest rate R_t . Firms need to borrow in order to pay the workers before the products are sold. The loan market clearing condition requires the supply of loans to equal the demand

$$W_t N_t = D_t + X_t \quad (9)$$

We assume the existence of a financial market where stocks are traded. A stock is defined as the right for the holder to receive a dividend payment. In this market a

¹³Cooley and Quadrini (1999b) use quadratic adjustment costs for deposits.

representative mutual fund (*mf*) buys and sells stocks of a continuum of firms j (which are presented later on). Its objective is to maximize the sum of expected discounted profits:

$$\sum_{i=0}^{\infty} E_t \left[\beta^{i+1} \frac{\lambda_{t+i+1}}{\lambda_t} \int_0^1 \left(Z_{t+i}^j \Pi_{t+i}^j + Z_{t+i}^j P_{t+i}^j - Z_{t+i+1}^j P_{t+i}^j \right) dj \right] \quad (10)$$

where Z_t^j is the holding of stocks of firm j , P_t^j is their price and Π_t^j is the dividend. The profits of the mutual fund are paid as dividends to the households. The time index of the discount factor $\beta \frac{\lambda_{t+i+1}}{\lambda_t}$ reflects the fact that time t dividends of the mutual fund at time t can be used by households to purchase consumption goods only at $t + 1$.¹⁴ Taking the first order condition of this maximization problem with respect to Z_{t+i+1} and substituting forward we obtain the price for a stock of firm j

$$P_t^j = \sum_{i=1}^{\infty} E_t \left[\beta^{i+1} \frac{\lambda_{t+i+1}}{\lambda_t} \Pi_{t+i+1}^j \right] \quad \forall j \in (0, 1) \quad (11)$$

The mutual fund is meant to be only a descriptive device to model participation by households in stock markets and it does not play any role in the transmission of monetary policy shocks.

In a symmetric equilibrium, where the profits of all monopolistic firms are equal, the prices of the stocks of these firms are identical and the mutual fund holds one stock for each firm.¹⁵

$$Z_t^j = 1 \quad \forall j \in (0, 1) \quad (12)$$

The dividends paid by the mutual fund to the households are given by:

$$\Pi_t^{mf} = \int_0^1 \Pi_t^j = \Pi_t \quad (13)$$

¹⁴We rule out speculative bubbles in the stock market: this implies that prices in these markets are equal to the fundamental values of the stocks.

¹⁵We assume, for simplicity, a fixed supply of stocks normalized to one.

where Π_t^j are the profits made by each monopolistic firm. Since all firms are equal, as will be discussed later, they achieve the same level of profits Π_t .

The households' budget constraint is given by:

$$M_{t+1} = [W_t N_t + Q_t - P_t C_t] + r_t K_t + R_t [M_t - Q_t] + R_t X_t - P_t I_t + \quad (14)$$

$$+ Z_t^{mf} \Pi_t^{mf} + Z_t^{mf} P_t^{mf} - Z_{t+1}^{mf} P_t^{mf}$$

where the term in the first bracket is the cash not spent in the goods market, $r_t K_t$ represents the payment received by the household for renting capital K_t to the firm sector at the rental price r_t , $P_t I_t$ is the value of investment goods purchased, $R_t X_t$ are the profits of the financial intermediary, Z_t^{mf} and P_t^{mf} are respectively the beginning of period holding of stocks of the mutual fund and their price, and Π_t^{mf} the dividends paid by the mutual fund.¹⁶ These are paid proportionally to the holding of stocks at the beginning of period t . Investment is subject to an adjustment cost, which we model as in Christiano, Eichenbaum and Evans (2001): this implies that one extra unit of investment does not transform into one extra unit of capital. The law of motion of the stock of capital is given by

$$K_{t+1} = (1 - \delta)K_t + F(I_t, I_{t-1}) \quad (15)$$

where δ is the depreciation rate, I_t is the amount of investment goods and F is a technology that transforms past and current investment into productive capital K_{t+1} . The properties of the F function are crucial in determining the shape of the response of investment to monetary shocks. This modelling of adjustment costs produces a hump-shaped response of investment to a monetary shock, a result that is well documented in the VAR literature on the macroeconomic effects of monetary policy. This function is given by:

$$F(I_t, I_{t-1}) = \left[1 - S \left(\frac{I_t}{I_{t-1}} \right) \right] I_t \quad (16)$$

¹⁶We assume for simplicity that the stock of capital is owned by the household.

Both the function S and its first derivative are equal to zero in the non-stochastic steady state, while the second derivative is equal to s ($s > 0$). The inverse of s measures the elasticity of investment to a one per cent increase in the current price of installed capital $P_{k',t}$.

In the asset market, M_{t+1} , Z_{t+1}^{mf} and Q_t are chosen, while in the goods market C_t , I_t , K_{t+1} and N_t are chosen. We now briefly present and discuss the first order conditions of the representative household's maximization problem. The first order condition for money holding is given by:

$$\lambda_t - \beta E_t (\lambda_{t+1} R_{t+1}) = 0 \quad (17)$$

where R_t is the interest rate on deposits and λ_t is the multiplier of the representative household's budget constraint, which measures the marginal utility of one extra dollar in the asset market. The first order condition for cash holdings is given by:

$$U_{t,H_t} H_{t,Q_t} \frac{1}{Q_{t-1}} - \beta E_t \left(U_{t+1,H_{t+1}} H_{t+1,Q_t} \frac{Q_{t+1}}{Q_t^2} \right) + \nu_t + \lambda_t - \lambda_t R_t = 0 \quad (18)$$

The term $\nu_t + \lambda_t$ measures the benefit of increasing Q_t by one dollar, which is given by the marginal utility of $1/P_t$ extra units of consumption goods while $\lambda_t R_t$ gives the cost in terms of utility of reducing deposits. The multiplier ν_t measures the value for the household of an extra dollar to be spent in the goods market, that is the value of the liquidity services of real money. The remaining terms represent the cost of adjusting cash holdings, respectively at time t and $t + 1$. The term H_{t,Q_t} denotes the derivative of H_t with respect to Q_t and U_{t,H_t} the derivative of period t utility with respect to H_t .

