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by

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

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March 2008

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 (Christiano et al., 1999). We find great interdependence between interest rate setting and real stock prices. Real stock prices immediately fall by 7-9 percent due to a monetary policy shock that raises the federal funds rate by 100 basis points. A stock price shock increasing real stock prices by one percent leads to an increase in the interest rate of close to 4 basis points.

Keywords: VAR, monetary policy, asset prices, identification.
JEL-codes: E61, E52, E43.

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1. Introduction

It is commonly accepted that monetary policy influences private-sector decision-making. If prices are not fully flexible in the short run, as assumed by the New Keynesian theory framework, the central bank can temporarily influence the real interest rate and therefore have an effect on real output in addition to nominal prices. It is commonly believed that the central banks have some objectives for their exertion of control over the real interest rates, e.g. to have low and stable inflation and production close to the natural rate. In order to best fulfill these objectives, the central bank needs to monitor, respond to and influence private sector decisions appropriately. The central bank and the private sector will thus both affect and be affected by the other, leading to considerable interdependence between the two sectors. For the financial markets where information is readily available and prices are sensitive to agents' expectations about the future, we would expect that a large part of the interdependence to be simultaneous. Allowing for simultaneity between monetary policy and financial markets is therefore likely to be both quantitatively and qualitatively important when measuring the degree of interdependence. The aim of this paper is to explore just how important this is.

Analyses of the effects of monetary policy have to a large extent been addressed in terms of vector autoregressive (VAR) models, initiated by Sims (1980). Yet, studies that use VAR models to identify the interdependence have found only small effects of interaction between monetary policy and asset prices, see for instance Lee (1992), Thorbecke (1997) and Neri (2004) among others. However, these conventional VAR studies have *not allowed* for simultaneous interdependence, as the structural shocks have been recovered using recursive, short-run restrictions on the interaction between monetary policy and asset prices.

In this study we analyze the interaction between asset prices and monetary policy in the U.S., represented by the S&P 500 and the federal funds rate respectively, using a VAR model that takes full account of the potential simultaneity of interdependence. We solve the simultaneity problem by imposing a combination of short-run and long-run restrictions on the multipliers of the shocks, leaving the contemporaneous relationship between the interest rate and real stock prices intact. Identification is instead achieved by assuming monetary policy can have no long-run effect on the real stock price, which is a common long-run neutrality assumption. 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. Contrary to what is found in previous studies, we find *strong* interaction effects between the stock market and interest rate setting. A considerable part of the interaction is simultaneous. These results are achieved without much affecting the conventional view on how monetary policy affects macroeconomic variables, previously found in the VAR literature.

Section 2 gives a brief survey of theoretical, methodological and empirical arguments regarding the interaction between asset prices and monetary policy. Section 3 presents the identification scheme used for the VAR study in identifying the interdependence between the monetary policy and the stock market. Section 4 presents and discusses our empirical results, including issues pertaining to robustness. Section 5 concludes.

2. Monetary policy and stock prices interaction: a short overview

Economic theory suggests several reasons why there should be interaction effects between monetary policy and asset prices, in particular, stock prices. Through its effect on both the current and the expected future real interest rate, the central bank influences the timing of both household consumption and business investment decisions. It is commonly assumed that asset prices and, in particular, stock prices are determined in a forward-looking manner, thereby reflecting the private sector 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. 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). Furthermore asset prices may include relevant information that is not available elsewhere. The monetary policymaker that manages aggregate demand in an effort to control inflation and output thus has incentives to monitor asset prices in general, and stock prices in particular, and use them as short run indicators for the appropriate stance of monetary policy.[1] Therefore, there is likely to be considerable interdependence between stock price formation and monetary policymaking.[2] Empirical modelers should thus be open to the potential influence of asset prices on monetary policymaking.

