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## **Identifying the Interdependence between US Monetary Policy and the Stock Market**

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# Identifying the Interdependence between US Monetary Policy and the Stock Market\*

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## Abstract

We estimate the interdependence between US monetary policy and the S&P 500 using structural VAR methodology. A solution is proposed to the simultaneity problem of identifying monetary and stock price shocks by using a combination of short-run and long-run restrictions that maintains the qualitative properties of a monetary policy shock found in the established literature (CEE 1999). We find great interdependence between interest rate setting and stock prices. Stock prices immediately fall by 1.5 percent due to a monetary policy shock that raises the federal funds rate by ten basis points. A stock price shock increasing stock prices by one percent leads to an increase in the interest rate of five basis points. Stock price shocks are orthogonal to the information set in the VAR model and can be interpreted as non-fundamental shocks. We attribute a major part of the surge in stock prices at the end of the 1990s to these non-fundamental shocks.

**Keywords:** VAR, monetary policy, asset prices, identification.

**JEL-codes:** E61, E52, E43.

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## 1. Introduction

Most economists acknowledge that monetary policy has a strong influence on private-sector decision-making. In accordance with New-Keynesian theory, the central bank exerts some control of the real interest rate due to prices being sticky in the short run. Through its effect on both the current and the expected future real interest rate, the central bank influences both the timing of household consumption and business investment decisions through the rental rate of capital. It is commonly assumed that asset prices and, in particular, stock prices, are determined in a forward-looking manner, thereby reflecting the expected future discounted sum of return on the assets. Changes in asset prices can then either be due to changes in expected future dividends, the expected future interest rate that serves as a discount rate, or changes in the stock returns premium. If goods markets are dominated by monopolistic competition and mark-up pricing, profits will, at least in the short run, be affected by all factors influencing aggregate demand. Moreover, the change in the path of profit may influence the expected dividends. Monetary policy, and in particular surprise policy moves, is therefore not only likely to influence stock prices through the interest rate (discount) channel, but also indirectly through its influence on the determinants of dividends and the stock returns premium by influencing the degree of uncertainty faced by agents. On the other hand, since asset prices may influence consumption through a wealth channel and investments through the Tobin Q effect and, moreover, increase a firm's ability to fund operations (credit channel), the monetary policymaker that manages aggregate demand in an effort to control inflation and output has incentives to monitor asset prices in general, and stock prices in particular, and use them as indicators for the appropriate stance of monetary policy. Therefore, there is likely to be a strong interdependence between stock prices and monetary policymaking.

Both the identification and the effect of monetary policy have to a large extent been addressed in terms of vector autoregressive (VAR) models, initiated by Sims (1980). The VAR literature has to a large extent disregarded the link between asset markets and monetary policy. There may be several reasons for this. One reason might be a belief that asset-price information conveys little additional information that is not incorporated elsewhere, i.e. in other macroeconomic variables incorporated in the VAR models. Another, but related, reason may be that asset price information does not provide additional information in forecasting neither the determinants of the target variables nor the target variables themselves.<sup>1</sup> A third reason may be that the empirical investigation has been hampered by a simultaneity problem: Since asset prices are likely to immediately respond to a monetary policy shock, and monetary policy may immediately respond to an asset price shock, the structural shocks cannot be recovered using recursive, short-run restrictions on the parameters, that has been the common way to identify monetary policy shocks in the traditional VAR models. It can, however be argued, that the first two suggested explanations in fact form interesting hypotheses that can be investigated using empirical methods. The third explanation is a more serious obstacle that needs to be addressed before any empirical investigation can be made.

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<sup>1</sup> The empirical finance literature has focused on explaining excess returns to assets, and the risk-free return is largely taken as given or explained by a simple, exogenous process.

In this study, we consider the interdependence between stock prices and monetary policy within a VAR model and take full account of the simultaneity problem. We solve the simultaneity problem by imposing a combination of short-run and long-run restrictions on the parameters of the VAR model. Asset price shocks are found to be important factors in explaining the variability of inflation and output. Furthermore, we find that a contractionary monetary policy shock has the usual effects identified in other studies as increasing the interest rate, temporarily lowering output and has a sluggish and eventually negative effect on consumer price inflation. Moreover, a contractionary monetary policy shock reduces real stock prices. Monetary policymaking is also influenced by the stock market, as the interest rate rises significantly in response to a positive stock market shock.

In Section 2, we discuss the role that might be played by asset prices in monetary policymaking and review the literature. Section 3 discusses the VAR methodology used and Section 4 discusses the empirical results. Then, Section 5 provides robustness checks and Section 6 concludes.

## **2. What role should asset prices play in monetary policymaking?**

What role asset prices should play in the conduct of a welfare-optimizing monetary policy is an important topic in current monetary-policy analysis. From a theoretical point of view, there are at least two important questions that could be addressed. First, should the central bank target asset prices *per se*, i.e., should the stabilization of asset prices be a separate objective of the central bank? Second, to what extent should the central bank use asset-price information as indicators of the monetary-policy stance, i.e., should the central bank respond with the monetary policy instrument to asset price movements? The beginning of this section discusses these questions.

### **2.1 Asset prices as separate objectives**

In providing some illumination to these questions, it is convenient to start considering the theoretical foundations of monetary policymaking. Milton Friedman (1969) shows that in a setting with no nominal rigidities, monetary policy should supply money at a rate that is consistent with having nominal interest rates at zero, implying a rate of deflation equal to the yield on a risk-free asset. Under the assumption of a Calvo (1983) type of nominal rigidities, Rotemberg and Woodford (1998) show that the central bank should stabilize the output gap, i.e., the deviations of actual output from the flexible-price level of output, in addition to inflation from a zero target level. The existence of nominal rigidities creates price dispersions disturbing the relative price signals of scarcity. By targeting inflation at the rate of zero, price dispersions are minimized, as price changes at the firm level are not caused by the requirement to keep up with the general increase in prices.

Price stickiness is not the only market imperfection that may provide a welfare enhancing role for monetary policy. Other market imperfections may rationalize other roles for monetary policy. Bernanke and Gertler (1999) and Carlstrom and Fuerst (2001) both argue that due to imperfect credit markets, the financial position of the firm may influence its ability to operate. An increase in asset prices may affect this operating constraint importantly by

affecting the net worth of the firm. By using a New-Keynesian framework where inflation is linked to real activity, Bernanke and Gertler conclude that responding to the forecast of inflation is sufficient to alleviate the adverse effect of the constraint; Carlstrom and Fuerst argue that the market imperfection substantiates a separate response of monetary policy to asset prices. Allen and Gale (2004) argue that agency problems between the bank and the investors may lead the investors to choose more risky investment projects and bid up asset prices: The greater the risk, the larger is the asset price bubble. Moreover, a negative bubble may occur when the bank starts liquidating assets as asset prices fall. They argue that the central bank should design policy so as to reduce uncertainties and stabilize asset prices around their fundamental values.

Borio and Lowe (2002) provide evidence of high asset price growth together with rapid credit expansion being an important indication for the risk of future financial instability, motivating a response from the central bank that explicitly cares about financial stability. However, they also argue that the indicator may suggest a threat to monetary stability, since financial instability may influence aggregate demand. Bordo and Jeanne (2002a, 2002b) also explore this idea. They argue that the existence of financial market imperfections, in particular the role played by collateral in making credit available to the firms, may be an argument in favor of the central bank restricting the expansion of credit in periods with high asset price growth. Their argument is that if asset prices suddenly fall (bust), the value of the collaterals will also fall, thus producing a high credit-to-collateral ratio and possibly a credit crunch associated with inefficient falls in both output and inflation. Thus, the risk of a future decline in asset prices and a credit channel of monetary policy introduce a role for reacting “pre-emptively” in times of booms to the risk of credit crunches in the future.<sup>2</sup>

Many central banks have announced inflation-targeting policies, where the policymaker mainly attempts at stabilizing inflation around some (positive) target level and the output gap around zero (see, e.g., Svensson 1997). These objectives can be seen from a welfare-theoretical point of view as either government adherence to the view that there are relatively few market economy inefficiencies that are addressable by monetary policy (given the present knowledge of the monetary policy transmission mechanism), or as a simplified policy to only address the more important inefficiencies in the economy that are relatively well understood. It may also reflect a view that there are few trade-offs between inflation targeting objectives and asset market targeting objectives, i.e., by addressing the market inefficiencies through inflation targeting, asset market inefficiencies will also be minimized.

## **2.2 The role of stock prices as indicator variables**

Stock and other asset price information may, however, be useful to the monetary policymaker, even if asset prices are not among the target variables. Thus, the qualitative answer to the second question in the introduction is not necessarily dependent on the answer to the first question. There are at least two reasons why stock price information may influence the monetary policy stance. The first is that stock prices may be leading indicators of the target

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<sup>2</sup> Eichengreen and Arteta (2002) find that a higher credit expansion increases the likelihood of a banking crisis.

variables.<sup>3</sup> Stock prices may influence consumption through wealth effects and influence investments through the Tobin Q effect (Tobin, 1969). If stock prices fall, the expected attainable stream of future consumption services is reduced and consumers will cut back on current consumption expenditure. Moreover, the market price of capital is reduced relative to its replacement cost, thus reducing the investment incentives. Further, a fall in asset prices is likely to reduce the value of collaterals, which makes it more difficult for borrowers to obtain credit, thereby restricting aggregate demand (see Bernanke, Gertler and Gilchrist, 2000, and Bernanke and Gertler, 1989). Reduced demand may imply a weakening of cash flows, which once more reduces spending. This is the financial accelerator effect as described in Bernanke, Gertler and Gilchrist (2000). Moreover, reduced spending and income may lead to a fall in asset prices and thereby, to a decrease in spending.