The first order condition for stock holdings is given by:

$$-\lambda_t P_t^{mf} + \beta E_t (\lambda_{t+1} P_{t+1}^{mf} + \lambda_{t+1} D_{t+1}^{mf}) = 0 \quad (19)$$

where P_t^{mf} is the price of a stock and Π_t^{mf} is the dividend paid by the mutual fund. Substituting forward equation (19) we obtain the usual pricing equation for an asset paying dividends:

$$P_t^{mf} = \sum_{i=1}^{\infty} E_t \left(\beta^i \frac{\lambda_{t+i}}{\lambda_t} \Pi_{t+i}^{mf} \right) \quad (20)$$

A similar asset pricing condition is derived by Lucas (1982) and Svensson (1985) who analyze cash-in-advance models. The price of a stock at time t is given by the sum of the discounted (by the marginal utility of wealth) flow of future dividends. The discount factor is given by $\beta^i \frac{\lambda_{t+i}}{\lambda_t}$. The price of a stock of the mutual fund can be seen as a stock market index in which individual firms' prices are averaged with equal weights.

The first order condition for consumption and hours worked together implies the following labour supply equation:

$$\frac{U_{t,C_t} + \beta E_t U_{t+1,C_t}}{P_t} + \frac{U_{t,N_t}}{W_t} = 0 \quad (21)$$

The first order condition for the choice of capital is

$$-\lambda_t P_{K,t} + \beta E_t [\lambda_{t+1} r_{t+1} + \lambda_{t+1} P_{K,t+1} (1 - \delta)] = 0 \quad (22)$$

where $P_{K,t}$ is the shadow price at time t of an extra unit of installed capital and $r_{t+1} + P_{K,t+1} (1 - \delta)$ is the corresponding benefit. It is an arbitrage condition according to which the cost of giving up one unit of consumption must be equal, in terms of utility, to the benefit that can be obtained from the extra unit of capital in the following period. If there were no adjustment costs for investment, the shadow price of new capital would be equal to the price of consumption goods. The first order condition for investment implies

$$-\lambda_t P_t + \lambda_t P_{K,t} F_{1,t} + \beta E_t (\lambda_{t+1} P_{K,t+1} F_{2,t+1}) = 0 \quad (23)$$

The term in brackets is the value, in terms of utility, of an extra unit of investment: this unit produces $F_{1,t}$ units of installed capital at time t and $F_{2,t+1}$ units at time $t + 1$. The cost of one extra unit of investment is equal to the price of consumption goods.

We now describe the firm sector. We assume the existence of a continuum of monopolists on the $(0, 1)$ interval that produce an intermediate good j using a constant return to scale technology with capital and labour as inputs. We rule out entry and exit into the intermediate firm sector and we assume that these firms are owned by the mutual fund. All these firms face the same problem, which consists in maximizing period t profits which are defined as

$$\Pi_t^j = P_t^j Y_t^j - C(r_t, R_t W_t, Y_t^j) \quad (24)$$

where Y_t^j is the demand by households for goods sold by firm j at price P_t^j , given by

$$Y_t^j = Y_t \left(\frac{P_t}{P_t^j} \right)^{\frac{\mu}{\mu-1}} \quad (25)$$

and $\frac{\mu}{(\mu-1)}$ is the constant elasticity of demand. The first order condition of the problem of choosing the price P_t^j that maximizes time t profits is given by the standard pricing formula:

$$P_t^j = \mu MC_t^j \quad (26)$$

where in equilibrium the marginal costs MC_t^j are equal for all firms since they have access to the same production technology and they face the same factor prices W_t and r_t . Marginal costs are given by:

$$MC_t = A r_t^\alpha (W_t R_t)^{1-\alpha} \quad (27)$$

where A is a constant.¹⁷ The production technology is a standard Cobb-Douglas function with capital share α and fixed cost of production ϕ . Since we focus on a symmetric

¹⁷The expression for marginal costs can be derived from minimization of total costs $w_t R_t N_t + r_t K_t$.

equilibrium, we set $P_t^j \equiv P_t$, where P_t is the price of the consumption good (produced by the competitive firm described below).