2.1 Empirical evidence

Compared to the vast amount of papers analyzing the influence of the monetary policy actions on the macroeconomic environment, there are relatively few papers trying to model interactions between monetary policy and asset prices. Early attempts, like Geske and Roll (1983) and Kaul (1987), examine the causal chain between monetary policy and stock market returns separately (see Sellin (2001) for a comprehensive survey). More recently, empirical studies have tended to use a joint estimation scheme like the vector autoregressive (VAR)

[1] See Vickers (2000) for overview of the use of asset prices in monetary policy in inflation-targeting countries.
[2] The form of interaction is further complicated by issues of whether asset prices should be included in the central bank loss function (see e.g. Bernanke and Gertler, 1999 and Carlstrom and Fuerst , 2001), on how to use asset price information efficiently and whether assets prices convey information that is not available elsewhere (e.g., Faia and Monacelli, 2008), whether the credit channel is important (see Bernanke, Gertler and Gilchrist, 2000, and Bernanke and Gertler, 1989) and whether asset prices include expectations-driven sunspot components that may influence target variables more than what is reflected by the fundamental part of the asset price (see e.g. Cecchetti et al., 2000, and Bernanke and Gertler, 2001).

approach, since it involves the joint interaction of all variables, see e.g. Lee (1992), Patelis (1997), Thorbecke (1997), Millard and Wells (2003) and Neri (2004) among others. All these find monetary policy shocks to account for only a small part of the variations in stock returns. Furthermore, stock prices frequently display a puzzling development which is difficult to understand from the perspective of financial market theory. More importantly, the above papers identify monetary policy and stock market shocks using the Cholesky decomposition, imposing a recursive ordering of the identified shocks. In many of these papers, stock prices are 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 interdependence is ruled out *by assumption*.

Lastrapes (1998) and Rapach (2001) identify instead monetary shocks in a VAR model using solely long-run (neutrality) restrictions. Both find considerably stronger effects of the monetary shock on the stock market. However, the reverse causation; from the stock market to systematic monetary policy is either ignored or addressed more rudimentarily.[3]

Recently, the simultaneity problem has been addressed using high frequency observation (i.e., daily data), to analyze how asset prices are associated with particular policy actions in the *short run*. In an influential paper, Rigobon and Sack (2004) use an identification technique based on the heteroscedasticity of shocks that is present in high frequency data to analyze the impact effect of monetary policy on the stock marked. They find that following a surprise interest rate increase, stock prices decline significantly. Furthermore, using the same method, but analyzing the reverse causation, Rigobon and Sack (2003) find that stock market movements have a significant impact on short term interest rates, driving them in the same direction as the change in stock price. These results are somewhat stronger than results found in more conventional "event studies" like Bernanke and Kuttner (2005).

[3] Another strand of literature estimates the contribution of asset prices in (Taylor type) interest rate reaction functions (i.e. Chadha et al. (2003)) but is subject to the same simultaneity problem as in the conventional VARs (see Rigobon and Sack (2003) for a more critical review).

The above cited studies are useful for quantifying the immediate (short run) effect of a specific action, such as a monetary policy surprise, while ignoring the issue of dynamic adjustments following the initial shock. Furthermore, they rarely provide for two way causation, focusing either exclusively on the effect of a monetary policy shock, or of a stock price shocks. To do so, we need to identify monetary policy shocks in a system like the structural VARs as is done in the present study. On the other hand, identification of the VAR system should be such that it does not violate the major finding from these event/impact studies, as seems to have been the case so far for the conventional VAR studies.

3. The identified VAR model

The VAR model comprises monthly data of the annual change in the log of consumer prices (π_t), the annual change in the log of the commodity price index in US dollars (Economist Commodity price index, all items) (c_t), the log of the (detrended)[4] industrial production index (y_t), the federal funds rate (i_t) and the log of the S&P 500 stock prices index (s_t). Stock prices are deflated by CPI, so that they are measured in real terms, and then differenced (to denote monthly changes, i.e. Δs_t). 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.