The second reason for using asset price information is that it provides details about the expected development of the determinants of the targeting variables. According to the traditional theory, going back to Gordon (1962), asset prices are forward-looking variables reflecting the expected future return to the asset which is once more determined by fundamental variables. If the central bank is at no informational disadvantage versus the private sector and the fundamentals are observable, the “fundamentalist view” implies that asset prices do not convey information that is not available elsewhere. Hence, asset prices should not provide additional information to the policymaker, irrespective of whether asset prices are targeting variables.

However, if the policymaker is at an informational disadvantage versus the private sector or the fundamentals are not fully observable to the policymaker, asset prices may be helpful as indicator variables since they reflect private sector expectations about the state of the economy.<sup>4</sup> Hence, asset prices may help extracting information about the state of the economy.<sup>5</sup> The extraction problem is, however, complicated by the fact that the information content of forward-looking asset prices is dependent on the particular policy implemented. The information as well as the leading indicator properties of asset prices would therefore be expected to change with the systematic part of monetary policy.

It can be argued, however, that asset prices do not only reflect the fundamentals, but also that they frequently include bubble components. Given the inefficiency of such bubble components and the assumption that monetary policy may reduce their size,<sup>6</sup> the non-fundamental view implies that there is a role for the central bank contributing to stabilizing the asset prices around the efficient price level. Moreover, due to the presence of bubble components, asset prices influence target variables more than what is reflected by the

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<sup>3</sup> Goodhart and Hofmann (2000) find that housing prices, equity prices and the yield spread may help predict CPI inflation. Stock and Watson (2001) argue, however, that asset prices are not stable explanatory variables of inflation and output; asset prices provide explanatory power only in some countries and some periods. Bordo and Wheelock (2004) also find no consistent relationship between inflation and stock market booms.

<sup>4</sup> See Vickers (2000) for an overview of the use of asset prices in guiding monetary policy at inflation-targeting central banks.

<sup>5</sup> Svensson and Söderlind (1997) review different methods of obtaining information through the use of asset-price information.

<sup>6</sup> Allen and Gale (2004) argue that an appropriately designed monetary policy may reduce the size of bubbles and that there is a welfare-improving role for monetary policymaking in doing so.

fundamental part of the asset price. Hence, asset prices become distinct indicators of monetary policy (see, e.g., Cecchetti et al., 2000). However, given the incomplete understanding of asset price determination (i.e., the underlying model), it may be difficult to identify possible bubble components and thus provide adequate monetary-policy responses. For instance, Bernanke and Gertler (2001) argue that the identification of the bubble component is difficult and the central bank is left with the opportunity to respond to the asset price itself. Using a New-Keynesian model incorporating a financial accelerator mechanism caused by financial market inefficiency, they find that if the central bank responds aggressively to expected future inflation (only), “there is no significant additional benefit to responding to asset prices” (p. 254). Their approach can, however, be criticized for not modeling optimizing monetary policy; the central bank is rather modeled according to an interest rate rule which only responds to a few (but important) arguments such as expected inflation, the output gap and a stock market price indicator. Hence, we do not know whether the conclusions of the paper reflect an inefficient monetary policy strategy or whether the stock market price is a bad indicator for monetary policy. Cecchetti et al. (2000) show that once we allow for efficient responses to the three indicators within this model, the ability to react to the asset price reduces the loss in terms of the weighted output and inflation variability by between 22 and 99 percent. The reaction parameter is always modest, ranging between 0.01 and 0.5. Within the model framework of Rotemberg and Woodford (1999), Bullard and Schaling (2002) argue that the benefits from responding separately to the asset prices are small. Moreover, a sufficiently strong response to asset prices may lead to indeterminacy of the rational expectations equilibrium and hence, to endogenous expectations-driven fluctuations.

Although there does not seem to be any clear theoretical consensus on how useful asset price information is for monetary policymaking, theory does not discard the possibility of stock prices being useful indicators. Indeed, there are many arguments why stock prices should influence monetary policymaking; at least to the extent that they influence the forecasts of the objectives variables. The lack of a unifying theoretical framework for studying the diversity of different arguments makes it difficult, however, to concretize how these arguments may in fact have influenced and are influencing monetary policymaking. This is clearly reflected in the empirical contributions to the literature to which we now turn.

### **2.3 Empirical evidence**

Compared to the vast amount of papers analyzing the influence of the monetary policy actions of the Central Bank on the macroeconomic environment, there have been relatively few papers trying to model the interactions between the Central Bank’s monetary policy actions and asset prices. Among the first we find are Geske and Roll (1983) and Kaul (1987). In these articles, the link in the causal chain between monetary policy and stock market returns is separately examined and estimated (see Sellin (2001) for a comprehensive survey of this literature). However, the error term in these individual estimations will be correlated and will therefore be more precisely identified using a joint estimation scheme. Recent empirical studies have therefore tended to use the vector autoregressive (VAR) approach, since it

involves the joint estimation of all variables in one system. The VAR approach has also been influential in the analysis of monetary policy effects in more standard macroeconomic analysis, starting with Sims (1980).

### **VAR studies**

VAR studies incorporating the stock market into the more traditional monetary analysis include, among others, Patelis (1997), Thorbecke (1997) and Neri (2004). All these find that stock returns respond negatively to a tightening shock of monetary policy, but that monetary policy shocks only account for a small part of the variations in stock returns.<sup>7</sup> For the US, Neri (2004) finds that the stock market immediately falls by around one percent due to a monetary policy shock corresponding to an increase in the interest rate by one-percentage point. However, the effect is considerably larger after 4 months, at 3.6 percent, but after six months, the effect is insignificant.

All the above papers identify monetary policy and stock market shocks using Cholesky decomposition, which imposes a recursive ordering of the identified shocks. In many of these papers, the stock market is ordered last, thus implying that it can react contemporaneously to all other shocks, but that the variables identified before the stock market (i.e. monetary policy stance) react with a lag to stock market news. Hence, simultaneous interactions are ruled out by assumption. As the focus in many of these papers has been to analyze the effect of monetary policy on the stock market, and not vice versa, this restriction has seemed reasonable, at least in the analysis using monthly data. However, to the extent that one wants to be able to account for the true simultaneous response in monetary policy and stock prices, using a recursive identification scheme in VAR models may still imply that the effects can be severely biased. We shall see that the simple Cholesky identification scheme severely underestimates the impact of both stock market shocks and monetary policy shocks on stock returns and interest rate setting.

Rapach (2001) identifies monetary and stock return shocks without resorting to using the traditional short-run Cholesky decomposition, but instead resorts to only using long-run restrictions. Addressing the simultaneity problem in a similar vein to the approach followed in our paper, Rapach finds considerably stronger interaction effects between the interest rate and the stock market.<sup>8</sup> However, by relying solely on the use of long-run (neutrality) restrictions, he fails to identify the monetary policy shocks (which is the focus of our study), but instead identifies a money supply shock. Further, Faust and Leeper (1997) have demonstrated that the results based on this type of restrictions may be very unreliable. In particular, there is a strong possibility that the effects of the different structural shocks may be confounded. This may

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<sup>7</sup> The surprisingly small impact of a monetary policy shock on the stock returns is also found by Durham (2003). He uses an error correcting co-integration approach to identifying the monetary policy shock and finds that the federal funds rate has no direct impact on stock prices. The federal funds rate does, however, affect the 10-year treasury yield, which has some impact on stock prices in the long run.

<sup>8</sup> A money supply shock that raises the interest rate by one percentage point, leads to a fall in stock prices by around 6 percent. Further, an unexpected increase in the stock prices of one percent, leads to a rise in the interest rate by around 0.05 percentage points.

clearly be the case in Rapach, as any temporary shock (aggregate demand, money demand etc.) could satisfy the neutrality assumptions imposed on the money supply shock.<sup>9</sup>

### **Non-VAR studies**

The simultaneity problem has also been addressed by Rigobon and Sack (2003). They use an identification technique based on the heteroscedasticity of stock market returns to identify the reaction of monetary policy to the stock market. They find that a “5 percent rise in stock prices over a day causes the probability of a 25 basis point interest rate hike to increase by a half” (p. 664). In a similar vein, Rigobon and Sack (2004) estimate that “a 25 basis point increase in the three-month interest rate results in a 1.9% decline in the S&P 500 index and a 2.5% decline in the Nasdaq index.”

Recently, the interaction between the stock market and monetary policy has also been addressed with other methods. In an event study, Bernanke and Kuttner (2004) estimate the effect of an unanticipated rate cut of 25 basis points to be a one-percent increase in the level of stock prices. They attribute most of the effects of the monetary policy shock on stock prices to its effect on forecasted stock risk premiums. In a similar event study, Ehrmann and Fratzcher (2004) find slightly stronger effects, estimating an unexpected tightening of 50 basis points to reduce US equity returns by 3% on the day of the announcement.

Fuhrer and Tootell (2004) estimate interest rate reaction functions and argue that the FOMC reacts to stock price movements, only to the extent that they influence forecasts of CPI inflation and real activity, and they argue that stock price stabilization is not an independent objective of monetary policy. Chadha et al. (2003) estimate augmented Taylor rules using GMM and find that both stock prices and real exchange rate deviations from their equilibrium values in addition to the instrumented future inflation and output gaps are significant in the FOMC reaction function. Stock prices and the real exchange rate enter significantly and robustly for different choices of lead lengths for both inflation and output gaps. However, they argue that the significance may be due to these variables proxying the part of expected inflation and output gaps that is not well explained by the instruments.

Summing up, the empirical literature seems to identify important interactions between monetary policy and the stock market. Studies that find small interaction effects can be criticized for failing to take full account of the possible simultaneity between these sectors. This latter problem has been most pronounced in VAR studies.