Finally, intermediate goods are combined into a final good by a competitive firm with the following CES technology:

$$Y_t = \left[\int_0^1 (Y_t^j)^{1/\mu} dj \right]^\mu \quad (28)$$

where goods are indexed by $j \in (0, 1)$, Y_t is the output of the competitive firm and Y_t^j is the output of the j^{th} monopolistic firm. Finally, the resource constraint of the economy, is

$$Y_t = C_t + I_t \quad (29)$$

5.1 Specification of monetary policy

In this section we specify how monetary policy is conducted in order to close the model. Rules that set the level of a short-term interest rate have become very popular in the literature on monetary policy: the most famous is the so-called ‘‘Taylor rule’’, according to which the interest rate responds to contemporaneous inflation and output gap. We will specify a general class of interest rate feedback rules of the type analyzed in Clarida, Galí and Gertler (1998). A target for the short-term interest rate is set by the central bank. The target is given by:

$$R_t^* = \bar{R} + \rho_Y (Y_t - \bar{Y}) + \rho_\pi (\pi_t - \bar{\pi}) + \rho_m (m_t - \bar{m}) \quad (30)$$

where \bar{R} , \bar{Y} , $\bar{\pi}$ and \bar{m} are respectively the steady state values of the short-term nominal interest rate, output, inflation and real balances. Potential output is assumed to be constant since shocks, such as technology, that can produce fluctuations in this variable are not considered. The Taylor rule is obtained by setting α to 0.5, β to 1.5 and γ to

0. The rule is referred to as partial accommodation if γ is different from zero: a positive value identifies an upward sloping supply of real money. The actual short-term interest rate is adjusted according to the following partial adjustment mechanism:

$$R_t = (1 - \rho_R) R_t^* + \rho_R R_{t-1} + \epsilon_t \quad (31)$$

where ρ , measuring the speed of adjustment, belongs to the $[0, 1]$ interval and ϵ_t is the monetary policy shock. Under these rules, the central bank provides, through money injections X_t to the financial intermediary, whatever amount of money is demanded by households.

Alternatively monetary policy can be defined in terms of a money growth rule, according to which the gross growth rate of the money supply $g_t = \frac{M_{t+1}}{M_t}$ is adjusted in response to the monetary policy shock. Therefore, the rule is given by:

$$A(L) g_t = B(L) \epsilon_t \quad (32)$$

where $A(L)$ and $B(L)$ are two lag operators and ϵ_t is the monetary policy shock. For simplicity we will assume an autoregressive process of order one for g_t with coefficient ρ_g .

5.2 Calibration of parameters and impulse responses

The first order conditions for the households, the cash-in advance constraint (assumed to be binding due to local non-satiation), the intermediate firms pricing condition, the loan market clearing conditions and the resource constraint are linearized around the steady state after having normalized all nominal variables by P_{t-1} to achieve stationarity. The system consisting of the linearized equilibrium conditions is solved with the method described in Christiano (1998).

The following table reports the calibrated parameters of the benchmark model.

TABLE 4
Calibrated parameters: benchmark model

utility function	β	γ	ψ	ψ_0^a	b	c	d
	0.9975	2.0	0.57	0.94	0.6	1000	0.00005
others	α	μ	ϕ	s	δ	$\bar{\pi}$	
	0.36	1.25	0.51	5.0	0.0087	2.5	

^a The parameter is chosen so that N is equal to 1 in steady state.

The calibration of the parameters is based on different sources. The value of the households' discount factor, β , is chosen so that the steady state value of the real interest rate is equal to 3 per cent per year. The values of b , which measures the degree of habits in consumption, is close to the estimate in the benchmark model in Christiano, Eichenbaum and Evans (2001). The parameter ψ , measuring the inverse of the elasticity of the labour supply, is taken from Christiano, Eichenbaum and Evans (1996b): it implies an elasticity of the labour supply of 1.75. The parameters c and d , which affect the marginal cost of adjusting cash holdings, are taken from Christiano and Eichenbaum (1992). This parameter is crucial in determining the persistence of the liquidity effect when a money growth rule for monetary policy is assumed. On the other hand, they have a smaller effect when an interest rate rule is assumed. With respect to the capital share in the production function, α , we have chosen the standard value of 0.36 used in the literature on business cycle models. The parameter s of the investment adjustment cost function is set close to the average of the values estimated in Christiano, Eichenbaum and Evans (2001). The parameter μ , measuring the mark-up of prices over marginal costs, is set to 1.25, close to the benchmark value used in Christiano, Eichenbaum and Evans (1997). The value of the fixed cost ϕ is calibrated assuming that the ratio of real profits to output is equal to 6 per cent as found in US data for the period 1985-2000.¹⁸ Finally, the steady state annual inflation rate is set at 2.5 per cent.

The following table reports the responses on impact and after two years of stock prices to a contractionary one per cent monetary policy shock.

¹⁸The fixed cost is given by $\phi = \frac{\mu(1-s_\pi)\bar{K}^\alpha - \bar{K}^\alpha}{\mu(1-s_\pi)}$ where s_π is the share of profits, in real terms, relative to output. We have set \bar{N} equal to 1. The steady state level of capital is denoted with \bar{K} .

TABLE 5
Monetary policy rules and response of stock prices^a

monetary policy rule	coefficients					response ^b	
	ρ_Y	ρ_π	ρ_m	ρ_R	ρ_g	$k = 1$	$k = 24$
1. Taylor	0.5	1.5	0	0	0	-4.9	-0.0
2. Taylor	0.5	1.5	0	0.75	0	-6.6	-0.3
3. partial accommodation	0.5	1.5	0.3	0.75	0	-6.4	0.1
4. inflation targeting	0	1.5	0	0.75	0	-11.0	-7.7
5. money growth	0	0	0	0	0.3	-9.4	-6.5

^a Responses, in nominal terms, to a contractionary one per cent policy shock.

^b Percentage deviation from unshocked path after k periods.