3.1 Identification

Assume Z_t to be the (5x1) vector of macroeconomic variables discussed above that are ordered as follows: $Z_t = [y_t, \pi_t, c_t, \Delta s_t, i_t]$, and assumed to be stationary (see the discussion in Section 4). The reduced form VAR has a MA representation,

[4] Giordani (2004) has argued that if one follows the model set up in Svensson (1997) as data generating process in monetary policy studies, the output gap, rather than the level of output, should be included in the VAR. Data properties as well as robustness to the various data transformations will be discussed further in Section 4.

$$Z_t = B(L)v_t, \quad (1)$$

where v_t is a (5x1) vector of reduced form residuals assumed to be identically and independently distributed, $v_t \sim iid(0,\Omega)$, with positive definite covariance matrix Ω. $B(L)$ is the (5x5) convergent matrix polynomial in the lag operator L, $B(L) = \sum_{j=0}^{\infty} B_j L^j$. We assume that the underlying orthogonal structural disturbances (ε_t) can be written as linear combinations of the innovations (v_t), i.e., $v_t = S\varepsilon_t$, where S is the (5x5) contemporaneous matrix. (1) can then be written in terms of the structural shocks as

$$Z_t = C(L)\varepsilon_t, \quad (2)$$

where $B(L)S = C(L)$. To identify S, we assume that the ε_t's are normalized so they have unit variance. We order the vector of uncorrelated structural shocks as $\varepsilon_t = \left[\varepsilon_t^y, \varepsilon_t^\pi, \varepsilon_t^c, \varepsilon_t^{SP}, \varepsilon_t^{MP}\right]'$, where ε^{MP} is the monetary policy shock and ε^{SP} is the stock price shock, while the remaining shocks are identified from their respective equations, but left un-interpreted. We follow the standard closed economy literature (Christiano et al. 1999, 2005) and identify monetary policy shocks by assuming macroeconomic variables do not simultaneously react to policy variables, while the simultaneous reaction from the macroeconomic environment to policy variables is allowed for. This is taken care of by placing the macroeconomic variables above the interest rate in the ordering and assuming zero restrictions on the relevant coefficients in the S matrix, as shown in (3).

$$\begin{bmatrix} y_t \\ \pi_t \\ c_t \\ \Delta s_t \\ i_t \end{bmatrix} = B(L)\begin{bmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix}\begin{bmatrix} \varepsilon_t^y \\ \varepsilon_t^\pi \\ \varepsilon_t^c \\ \varepsilon_t^{SP} \\ \varepsilon_t^{MP} \end{bmatrix}. \qquad (3)$$

Regarding the stock price, the standard practice in the VAR literature has been to either assume that real stock prices respond with a lag to monetary policy shocks (S_{45} = 0), or, that monetary policy responds with a lag to stock price shocks (the stock price is ordered below the interest rate). Only the latter allows for an immediate reaction in real stock prices to a monetary policy shock. However, as discussed above, such identifications rules out a potential important channel for interaction between monetary policy and the stock price, which if empirically relevant, would bias the result. We therefore instead impose the alternative identifying restriction that a monetary policy shock can have no long-run effects on the level of real stock prices. The restriction can be applied by setting the infinite number of relevant lag coefficients in (2), $\sum_{j=0}^{\infty} C_{45,j}$ equal to zero. Writing the long-run expression of $C(L)$ as $B(1)S = C(1)$, 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 $C_{45}(1)$=0 implies

$$B_{41}(1)S_{15} + B_{42}(1)S_{25} + B_{43}(1)S_{35} + B_{44}(1)S_{45} + B_{45}(1)S_{55} = 0 \qquad (4)$$

The system is now just identifiable.[5] The recursive Cholesky restriction identifies the non-zero parameters above the interest rate equation, whereas the remaining parameters are uniquely identified from the long run restriction $C_{45}(1)$=0. Note that the responses to the monetary policy shock (or the stock price shock) will be invariant to the ordering of the three

[5] Note that (4) reduces to $B_{44}(1)S_{45} + B_{45}(1)S_{55} = 0$ with the zero contemporaneous restrictions applied.

first variables. This follows from a generalizing of Christiano et al. (1999; Proposition 4.1), and can be shown on request.