### **3. The identified VAR model**

In this study, we explicitly account for the interdependence between stock prices and monetary policy within a VAR model by imposing a combination of short-run and long-run restrictions. In particular, we build on the traditional VAR literature in that we identify a

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<sup>9</sup> Lastrapes (1998) is the first study identifying the interaction between the interest rates and the stock market solely using long-run restrictions. However, except for the money supply shock, the model is left underidentified, thereby failing to identify stock price shocks. This makes the criticism by Faust and Leeper (1997) even more relevant, as all types of temporary (demand and supply) shocks can now be effectively lumped into the identified money supply shock.

recursive structure between macroeconomic variables and monetary policy, so that monetary policy can react to all shocks, but the macroeconomic variables react with a lag to monetary policy shocks. Stock prices and monetary policy operationalized through the short-term interest rates are, on the other hand, allowed to react simultaneously to each other. We make the identifying assumption that monetary policy has no long-run effects on real stock prices. It seems reasonable to assume that due to the long-run monetary policy neutrality proposition, such a restriction on the interdependence between monetary policy and stock prices is uncontroversial. Moreover, by using only one long-run restriction, we address the simultaneity problem without extensively deviating from the established literature (i.e., Christiano et al., 1999, 2005) of identifying a monetary policy shock as an exogenous shock to an interest rate reaction function (the systematic part of monetary policy).<sup>10</sup> Once we allow for full simultaneity between monetary policy and the stock market, the VAR approach is likely to give very useful information about the simultaneous interaction between monetary policy and asset markets.

The VAR model comprises the log of the annual changes in the consumer price index (CPI) ( $\pi_t$ ) – hereafter referred to as inflation, the log of the industrial production index ( $y_t$ ), the federal funds rate ( $i_t$ ), the log of the commodity price index in US dollars (USA PPI Raw materials, *source: OECD*) ( $c_t$ ) and the log of the S&P 500 stock prices index ( $s_t$ ). Industrial production and stock prices are deflated by CPI, so that they are measured in real terms. The federal funds rate and the stock prices index are observed daily, but they are averaged over the month, so as to reflect the same information content as the other monthly variables. The first three variables are well-known variables in the monetary policy and business cycle literature. The commodity price variable is included as it has been observed that omitting an important variable from the VAR representing inflation pressure to which the FED reacts, may lead to the so-called “price puzzle” (Eichenbaum, 1992), where prices increase significantly in response to an interest rate. By including a leading indicator for inflation such as a commodity price index, one may eliminate this positive response of prices to the contractionary monetary policy shock (see e.g. Sims 1992, Leeper et al. 1996, and many subsequent studies in the VAR literature). Finally, the stock price index is included to both investigate the importance of monetary policy shocks for the stock market and to what extent the (systematic) monetary policy stance is influenced by stock market developments. This final issue has rarely been discussed in the applied VAR literature. As discussed above, we believe the reason to be that empirical investigation has been hampered by the simultaneity problem of including asset price information in the VAR models.

Below, we will show that using a combination of short-run and long-run restrictions on the estimated VAR model will be sufficient to identify monetary policy and stock price shocks allowing monetary policy stance and stock prices to react simultaneously to the identified shocks.

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<sup>10</sup> As opposed to Rapach (2001) who uses long-run restrictions to identify *money supply shocks*, which may be quite distinct from the *monetary policy shocks* traditionally identified in the literature.

### 3.1 Identification

Throughout this paper, we follow what has now become standard practice in VAR analysis (see e.g. Christiano et al. 1999) and identify monetary policy shocks with the shock in an equation of the form

$$i_t = f(\dots)_t + \sigma \varepsilon_t^{MP}, \quad (1)$$

where  $i_t$  is the instrument used by the monetary authority (the federal funds rate in the U.S.) and  $f$  is a linear function relating the instrument to the information set (feedback rule). The monetary policy shock  $\varepsilon_t^{MP}$  is normalized to have unit variance, and  $\sigma$  is the standard deviation of the monetary policy shock. Having identified the feedback rule (from the variables in the information set), the VAR approach focused on the exogenous deviations from this rule. Hence, such deviations provide researchers with an opportunity to detect the responses of macroeconomic variables to monetary policy shocks not already incorporated in private agent expectations.

In a similar vein, stock price shocks are identified from the equation of stock prices. To the extent that the variables in the VAR reflect true fundamental variables relevant for the stock market, any reaction above the average response in the stock market to these variables can be interpreted as a non-fundamental stock price shock, and the source of bubbles in the stock market.

Below, we set out to follow standard practice in many recent VAR applications, namely to identify the different structural shocks through a series of contemporaneous restrictions on the effects of the shocks on the variables. In particular, it is commonly assumed that macroeconomic variables, such as output and prices, do not react contemporaneously to monetary shocks, while there might be a simultaneous feedback from the macro environment to monetary variables, see e.g. Sims (1980, 1992), and Christiano et al. (1999) among many others. Bagliano and Favero (1998) show that when monetary policy shocks are identified in this recursive way on a *single* monetary policy regime, these shocks suggest a pattern for the monetary transmission mechanism that is consistent with the impulse responses of monetary policy shocks identified by instead using financial market information from outside the VAR, as in, e.g., Rudebusch (1998). This would also limit the practical importance of the Lucas critique, since a stable regime does not require any re-parameterization.

However, as discussed above, a more profound problem with this recursive identification, is that once one include high frequency data such as stock prices in the VAR, it becomes difficult to validate that monetary policy should not be contemporaneously affected by shocks to these financial variables. To solve this simultaneity problem, we therefore instead use a long-run restriction that does not limit the contemporaneous response in the variables. The restriction identifies monetary policy shocks as those shocks that have no longrun effect on the level of stock prices.

Assume  $Z_t$  to be the (5x1) vector of macroeconomic variables discussed above. Ordering the variables as follows:  $Z_t = (\Delta y_t, \pi_t, \Delta c_t, i_t, \Delta s_t)'$ , where, for now, we assume that all variables but inflation and the interest rate are first differenced to obtain stationarity, the reduced-form VAR can be written by its moving average<sup>11</sup>

$$Z_t = B(L)v_t, \quad (2)$$

where  $B(L) = \sum_{j=0}^{\infty} B_j L^j$  is the matrix lag operator and  $v_t$  a vector of reduced-form residuals with the covariance matrix  $\Omega$ . The identification of the relevant structural parameters, given the estimation of the reduced form, is a traditional problem in econometrics. A structural model is obtained by assuming orthogonality of the structural shocks and imposing some plausible restrictions on the elements in  $B(L)$ . Following the literature, we assume that the underlying orthogonal structural disturbances ( $\varepsilon_t$ ) can be written as linear combinations of the innovations ( $v_t$ ), i.e.,

$$v_t = S\varepsilon_t. \quad (3)$$

With a five-variable VAR, we can identify five structural shocks; The first two are the main focus and can be interpreted as monetary policy shocks ( $\varepsilon_t^{MP}$ ) and real stock price shocks ( $\varepsilon_t^{SP}$ ). As discussed further below, we follow the practice in the VAR literature and only loosely identify the last three shocks as commodity price shocks ( $\varepsilon_t^{CO}$ ), inflation shocks (interpreted as cost push shocks) ( $\varepsilon_t^{CP}$ ) and output shocks ( $\varepsilon_t^Y$ ). Ordering the vector of uncorrelated structural shocks as  $\varepsilon_t = (\varepsilon_t^Y, \varepsilon_t^{CP}, \varepsilon_t^{CO}, \varepsilon_t^{MP}, \varepsilon_t^{SP})'$ , the VAR can then be written in terms of the structural shocks as

$$\begin{bmatrix} \Delta y \\ \pi \\ \Delta c \\ i \\ \Delta s \end{bmatrix}_t = C(L) \begin{bmatrix} \varepsilon_Y \\ \varepsilon_{CP} \\ \varepsilon_{CO} \\ \varepsilon_{MP} \\ \varepsilon_{SP} \end{bmatrix}_t \quad (4)$$

where  $B(L)S=C(L)$ . Clearly, if  $S$  is identified, we can derive the MA representation in (4) since  $B(L)$  can be calculated from the reduced-form estimation of (2). Hence, to go from the reduced-form VAR to the structural interpretation, restrictions must be applied on the  $S$  matrix. Only then can the relevant structural parameters from the covariance matrix of the reduced-form residuals be recovered.

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<sup>11</sup> This assumption is further discussed and relaxed in the empirical analysis below.

To identify  $S$ , we first assume that the  $\varepsilon_t$ 's are normalized so that they all have unit variance. The normalization of  $\text{cov}(\varepsilon_t)$  implies that  $SS' = \Omega$ . With a five-variable system, this imposes fifteen restrictions on the elements in  $S$ . However, as the  $S$  matrix contains twenty-five elements, to orthogonalize the different innovations, ten more restrictions are needed. Nine of these will be contemporaneous restrictions directly on the  $S$  matrix. These are consistent with a Cholesky decomposition used on the part of the  $S$  matrix that ignores the financial variables and, as discussed above, are standard in the VAR literature on monetary policy shocks. In addition, we impose one commonly accepted restriction on the long-run multipliers of the  $C(L)$  matrix.

Following the standard literature in identifying monetary policy shocks, the recursive order between monetary policy shocks and the macroeconomic variables implies the following restriction on the  $S$  matrix

$$\begin{bmatrix} \Delta y \\ \pi \\ \Delta c \\ i \\ \Delta s \end{bmatrix}_t = B(L) \begin{bmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_Y \\ \varepsilon_{CP} \\ \varepsilon_{CO} \\ \varepsilon_{MP} \\ \varepsilon_{SP} \end{bmatrix}_t. \quad (5)$$

The standard Cholesky restriction, namely to assume that macroeconomic variables do not simultaneously react to the policy variables, while the simultaneous reaction from the macroeconomic environment to policy variables is allowed for, is taken care of by placing the macroeconomic variables above the interest rate in the ordering, and by assuming zero restrictions on the relevant coefficients in the  $S$  matrix as described in (5). By examining the first two columns in  $S$ , one can further note that while price shocks can affect all variables but output contemporaneously, output shocks can affect both output and prices contemporaneously. Hence, it seems reasonable to interpret a price shock as a cost push shock (moving prices before output), whereas output shocks will be dominated by both demand shocks and supply shocks. Consistent with the VAR literature (see Bagliano and Favero, 1998), we have placed commodity prices after output and prices in the ordering, thereby assuming that commodity prices will react to output and cost price shocks, while commodity price shocks will have no contemporaneous effect on output and prices.<sup>12</sup>

Still, we are one restriction short of identification. The standard practice in the VAR literature, namely to place the financial variable last in the ordering and assuming  $S_{45} = 0$ , (so that neither macroeconomic nor monetary variables can react simultaneously to the financial variables, while financial variables are allowed to react simultaneously to all other variables), would have provided enough restriction to identify the system, thereby allowing for the use of the standard Cholesky recursive decomposition.