Under all these rules, a contractionary monetary shock determines an increase in the short-term interest rate and a decrease in nominal stock prices and money. Inflation targeting and money growth rules produce persistent effects on stock prices, while this is not the case for those rules in which the coefficient of the output gap is different from zero. The reason is that the latter have a stabilizing effect on the economy: when the output gap becomes negative, the central bank reduces the target and the actual short-term interest rate and this has a positive effect on production, inflation and profits. In these cases, the level of nominal variables is not permanently affected by monetary policy: nominal profits, which are a determinant of stock prices, return to the baseline value after a monetary policy shock and this produces a transitory effect on nominal stock prices. The same results are obtained if a positive coefficient is assumed for real money and the coefficient for the output gap is set at zero.

The following figure reports the responses of the interest rate, money and stock prices to a contractionary monetary policy shock under the different rules specified in section 5.1.

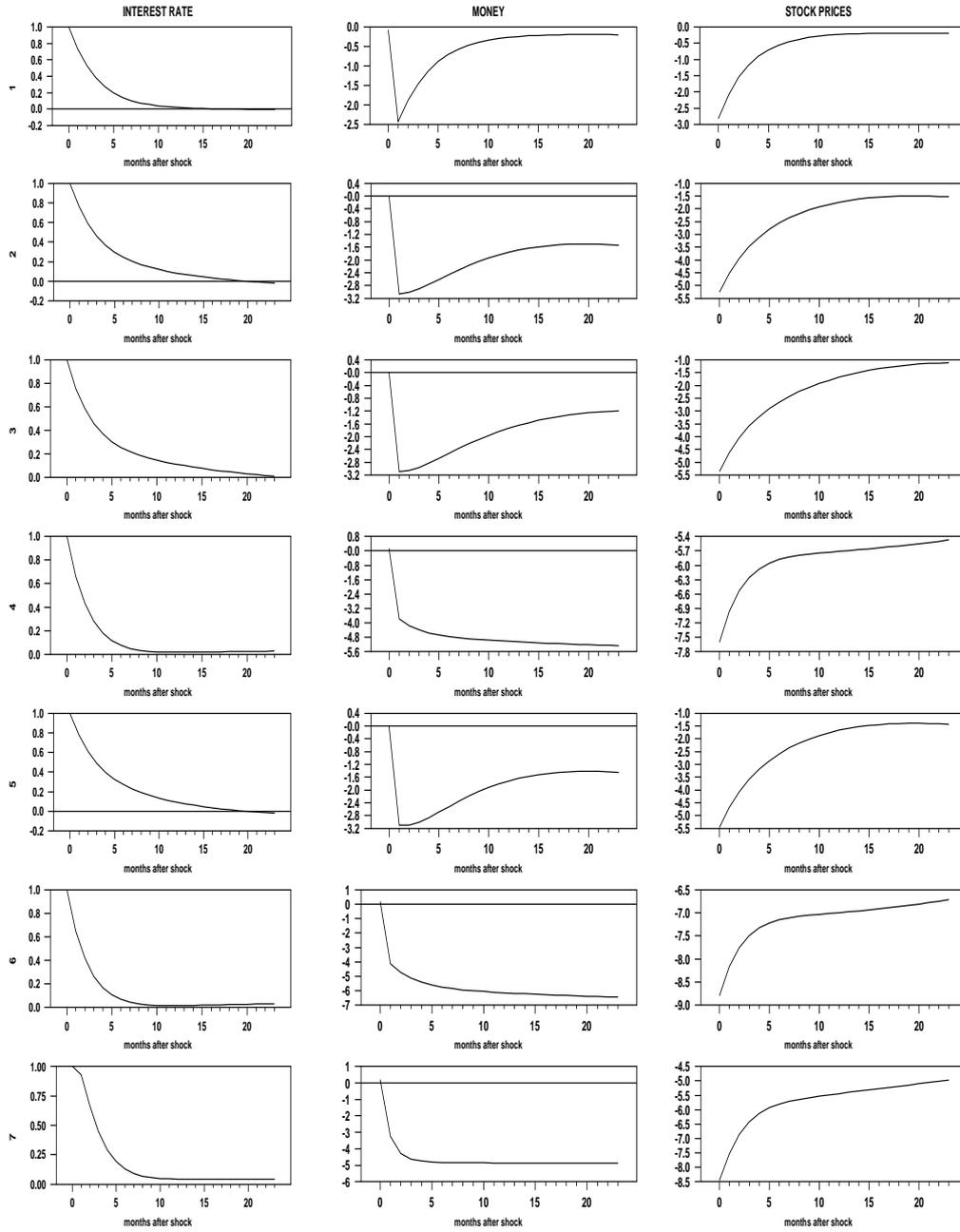


Fig. 2 Response of stock prices to a contractionary monetary policy shock under different rules

The interpretation of the response of stock prices to a monetary policy shock can be based on the pricing condition (20), according to which the price of a stock is equal to the sum of future discounted dividends, given the information available at time t . Monetary policy shocks influence stock prices either through the discount factor $\beta^i \frac{\lambda_{t+i}}{\lambda_t}$ or future dividends D_{t+i}^{mf} . In our model a contractionary monetary shock, measured either by an exogenous decrease in the growth rate of money or an increase in the short-term interest rate, produces an increase in firms' marginal costs and a decrease in production and profits. As a consequence of the decrease in labour and capital income, households decrease deposits, investment and stock holdings in order to smooth consumption. The returns to these assets are linked by no-arbitrage conditions (as can be seen from equations (17), (18), (19), (22) and (23)). Therefore, the decrease in stock prices is the consequence of lower future dividends and a lower demand for stocks for a given supply.