4. Empirical modeling and results

The model is estimated using monthly data from 1983M1 to 2002M12. As noted in section 3, the choice of data and transformation reflect the model set up in Svensson (1997) as data generating process, suggesting we include annual inflation rates and the output gap (de-trended using a linear trend) in the VAR. It is, however, important that the VAR is stationary, as otherwise the MA-representation of the VAR may be non-convergent. This is confirmed using unit root tests, with the exception of consumer price inflation, that displays clear evidence of stochastic trend that drifts downwards (that could reflect a fall in the inflation target). We therefore remove the non-stationarity by taking first differences (although in the appendix we show that results are robust to this kind of transformation). Lag reduction tests suggest that four lags could be accepted at the one-percent level by all tests. There is no evidence of autocorrelation, heteroscedasticity or non-normality in the model residuals.

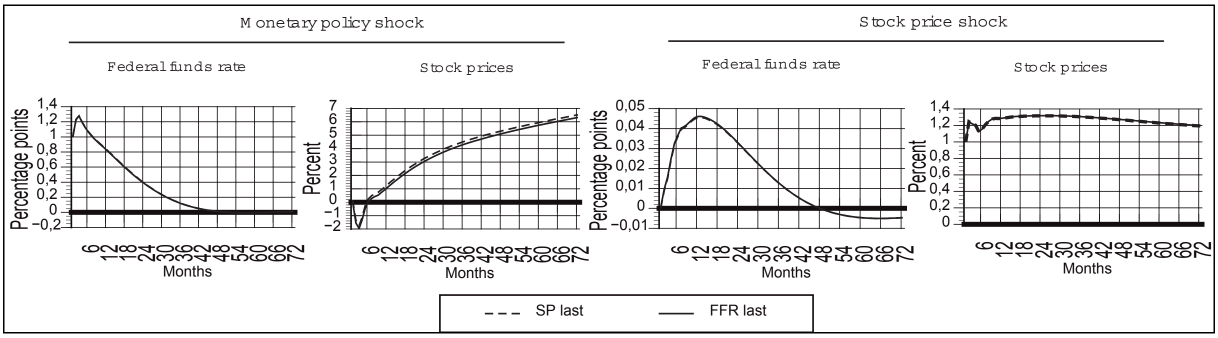
4.1 Cholesky decomposition

Figure 1 gives an account of the impulse responses of interest rates and real stock prices to a both a monetary policy shock and a stock price shock under the standard Cholesky decomposition. These are shown for two different orderings of variables, with the interest rate and the stock price alternating as the ultimate and penultimate variables.

Both orderings produce almost identical impulse responses. Neither the monetary policy shock nor the stock price shock has any important contemporaneous effects on the other variables. In addition, the effect of a monetary policy shock on real stock prices is counterintuitive. Assuming that both the stock market and the monetary policymaker react 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.

Figure 1: Cholesky decomposition: Impulse responses due to monetary policy and stock price shocks.



Note: From left, the two first panels show the impulse responses due to the identified monetary policy shock, while the latter two show the response to the stock price shocks. We use Cholesky decomposition for two different ordering of the variables. The solid lines order the federal funds rate after stock prices and the dashed line order the variables in the opposite order.