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<sup>12</sup> We have also experimented with alternating the order of the first three variables in  $Z$ , without the results being much affected.

However, if that restriction is not valid, the estimated responses to the structural shocks will be severely biased. The standard test in the literature, namely to include one variable above the other and then rearrange the order to test whether that makes a difference, will not produce the correct impulse responses if there is a genuine simultaneous relationship between the two variables. Most likely, this will lead to the effects of the shocks being underestimated, as a recursive ordering will always either a) disregard the simultaneous reaction of the monetary policy stance to the stock price shocks, or b) exclude the simultaneous reaction of stock prices to the monetary policy shocks. This will be effectively demonstrated in the next section.

Instead, we impose the restriction that a monetary policy shock can have no long-run effects on the level of real stock prices which, as discussed above, is a plausible neutrality assumption when we measure stock prices in real terms. The restriction can be applied by setting the infinite number of relevant lag coefficients in (4),  $\sum_{j=0}^{\infty} C_{54,j}$ , equal to zero. Using the long-run restriction rather than a contemporaneous restriction between asset prices and monetary policy shocks,  $S_{45}$  may now differ from zero. However, by using the long-run restriction, we have enough restriction to identify and orthogonalize all shocks. Writing the long-run expression of  $C(L)$  as

$$B(1)S=C(1), \quad (6)$$

where  $B(1)=\sum_{j=0}^{\infty} B_j$  and  $C(1)=\sum_{j=0}^{\infty} C_j$  indicate the (5x5) long-run matrix of  $B(L)$  and  $C(L)$ , respectively, the long-run restriction that  $C_{54}(1) = 0$  implies

$$B_{51}(1)S_{14}+B_{52}(1)S_{24}+B_{53}(1)S_{34}+B_{54}(1)S_{44}+B_{55}(1)S_{54}=0. \quad (7)$$

#### 4. Empirical modeling and results

The model is estimated using monthly data from 1983M1 to 2002M12. Using an earlier starting period will make it hard to identify a stable monetary policy stance, as monetary policy prior to 1983 has experienced important structural changes and unusual operating procedures (see Bagliano and Favero, 1998, and Clarida et al., 2000).

We follow the standard practice in many VAR models on monetary policy and set out to model all variables (but real stock prices) in levels. This implies that any potential cointegrating relationship between the variables will be implicitly determined in the model (see Hamilton 1994).<sup>13</sup> However, Giordani (2004) has argued that if following the theoretical model set up in Svensson (1997) as a data generating process in monetary policy studies,

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<sup>13</sup> Based on the standard Augmented Dickey Fuller (ADF) unit root test, we cannot reject that any of the variables except possibly inflation and the interest rate are integrated of first order. However, none of the variables are cointegrated. Therefore, the variables should be represented in their first differences. However, due to the low power of the ADF tests to differentiate between a unit root and a persistent (trend-) stationary process, we cannot rule out that the variables could equally well be represented in levels, but with a trend.

instead of including output in levels, the output gap should either be included in the VAR, or the output gap along with the trend level of output. However, as pointed out by Lindé (2003), a practical point not addressed by Giordani is how to compute trend output (thereby, also the output gap). Therefore, we instead follow Lindé (2003), and include a linear trend in the VAR along with output in levels. In that way, we try to address this problem by modeling the trend implicit in the VAR. The use of a trend in the VAR serves as a good approximation for ensuring that the VAR is invertible if the variables are non-stationary, in particular given the short span of data we are using. Note also that the inclusion of such a time trend makes the discussion of the effects of the identified shocks on different variables relative to some average development of these variables. There are no qualitative changes to the impact of the shocks.

Finally, the stock price index is specified using first differences in the VAR. As we want the long-run restriction to be binding for the level of stock prices in the long run, it must be applied to the first differences of stock prices (see Blanchard and Quah, 1989).<sup>14</sup>

The lag order of the VAR-model is determined using the Schwarz and Hannan-Quinn information criteria and the F-forms of likelihood ratio tests for model reductions. A lag reduction to four lags could be accepted at the one-percent level by all tests. Using four lags in the VAR, there is no evidence of autocorrelation, heteroscedasticity or non-normality in the model residuals.

#### **4.1 Cholesky decomposition**

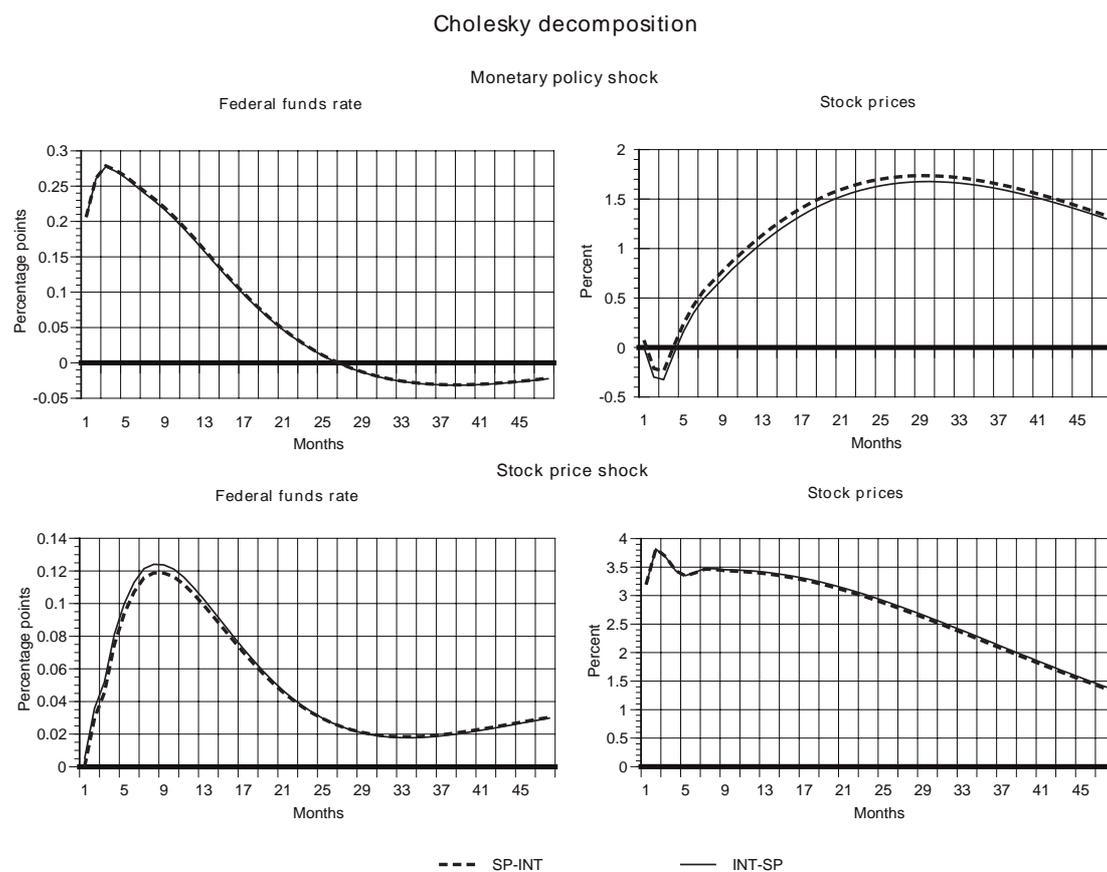
If there is strong simultaneity between shocks to monetary policy and stock prices, we would not expect a Cholesky decomposition of the effects on shocks to pick up this simultaneity, since one of the shocks is restricted to have no immediate effect on one of the variables. Figure 1 gives an account of the impulse responses of interest rates and stock prices to both a monetary policy shock and a stock price shock. These are shown for two different orderings of variables, with the interest rate and the stock price alternating as the penultimate and ultimate variables.

Restricting either the monetary policy shock to have no immediate effect on stock prices or the stock price shock to have no immediate effect on interest rates, we see that neither the monetary policy shock nor the stock price shock has any important immediate effects on the other variables. In addition, the effect of a monetary policy shock on stock prices is counterintuitive, increasing stock prices by more than one percent after a year. Assuming that both the stock market and the monetary policymaker react importantly to shocks in the other sector so that interaction is important, the restriction imposed by either Cholesky ordering distorts the estimates of the two shocks in such a way that the degree of interaction will seem unimportant.

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<sup>14</sup> This restriction is relaxed in section 5, where we test the robustness of our results.

**Figure 1.** Impulse responses with two Cholesky identification schemes.



Note: The solid line represents the ordering with the federal funds rate (INT) last and the dashed line the ordering with real stock prices (SP) last.