A sensitivity analysis of the response of stock prices to a contractionary monetary shock (see Figure 3) shows that, in the benchmark calibration and under a partial adjustment Taylor rule, the value of the mark-up μ and of the fixed cost ϕ play an important role in shaping the response. These parameters affect both the steady state of the model and the dynamics of dividends, as can be seen from the following equation:

$$\hat{\Pi}_t = \frac{1}{\bar{\Pi}} \left(\bar{\pi}\bar{Y} - \frac{\bar{\pi}\bar{Y}}{\mu} - \phi \frac{\bar{\pi}}{\mu} \right) \hat{\pi}_t + \frac{\bar{\pi}\bar{Y}}{\bar{\Pi}} \left(1 - \frac{1}{\mu} \right) \hat{Y}_t \quad (33)$$

where a hat denotes the percentage deviation from steady state of real dividends Π , output, Y , and inflation, π . The fixed cost ϕ , when different from zero, and the mark-up μ determine the dynamics of profits and consequently stock prices. This is not the case when ϕ is equal to zero¹⁹, in which case the above equation becomes:

$$\hat{d}_t = \hat{\pi}_t + \hat{Y}_t \quad (34)$$

¹⁹This can be seen by noting that $\bar{\Pi} = \bar{\pi}\bar{Y} \left(1 - \frac{1}{\mu} \right)$.

As can be seen from Figure 3, setting the fixed cost equal to zero determines a smaller and less persistent response of nominal stock prices than the benchmark calibration. The reason is that, as it can be seen from (33), the presence of fixed costs implies a higher dependence of real profits on output (the coefficient on \hat{Y}_t is equal to 3.3 compared with a coefficient of 1). The choice of the mark-up μ is not relevant when the fixed cost is calibrated as it is described in footnote 7. On the other hand, it becomes relevant when the fixed cost is set at zero by affecting the steady state of the economy. A smaller mark-up (1.05) implies a larger response of stock prices, mainly reflecting a larger impact of monetary policy on inflation, partially compensated by a smaller effect on output. The opposite happens for a larger mark-up (1.8). The higher the degree of monopolistic competition in the intermediate firm sector, the smaller is the response of dividends and nominal stock prices.

The parameter c that determines the magnitude of adjustment costs for changing cash holdings is also important in determining the behaviour of stock prices. A low value of c (200) implies a quicker adjustment of cash and deposits and consequently, by an arbitrage condition, stock holdings. For a given supply of stocks, this implies larger movements in stock prices. A larger c (2000) does not yield significantly different responses from the benchmark calibration. Changing the degree of risk aversion (γ) (from 1.01 to 4), the degree of habits in consumption (setting b equal to zero) and the elasticity of labour supply ($\frac{1}{\psi}$) (from 0.057 to 10.57) has a smaller impact on the response of stock prices to monetary policy shocks. The following figure reports the responses of nominal stock prices under different calibration of parameters.