#### 4.2 Our identification scheme

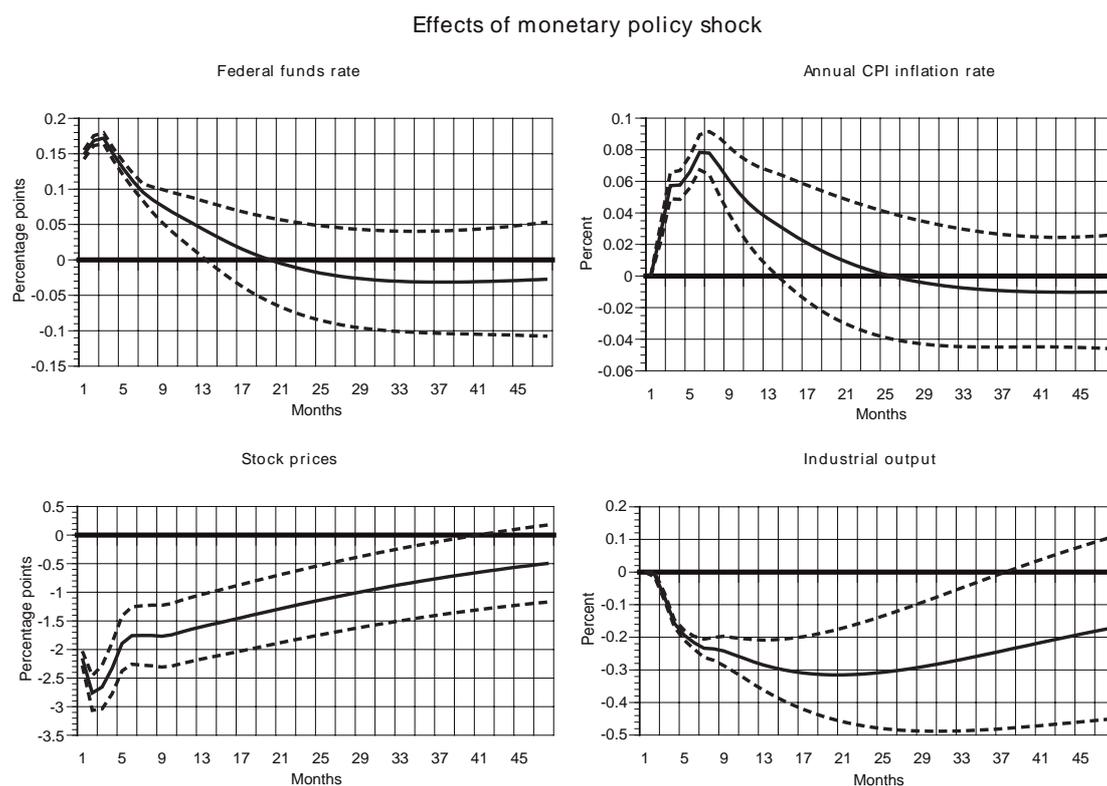
The alternative to the simple Cholesky decomposition was outlined in Section 3. Since our prime interest is to understand the interaction between monetary policy and the stock market, we focus on illustrating the impact of the monetary policy shock and the stock price shock.<sup>15</sup>

Figures 2 and 3 show the impulse responses to the federal funds rate, the stock market price, annual inflation and the industrial production of a monetary policy shock and a stock market shock, respectively. The figures also give a one standard deviation band around the point estimates, reflecting the uncertainty of the estimated coefficients.<sup>16</sup>

<sup>15</sup> The impact of the other shocks on the variables can be obtained from the authors upon request.

<sup>16</sup> The standard errors reported are calculated using a Monte Carlo simulation based on normal random drawings from the distribution of the reduced-form VAR. The draws are made directly from the posterior distribution of the VAR coefficients, as suggested in Doan (2004). The standard errors that correspond to the distributions in the D(L) matrix are then calculated using the estimate of  $D_0$ .

Figure 2. Impulse responses to a monetary policy shock.



Note: The charts show the impulse responses of a monetary policy shock to the federal funds rate, real stock prices, inflation and industrial output with a standard error band.

### The monetary policy shock

The monetary policy shock temporarily increases interest rates, as expected. Output falls temporarily and reaches its minimum after a year and a half. The negative effect on output is clearly significantly different from zero.

Inflation first increases, disinflation is present after six months and prices start to fall after another year and a half. The effect on inflation is small, and eventually not significant. The small effect of a monetary policy shock on inflation has also been found in many traditional VAR studies of the US economy, such as Christiano et al. (1999), but also recently by Faust et al. (2004), who identify monetary policy shocks based on high frequency futures data. Whereas the initial increase in inflation has recently been explained (see, Ravenna and Walsh, 2003, and Chowdhury et al., 2003) by a cost channel of the interest rate (i.e., the increased interest rate increases the borrowing costs for firms and therefore, the prices) and is less of a puzzle. The positive long-run effect of the interest rate on inflation is more difficult to explain. Neo-Keynesian (e.g, Svensson, 1997) and New-Keynesian (see, Rotemberg and Woodford, 1998, 1999, Clarida et al., 1999, and Woodford, 2003b) models predict that inflation falls as a result of output deviating negatively from its potential. The puzzle has typically been addressed by adding a commodity price index to the VAR model, initially suggested by Sims (1992). The idea is that commodity prices are leading indicators of inflation and likely to be important indicators for the monetary policymaker in setting interest

rates, thus affecting the systematic part of monetary policy. Including the commodity price index is therefore important to extract the true monetary policy shock. As noted by Hanson (2004), however, this approach is less successful in alleviating the price puzzle in VAR models estimated with data for the past twenty years. Although our VAR model does eventually produce a reduction in inflation, this is small and the total long-run effects on prices are almost neutral, thereby broadly supporting the conclusions in Hanson.<sup>17</sup>

There is a high degree of interest-rate inertia in the model, as a monetary policy shock is only offset by a gradual reduction in the interest rate. The federal funds rate returns to its steady-state value after a year and a half and then, although not significantly so, falls below its steady-state value. The monetary policy reversal combined with the interest-rate inertia is consistent with what has become known as good monetary policy conduct. As shown by Woodford (2003a), interest-rate inertia is known to let the policymaker smooth out the effects of policy over time by affecting private-sector expectations. Moreover, the reversal of the interest rate stance, though arriving late, is consistent with the policymaker trying to offset the adverse effects of the initial policy deviation from the systematic part of policy.

The monetary policy shock has a strong impact on stock returns, as stock prices immediately fall by around one and a half percent for each (normalized) ten basis-point increase in the federal funds rate.

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**Result 1**

*A monetary policy shock that initially increases the interest rate has an immediate and significant negative impact on stock prices.*

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The result of a fall in stock prices is consistent with the increase in the discount rate of dividends associated with the increase in the federal funds rate, but also with the temporarily reduced output and higher cost of borrowing which are likely to reduce expected future dividends. Real stock prices remain depressed for a prolonged period after the monetary policy shock.

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**Result 2**

*Stock returns are higher after the monetary policy shock and gradually fall back to average returns.*

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After the initial negative jump, stock returns are higher immediately after a monetary policy shock, but gradually decline towards the average level as the long run restriction bites. Although interpretations of this result should be made with great care, a potential explanation might be that as the interest rate gradually falls, the discounted value of expected future

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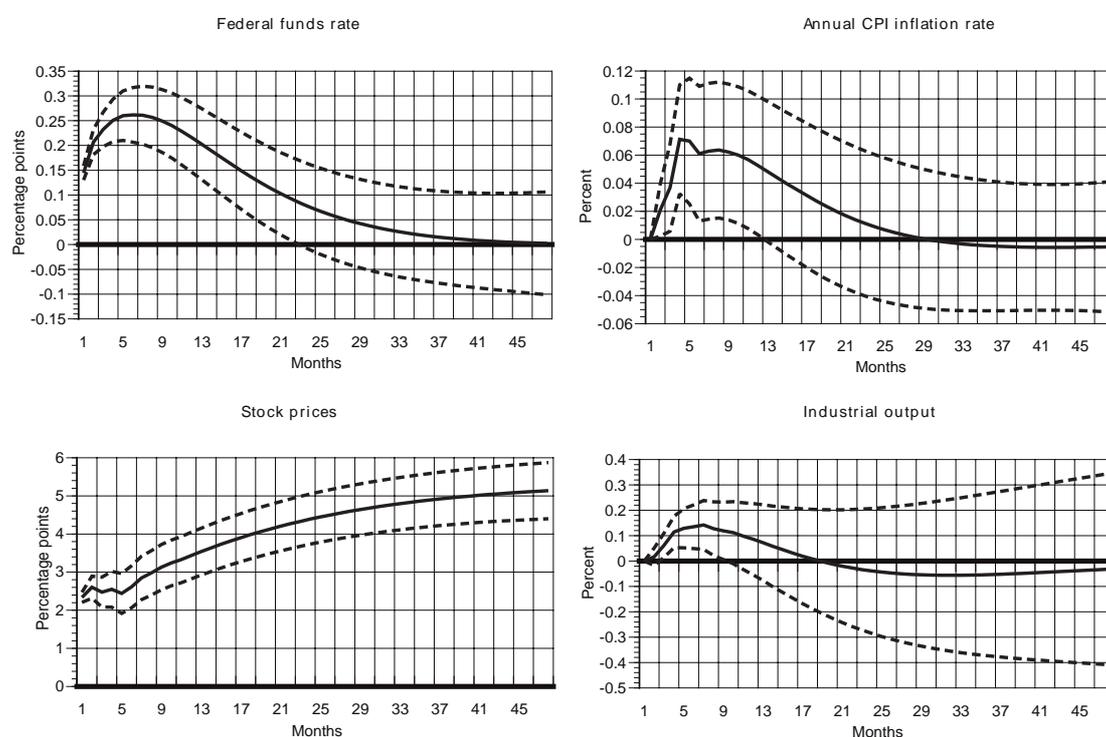
<sup>17</sup> Hanson (2004) obtains the most favorable results in reducing the prize puzzle by using the Commodity Research Bureau spot commodity price index. However, trying the same index as in Hanson as well as some other indexes, the results basically remain unchanged. These results can be obtained from the authors upon request.

dividends increases and there is a normalization of dividends, leading to an increase in stock prices.

### The real stock price shock

The way we have set up the VAR model, stock prices may react simultaneously to all shocks in the model. As noted in Section 3, given that the choice of variables in the model gives a reasonable account of the fundamental variables determining the forward-looking stock prices, the own shock to stock prices can be interpreted non-fundamental – unexplained by the other variables in the model. The impulse responses are depicted in Figure 3.

**Figure 3.** Impulse responses to a real stock price shock.  
Effects of stock price shock



Note: The figure shows the impulse responses of a stock price shock to the federal funds rate, real stock prices, inflation and industrial output, with standard error bands.

The stock price shock increases both inflation and output in the short run, but the effect has faded out within a year, and inflation and output are back in steady state. Explanations consistent with this are that the rise in stock prices increases consumption through a wealth effect and investment through a Tobin Q effect, thus affecting both aggregate demand and inflation. The stock price shock has persistent effects on stock prices. It allows for long-lasting booms in the stock market to be explained by non-fundamental factors.

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**Result 3**

*A stock market shock that raises stock prices leads to an immediate increase in the federal funds rate.*

---

We find stock price shocks to be important indicators for the interest rate setting. Interest rates immediately increase by about eight basis points to a (normalized) stock price shock of one percent. This relatively strong response might be motivated both by the FOMC's concern about reducing the impact of the shock on inflation and output by conducting a policy that will offset the effect on inflation and output through other channels, and by reducing the stock price shock's impact on stock prices themselves – thereby diminishing the source of the problem.

**4.2. The error variance decomposition**

We now turn to discussing the importance of the different shocks in accounting for the variance in the federal funds rate and in stock prices at different forecast horizons. Such error variance decomposition can shed some light on the optimality of monetary policy. Furthermore, it may tell us more about the importance of stock market shocks as indicators for interest rate setting as well as for movements in stock prices themselves. Table 1 shows the error variance decomposition for monetary policy, stock prices, cost push and output shocks.

In the short run, the monetary and stock price shocks account for almost all variation in the federal funds rate and stock prices, leaving the other shocks to influence these variables only in the longer run. Monetary policy shocks are important for explaining the variances in stock prices and the stock market conveys information that is important for explaining variations in the federal funds rate.

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**Result 4**

*Monetary policy shocks and stock market shocks are both quantitatively important in explaining variations in both the federal funds rate and stock prices.*

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To the extent that our model includes all relevant variables for monetary policy decisions, the results indicate that the unsystematic part of policy explains a large part of the interest rate movements in the short run, thus inducing stock prices to move extensively. Hence, making policy more transparent and reducing the surprises are likely to substantially stabilize both the interest-rate setting and the stock market. The value of an improvement to interest rate forecasting should be significant for agents operating in the stock market.

Are the results obtained consistent with the systematic part of policy being in accordance with good monetary policy conduct? According to New Keynesian theory (see, Clarida et al., 1999, for an overview), a central bank concerned with stabilizing inflation and the output gap (actual output deviations from its potential) will try to completely neutralize the impact of the demand shock on the output gap and trade off the impact of cost-push

shocks between inflation and the output gap. Hence, movements in inflation should only be explained by cost-push shocks, whereas output should be explained by cost-push shocks and productivity shocks (affecting potential output). We find that inflation movements are to a large extent explained by cost-push shocks. As noted earlier, our identifying restrictions do not allow us to separate demand shocks from productivity shocks, and the output shocks are likely to represent a mixture of these. Whereas the central bank should neutralize the impact of demand shocks on output, it should fully accommodate productivity shocks and let them affect output. However, since there is clearly a lagged effect of monetary policy on output, the demand part of the output shocks can only be gradually neutralized over time. As a result, we would expect output shocks to have more of an impact on output in the shorter than in the longer run (when the effect of the demand shocks is neutralized). Our results are consistent with these implications.

**Table 1. Error variance decomposition.**

	Forecast		MP-shock (%)	SP-shock (%)	Cost push - shocks (%)	Output shocks (%)
	horizon					
<b>Federal</b>						
<b>funds rate</b>	1		50.07	47.27	0.99	1.21
	4		30.24	53.36	5.18	10.74
	12		12.96	52.82	8.56	23.18
	24		8.96	47.76	6.60	27.94
	48		8.40	41.08	11.88	31.26
<b>Real stock</b>						
<b>prices</b>	1		45.14	53.23	1.07	0.56
	4		45.94	46.21	4.78	0.79
	12		26.36	52.30	14.60	1.20
	24		14.97	59.97	17.48	2.37
	48		7.30	71.34	13.48	2.32
<b>Inflation</b>						
	1		0.00	0.00	95.63	4.37
	4		2.37	2.22	91.07	3.10
	12		5.31	5.03	86.73	1.87
	24		5.14	5.53	84.40	1.63
	48		5.23	5.50	83.39	1.89
<b>Industrial</b>						
<b>output</b>	1		0.00	0.00	0.00	100.00
	4		3.09	1.75	1.00	92.92
	12		9.52	2.56	9.38	74.49
	24		11.72	1.07	29.33	55.24
	48		11.86	0.78	43.14	42.62

The Table shows how monetary policy (MP) shocks, stock price (SP) shocks, cost-push shocks (CP) and output (Y) shocks contribute to the forecast error variance of key variables at different horizons. The remaining variability is due to non-reported commodity price shocks.

Although the direction and the magnitude of the responses of the FOMC seem to be in accordance with good monetary conduct, there seems to be a lagged response to variables. The federal funds rate response to output shocks is modest within a quarter of the shock. Only after a year does the response explain a quarter of the variation in the federal funds rate. Note

that this caution and implementation lag in monetary policy might be due to uncertainty about the present state as real-time estimates are subject to measurement errors (see Orphanides, 2001, Leitemo and Lønning, 2004 and Apel and Jansson, 2005).

The strong response by the FED to stock price shocks is no direct evidence of the stabilization of stock prices independent of the less controversial objectives such as inflation and output. More likely, it is the result of stock prices being leading indicators of inflation and output, and the monetary policymaker reacting to stock prices due to the monetary policy lag in influencing these objective variables. From Figure 2, we see that a stock-price shock raises both inflation and output which justifies a strong monetary policy response in itself as no trade-off between these typical objective variables is present. However, it can be argued that due to the stock prices explaining so little of inflation and output variability, the strong response to the stock price shock is unjustified if this is the case. This argument fails to take account of the fact that it can be the result of an appropriate systematic policy of trying to reduce the impact of these shocks on inflation and output.

Under the condition that the model gives a reasonable account of the systematic part of policy by the inclusion of relevant variables in the VAR model, the hypothesis of stock price stabilization being an import independent objective is further weakened by the fact that unsystematic part of policy is contributing so much to instability in stock prices itself. If stock price stabilization is an important objective, reducing the extent of monetary policy shocks also seems to be so.

### **4.3 Historical evolution of stock prices**

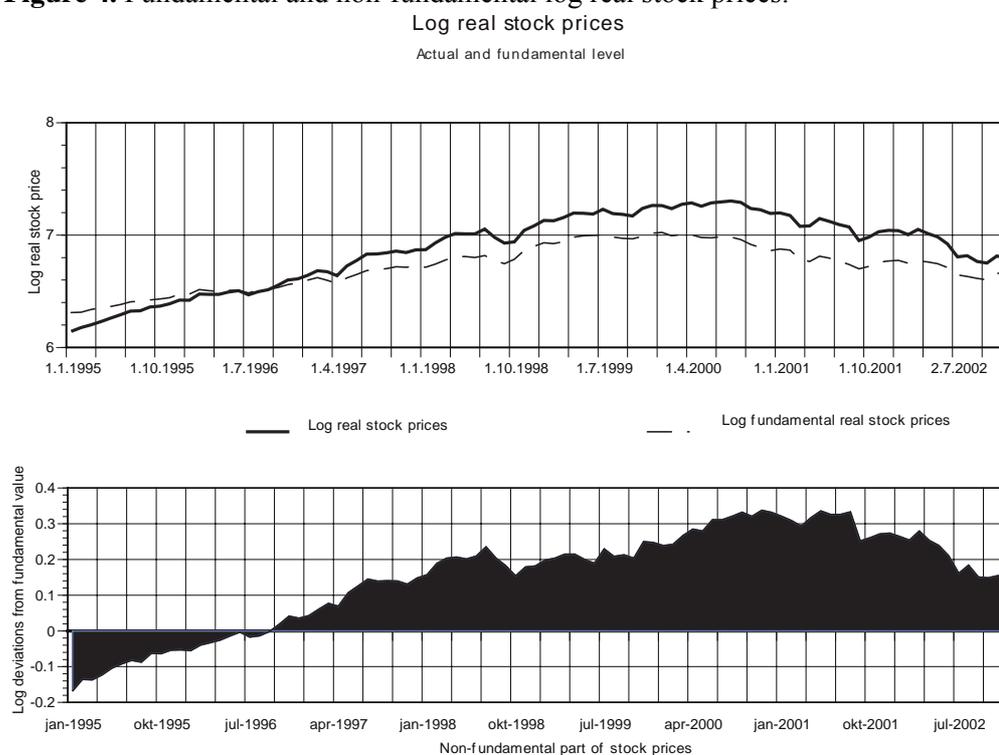
The previous section discussed the average impact of shocks on the variables. In this section, we consider the period 1995 to 2002 and discuss the contribution of shocks to the interest rate and real stock prices. Two questions seem interesting. Since stock price shocks can be interpreted as a non-fundamental shock, unrelated to any fundamental variable, the contribution of real stock price shocks is a contribution to the bubble part of stock prices. How large a part of the surge in stock prices over this period was due to a bubble? Second, how much of the interest rate setting was motivated by this bubble?

In the upper chart of Figure 4, we plot two series. The first is the log real stock prices. The second, which has been derived simulating the VAR model, shows what real stock prices would be if the non-fundamental stock price shocks were set to zero for all periods. Therefore, it has the interpretation of being the fundamental stock price level. The lower chart shows the recent stock prices “bubble”, that is, the contribution of the non-fundamental factors to stock prices, shown as a percentage deviation of log real stock prices from the fundamental level.