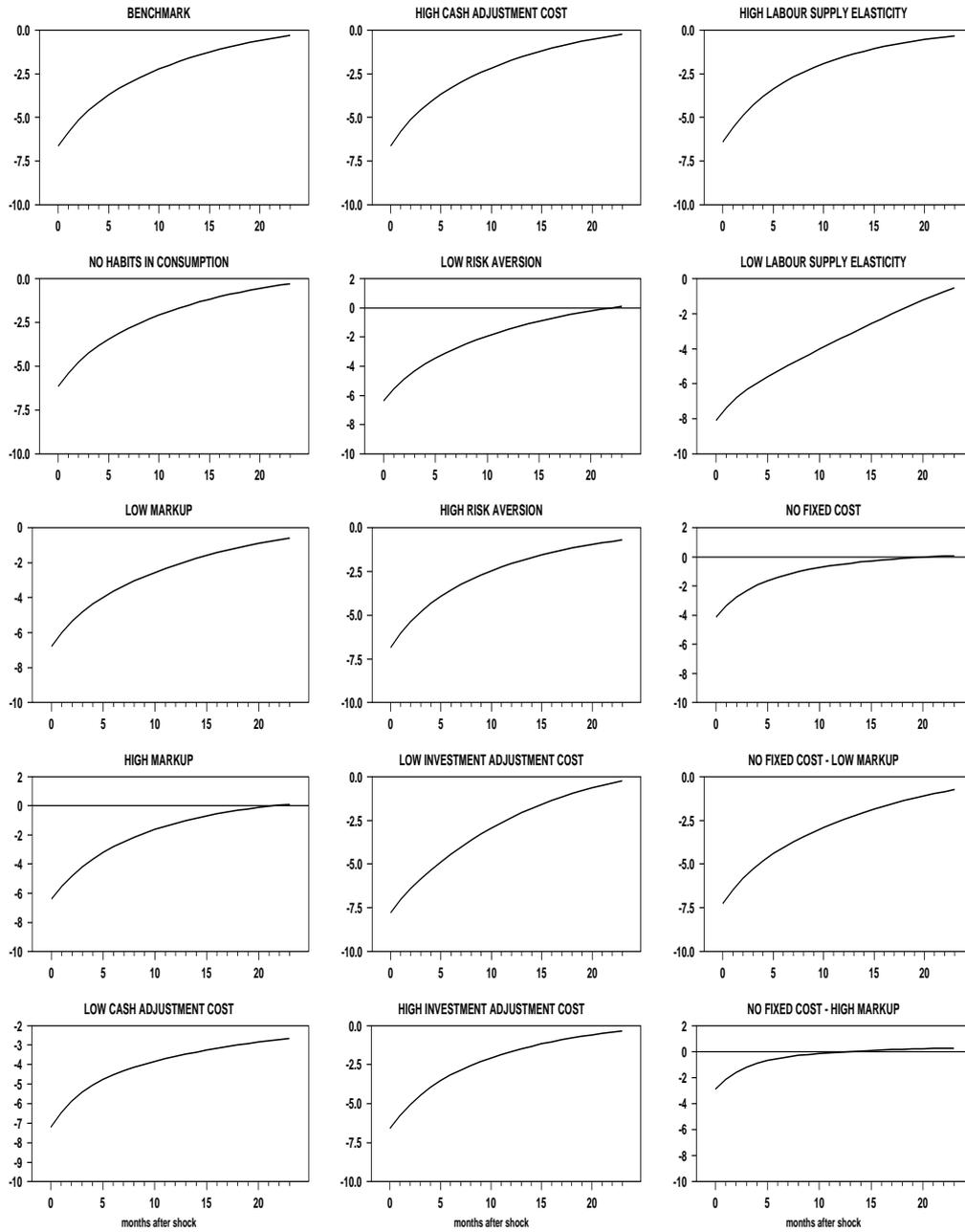


Fig. 3 Sensitivity analysis of the response of stock prices

6. Validating the model

In this section we will proceed in validating the proposed model against actual data. We will apply the methodology described in Canova (2001) to US and German data

(since these are the only results available for the moment). This approach takes seriously the objection that the proposed model represents an approximation to the true data generating process (DGP) and the idea that economic theory should be used in validating DSGE models. The proposed approach to validation combines calibration of theoretical models and VAR analysis.

We now briefly describe the approach. The first step consists in finding robust implications of the model. These are implications that are robust to different sets of parameters, different functional forms of the primitives and different monetary policy rules. In the second step, these implications, in the form, for example, of the signs of the impulse responses or their cross-correlations, are used to identify shocks in the data. An argument in favour of this identification strategy for VARs can be found in Canova and Pina (1999). The authors find that the zero restrictions generally used in the VAR literature can be inconsistent with the dynamic relationships among variables predicted by DSGE models.

In the third step, a qualitative comparison is made of the responses of variables to identified shocks, in order to examine whether and to what extent the dynamics of the model and the data are similar. In the last step the validation process uses the quantitative implications (impulse responses and variance decompositions) of the model and the data and tests the significance of their equality. Canova (2001), for example, compares the value of the half-life of output predicted by sticky price and limited participation models to see whether they are able to generate sufficient persistence in the response of output to monetary shocks.

The responses of money, stock price, output and prices to a monetary shock are used as a robust implication of the limited participation model we have set up. To evaluate the robustness of the signs of the responses we have used different sets of calibrated parameters and different monetary policy rules (see Figures 2 and 3). A contractionary monetary shock always increases the short-term interest rate and decreases nominal stock prices and money. Also output and prices always decline.

The signs of the responses are used as restrictions to be imposed on US and German

data following Canova and De Nicoló (2002). The covariance matrix of the reduced-form VAR residuals, Σ , is decomposed into PDP' where D is the matrix of eigenvalues and P the matrix of corresponding eigenvectors. An algorithm searches along all possible rotation matrices $Q_{m,n}$ and angles ω that satisfy the sign restrictions we have imposed using the following decomposition: $\Sigma = PD^{\frac{1}{2}}Q_{m,n}Q'_{m,n}D^{\frac{1}{2}}P'$. The matrices $Q_{m,n}$ are orthonormal (such that $QQ' = I$).²⁰ The algorithm found three identifications that satisfy the sign restriction. Two identifications were discarded because they implied implausible magnitudes for the responses of stock prices and output. The following figure reports the responses of the short-term interest rate, money and stock prices to a contractionary monetary policy shock. For comparison we also report the responses obtained in section 4 and those obtained with the theoretical model under a partial adjustment Taylor rule (rule 2 in Table 6).

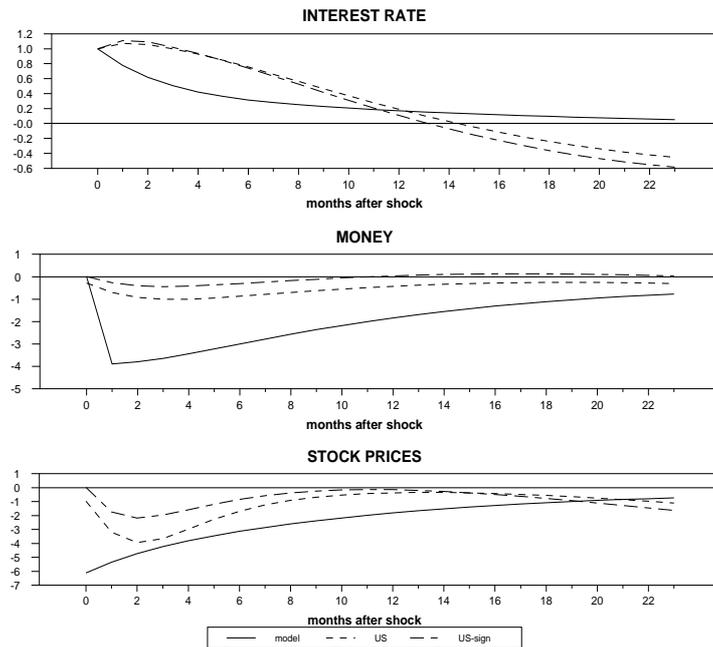


Fig. 4 Responses to a contractionary monetary policy shock (US)