We see that the bubble has had an important impact on stock prices. Initially, non-fundamental factors made a negative contribution to stock prices but from 1996, non-fundamental factors increasingly added to the fundamental level. In July 1998, the contribution reached a temporary peak of 20 percent. The contribution was similarly high from November 1999, with the contribution varying between 25 and 30 percent until August 2001. The September 11, 2001 event contributed to reducing the bubble and since then, the

non-fundamental factors have been gradually reduced, but still contributing by ten percent by the end of 2002.

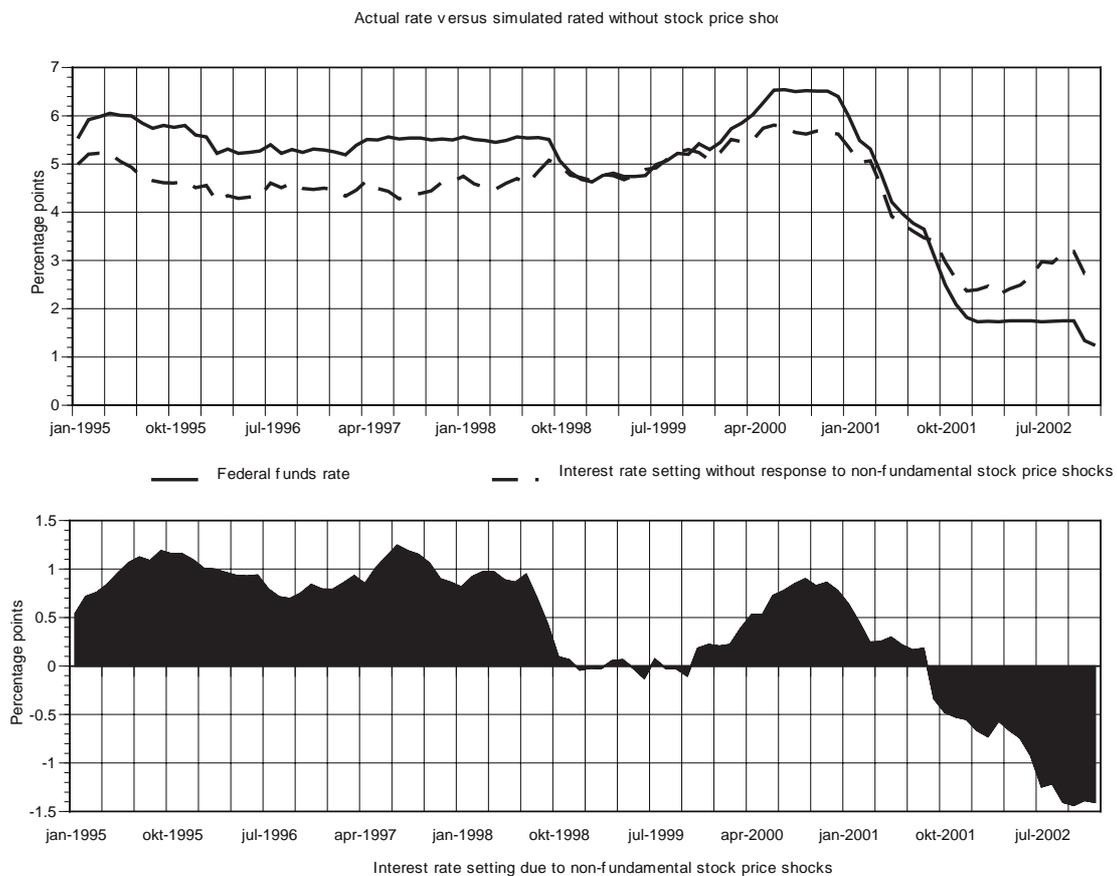
**Figure 4.** Fundamental and non-fundamental log real stock prices.



Note: The upper chart shows actual and fundamental log real stock prices. The lower chart shows the stock price “bubble” – the non-fundamental component of real stock prices as deviations of the log real stock price from the log fundamental level.

For the second question, Figure 5 illustrates the contribution of stock price shocks to the interest rate setting. The upper chart shows the federal funds rate together with the simulated rate with the stock price shocks set to zero. The lower chart shows the contribution of the stock price shocks to the interest rate setting. Stock price shocks contributed to about a one percentage point higher interest rate throughout the period 1995-1998. From October 1998 and until December 1999, the stock price shocks had an almost neutral effect on the interest rates, while they increased the interest rate again from the start of 2000. From late 2001, stock price shocks contribute negatively to the interest rates, at the end of 2002 by almost one and a half percentage points. We take this as evidence of the FOMC having been considerably involved in counteracting the effects of the stock price bubble and the subsequent effect on the central bank objectives in this period.

**Figure 5.** Federal funds rate: Actual and simulated without stock price shocks.



Note: The upper chart shows the actual federal funds rate and the simulated federal funds rate without any response to the non-fundamental stock price shocks. The lower chart shows the part of the federal funds rate devoted to responding to the non-fundamental stock price shocks.

## 5. Robustness of results

The robustness of the results reported above deserves further discussion on at least three issues: (1) Alternative identification of the VAR, (2) sample stability and (3) the importance of a few stock market crashes for the average results. This is examined next.

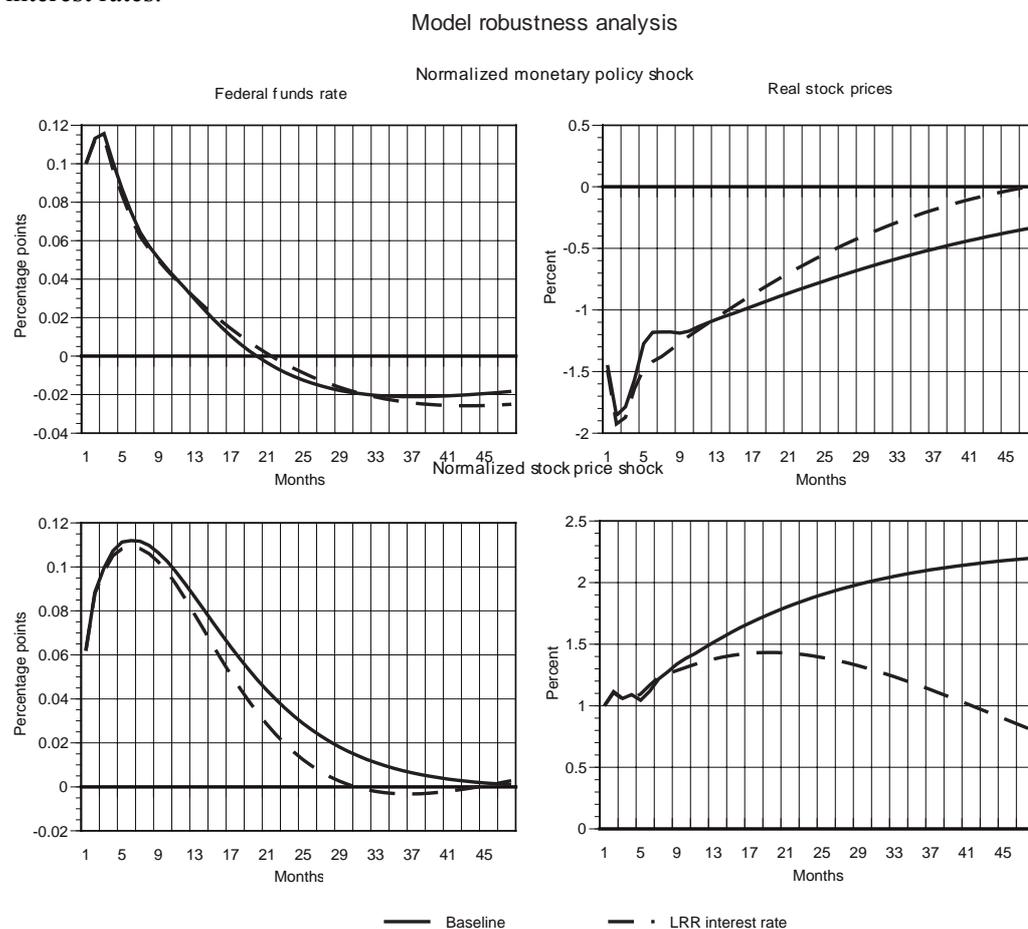
### 5.1 Alternative identifying restrictions

Above, monetary policy shocks were identified as those shocks with no long-run effects on real stock prices. Here, we replace this restriction by the restriction that a monetary policy shock can have no long-run effects on the federal funds rate itself. Moreover, to more precisely pin down policy errors, we assume that in the long run, interest rate deviations from steady state due to a policy shock will sum to zero. As noted above, this feature of the policy response to a policy shock is by and large present in both the Cholesky schemes and our main identification scheme. No restrictions will be placed on stock prices. By assuming that a monetary policy shock can have no long-run effects on the federal funds rate, we preserve the interpretations of monetary policy shocks as the unanticipated components of interest rate

movements, at the same time as we have sufficient restrictions to identify and orthogonalize all shocks.

The restriction can simply be found by setting the infinite number of relevant lag coefficients in (5),  $\sum_{j=0}^{\infty} C_{44,j}$ , equal to zero. Using the long-run restriction,  $S_{45}$  may still differ from zero. Once more, the system is now just identifiable. The model is estimated using four lags, as in the base model. However, all variables are now measured in levels. Applying a long-run restriction to the level of interest rates essentially implies that a monetary policy shock temporarily increasing the interest rate, must eventually be offset by the policymaker as described above.

**Figure 6. Model robustness.** Comparison with a model using a long-run restriction on interest rates.



Note: The figure shows the impulse responses of a normalized monetary policy shock and a stock price shock. Each figure compares the baseline model to the model where monetary policy shocks are identified as those shocks with no impact on the sum of the deviation of the short-term interest rate from the steady-state value (dashed lines).