The responses are qualitatively similar although the magnitudes are slightly different. It is important to underline that the responses obtained with the structural identification

²⁰For the definition of matrices $Q_{m,n}$ see Canova (2001).

are very close to those obtained with the sign restriction identification: the reason is that in the identification scheme we proposed, money and the stock price index can respond contemporaneously to changes in the short-term interest rate. The model and the data responses can also be compared using the cross-correlations of the impulse responses of interest rate, money and stock prices. Figure 5 reports these correlations.

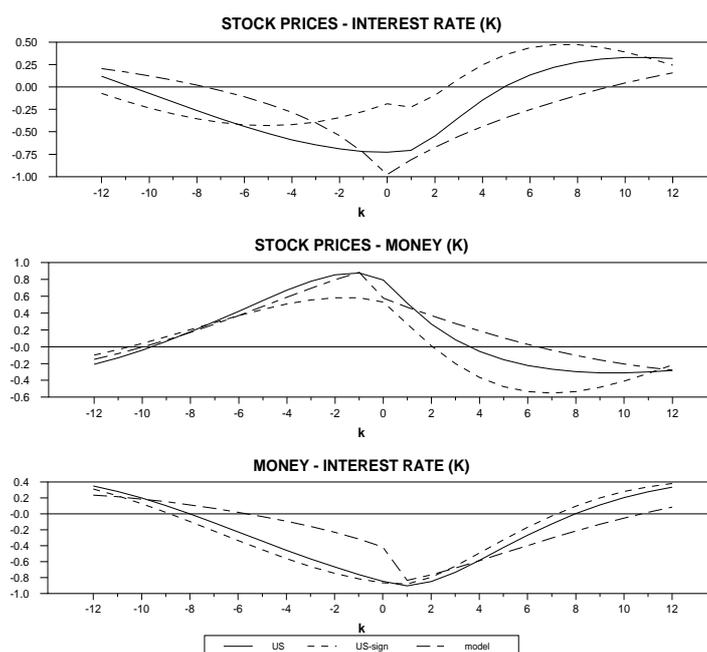


Fig. 5 Cross-correlations of responses to a contractionary monetary policy shock (US)

The figure shows that the cross-correlations of the responses are very similar in the model and in the data for the US: the model performs well in accounting, at least qualitatively, for the responses of interest rate, money and stock prices.²¹ The results for Germany are reported in the appendix (Figures 7 and 8).

7. Conclusions

In this paper we have analyzed the relationship between monetary policy and stock market indices in the G-7 countries and Spain using the methodology of structural VARs. We have found that contractionary monetary policy shocks, measured by exogenous increases

²¹Similar results are obtained using a forward-looking Taylor rule in the theoretical model.

in the short-term interest rate have, on average, small, negative and transitory effects on stock market indices. The persistence, the magnitudes and the timing of these effects differ significantly across countries. The results are in line with previous works that have relied on an alternative identification of monetary policy shocks.

The limited participation model, modified to allow households trading in stocks, which we have set up is able to replicate, at least from a qualitative point of view, the empirical responses of stock price indices to monetary policy shocks under a variety of monetary policy rules and calibration of parameters.