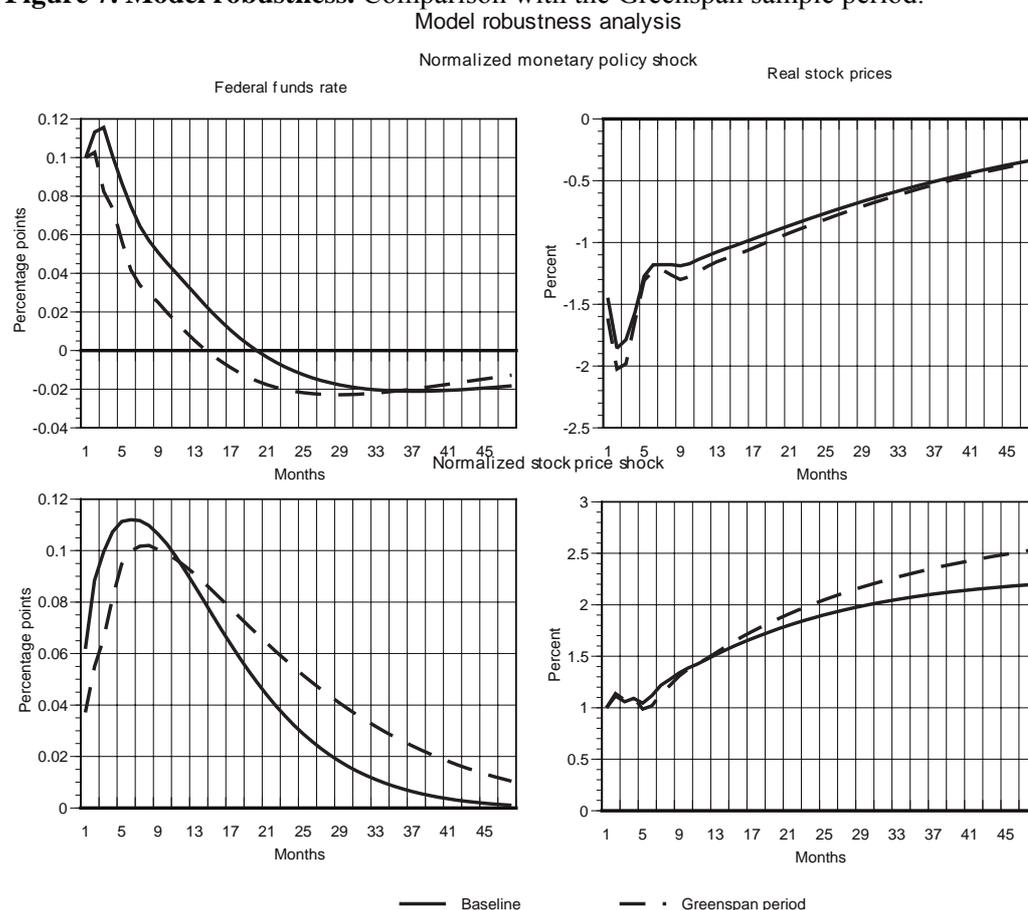
Figure 6 compares the impulse responses emanating from monetary policy and real stock price shocks, in both the baseline model and the model using a long-run restriction on interest rates. The results are broadly consistent with the findings reported above. In particular, we find the same response of the stock market to a monetary policy shock. The effects on

inflation and output are also similar to what we found in the baseline model (not reported). The main differences are found in the stock price shocks having a smaller impact on stock prices after about a year. However, the difference only has small effects on the evolution of interest rates to the stock price shock.

## 5.2 Sample stability – Greenspan period

Above, we argued that the choice of 1983 as a starting period reflected the need of having a statistical model with stable parameters (see, e.g., Bagliano and Favero, 1998, and Clarida et al., 2000). However, Bagliano and Favero also found some evidence of instability before 1988, and by starting the estimation in late 1988 (denoted the Greenspan period), no sign of mis-specification could be detected. However, the evidence was not overwhelming and, in the end, they found the impulse responses from a period starting in 1983 not to be statistically different from a period starting in 1988.

**Figure 7. Model robustness.** Comparison with the Greenspan sample period.



Note: The figure shows the impulse responses of a normalized monetary policy shock and a stock price shock from the baseline model and the Greenspan period model (dashes).

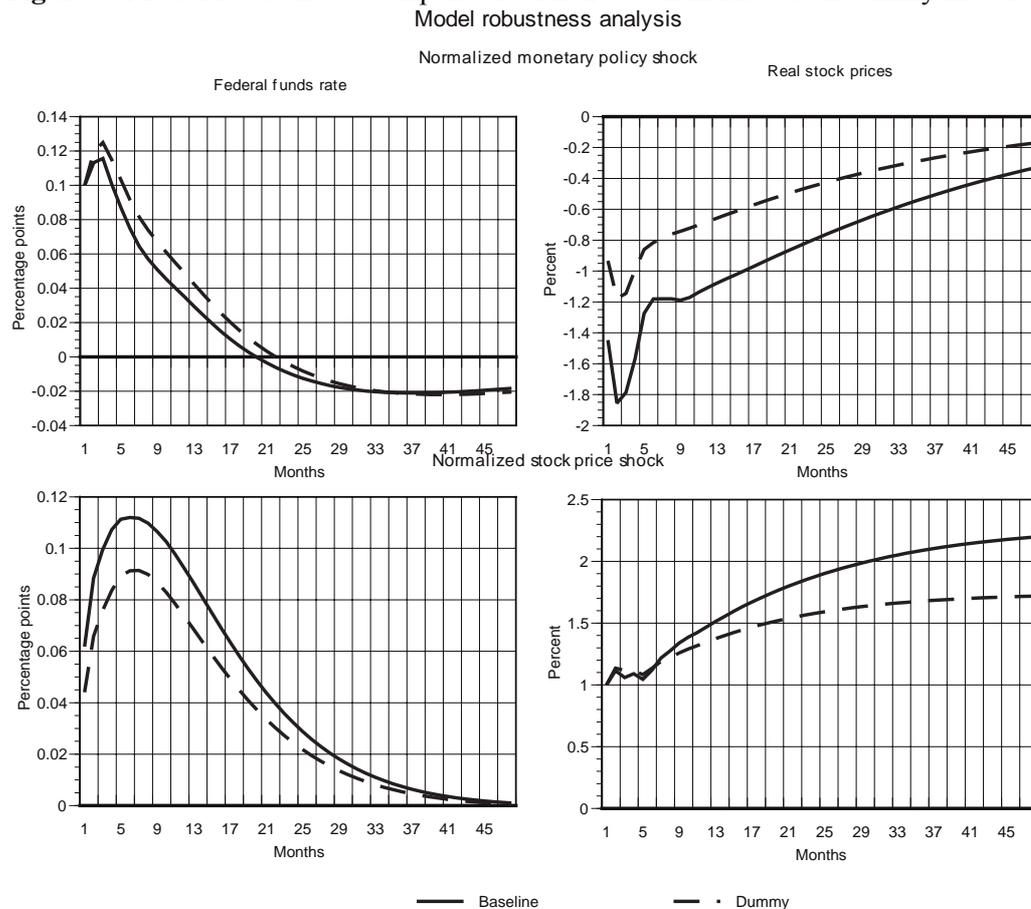
Nevertheless, it is interesting to analyze the effects of monetary policy in the period after Greenspan took office, so as to investigate the significance of monetary policy in more recent time. We re-estimate the model over the period 1987M1 to 2002M12. We choose 1987 as the

starting year as this is when Volcker resigned and Greenspan took office (August 1987). Impulse responses for monetary policy and stock price shocks are reported in Figure 7. The results are broadly consistent with the baseline model. We believe that any instability prior to 1988 may well reflect unusual shocks in that period, rather than the actual monetary policy stance. The stock market crash in October 1987 is a candidate for such a shock that is explicitly investigated in section 5.3 below.

### 5.3 Stock market crashes

An interesting question is whether our results are driven by a few extreme events of strong and simultaneous responses between stock prices and monetary policy. Throughout the period examined, there have been a few periods where the stock market fell severely (without the fundamentals changing significantly) while, at the same time, monetary policy became accommodating to counteract the negative effects of the stock market. The stock market crash in October 1987 is one example and the September 11, 2001 terror attack is another. Below, we report the impulse responses when these events are represented by dummy variables in the VAR analysis.

**Figure 8. Model robustness.** Comparison with the stock market crash dummy model.



Note: The figure shows the impulse responses of a normalized monetary policy shock and a stock price shock from the baseline model and the model with dummies for stock market crashes (dashes).

From the inspection of Figure 8, we see that the impulse responses remain qualitatively unchanged, although the response of the federal funds rate to a stock price shock and the response of the stock prices to a monetary policy shock are both reduced. We conclude that our reported results are not exclusively driven by these events, but are more likely through a stable interaction between monetary policy and stock market developments.

## **6. Concluding remarks**

Interest rate decisions are closely followed by the financial market and a vast amount of resources goes into monitoring and interpreting the decisions taken. Our empirical study supports the idea that monetary policymaking is indeed important for the stock market: We find a substantial degree of interdependence between monetary policy decisions and stock prices. Working both ways, a shock to either sector has a strong and immediate impact on the other sector. The results appear to be robust.

We find evidence of the systematic part of interest rate setting having contributed to stabilizing inflation and output in an efficient manner over the estimation period. The unsystematic part of policy is, however, an important source of volatility in the stock market and interest rates. An important part of the rise and subsequent fall in stock prices over the period 1995-2002 is here attributed to non-fundamental factors. The systematic part of policy responded to the bubble by keeping interest rates higher, thereby reducing both the size of the bubble and its consequence for inflation and output. This is no evidence of the FOMC targeting stock prices *per se*, as the monetary policy response to stock price shocks can be rationalized by their property of being leading indicators of inflation and output.

Although our results indicate the inclusion of stock market information in the VAR model to seem important for identifying monetary policy, we find little evidence leading us to reconsider the effects of a monetary policy shock on macroeconomic variables. This remains more or less unchanged from previous studies.

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