Appendix I. Figures

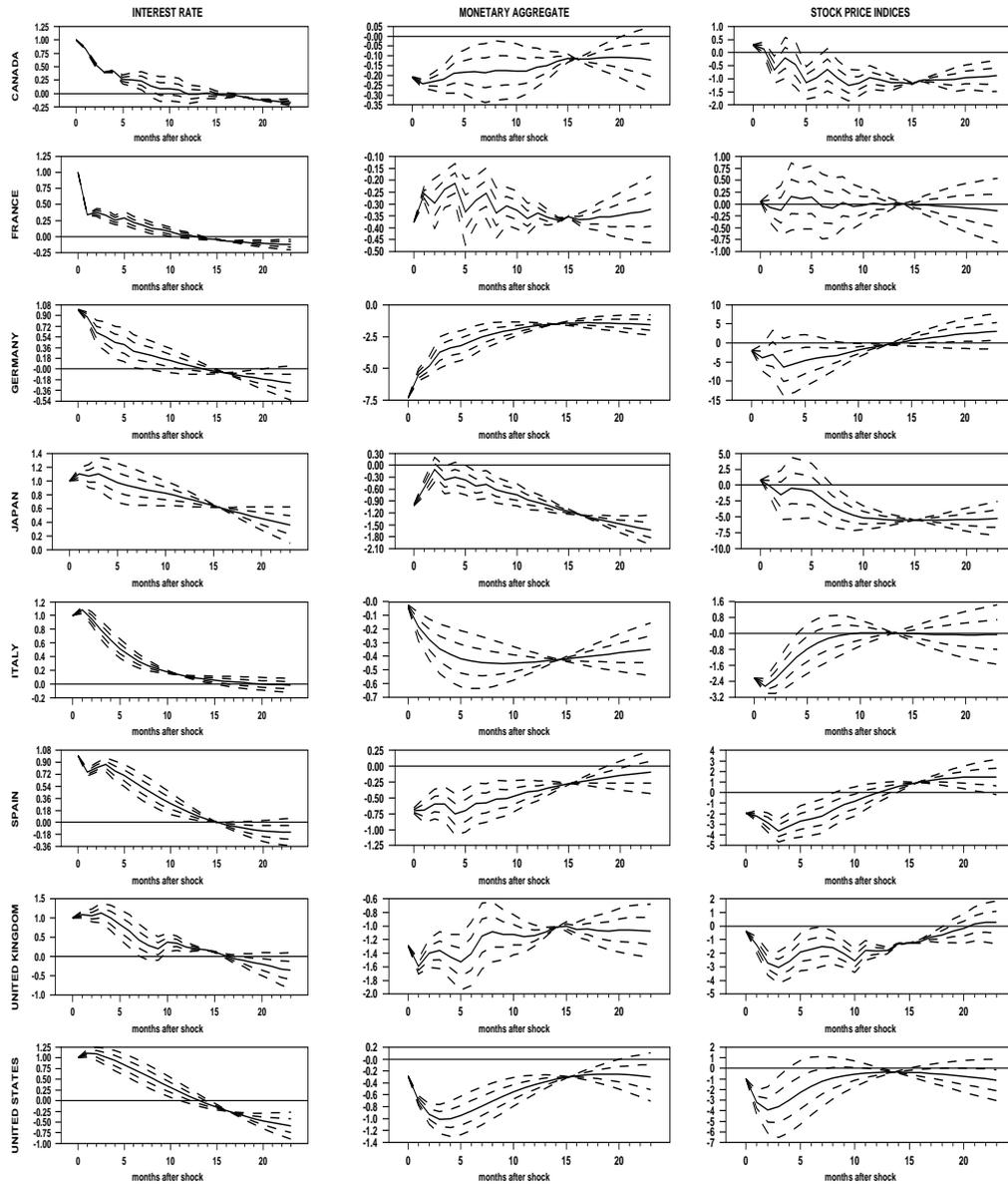


Fig. 6 Contractionary monetary policy shock: second principal component (68 and 95 per cent probability bands)

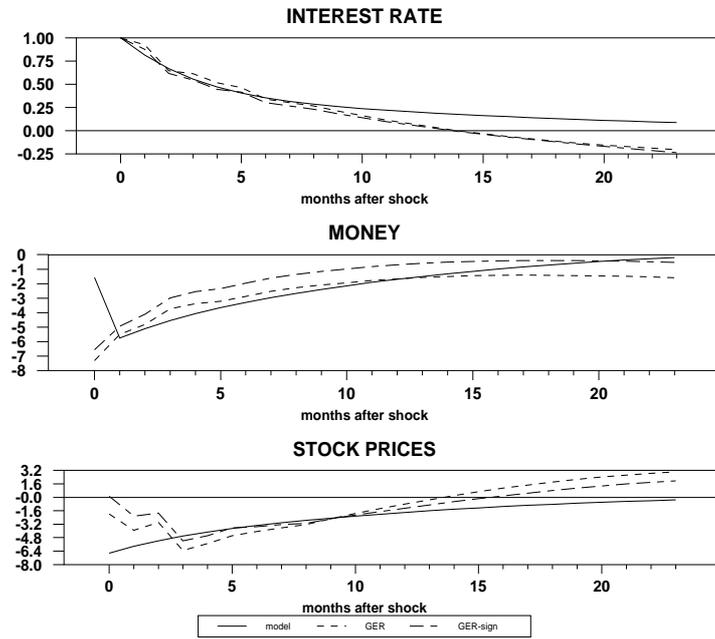


Fig. 7 Responses to a contractionary monetary policy shock (Germany)

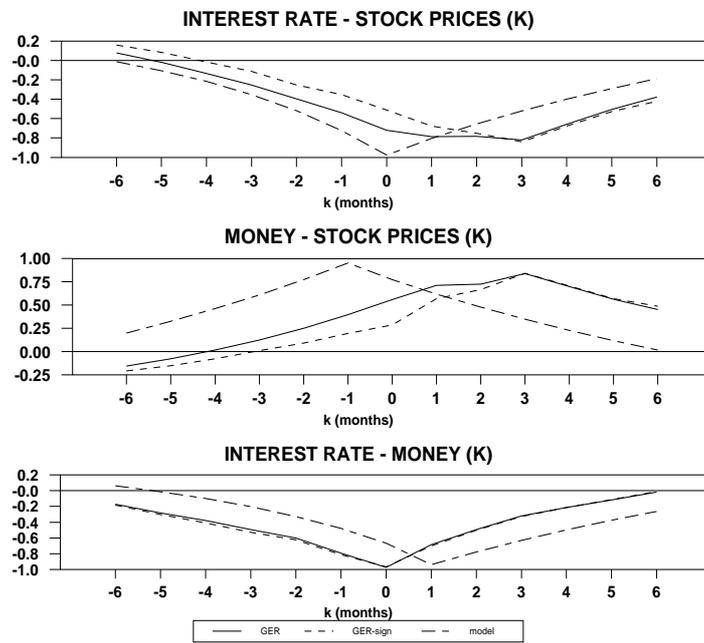


Fig. 8 Cross-correlations of responses to a contractionary monetary policy shock (Germany)

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