4.2 Structural identification scheme

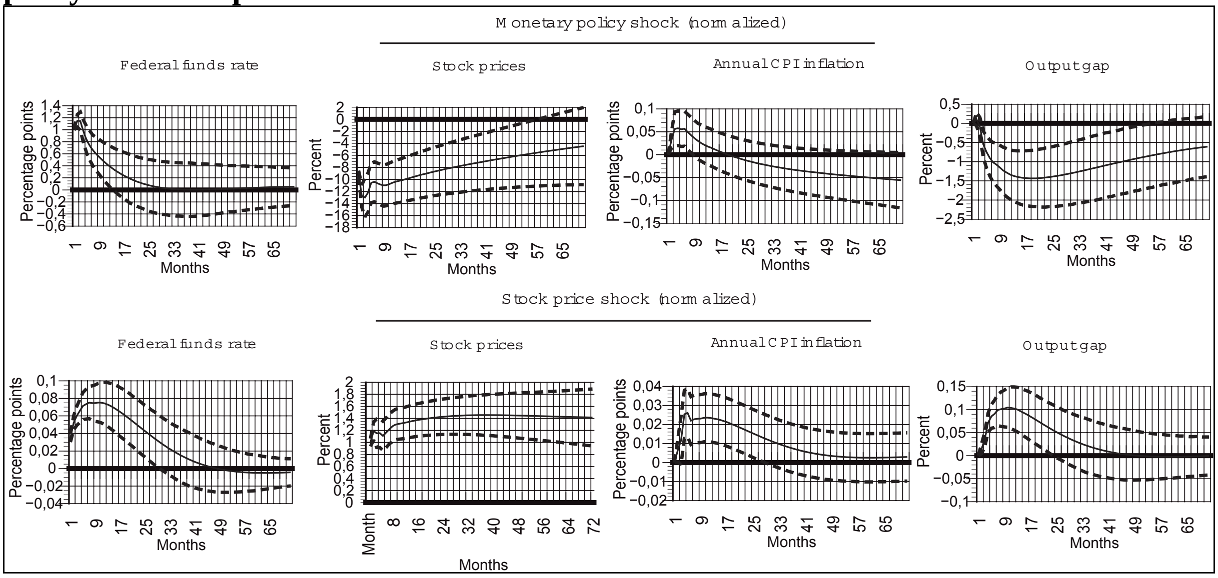
Turning to the structural model, Figure 2 shows the impulse responses for the federal funds rate, the real stock price, annual inflation and the industrial production (gap) from a monetary policy shock (top panels) and a stock price shock (lower panels). The responses are graphed with probability bands represented as .16 and .84 fractiles (as suggested by Doan, 2004).[6]

The upper panels of Figure 2 show that the monetary policy shock temporarily increases interest rates. As is commonly found in the literature, output falls temporarily and reaches its minimum after a year and a half. The negative effect on output is clearly significantly different from zero, but after four years, the effect has essentially died out. Inflation first increases. This initial increase – a price "puzzle" (see Eichenbaum, 1992) - may be due to a cost channel of the interest rate (see, Ravenna and Walsh, 2006, and Chowdhury et al., 2003).

[6] This is the Bayesian simulated distribution obtained by Monte Carlo integration with 2500 replications, using the approach for just-identified systems. The draws are made directly from the posterior distribution of the VAR coefficients (see Doan, 2004).

After 4-6 months, however, inflation starts to decline, so that in the long run prices fall following a contractionary monetary policy shock.

Figure 2: Structural identification: Impulse response due to the identified monetary policy and stock price shock.



Note: The eight panels show the impulse responses with probability intervals associated with the .16 and .84 fractiles. The top panels refer to the impulse responses due to the identified monetary policy shock, while the bottom row shows the responses to the stock price shocks.

Turning to real stock prices, the monetary policy shock has a strong impact on stock returns that immediately fall by about nine percent for each (normalized) 100 basis-point increase in the federal funds rate. This is consistent with results found in Rigobon and Sack (2004) (that focus on short run responses),[7] but much larger than those found in the traditional VARs. The result of a fall in real 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. Following the initial shock, real stock prices fall for an additional month or so, before returning back towards the average level as the long run restriction bites. Although

[7] Rigobon and Sack (2004) find 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."

interpretations of this result should be made with care, a potential explanation might be that as the interest rate gradually falls, the discounted value of expected future dividends increases while output and profits build up, leading to a normalization of real stock prices.

The lower panels of Figure 2 show that a positive stock price shock increases both inflation and output in the short run. This is consistent with the view that the rise in real stock prices increases consumption through a wealth effect and investment through a Tobin Q effect, thus affecting aggregate demand. Due to nominal rigidities, prices react slowly and inflation rises in the intermediate run. The increase in inflation may, however, also be partly driven by the increase in the interest rate itself due to the initial price puzzle in the model. In any case, the response of the interest rate is consistent with an inflation-targeting central bank raising interest rates to curb the inflationary effects of increased aggregate demand.

Stock price shocks are important indicators for the interest rate setting. A shock that increases real stock prices by one percent causes the interest rates to increase immediately by just less than four basis points, increasing to seven basis points within a year. By increasing the interest rate, the FOMC achieves the reduction in aggregate demand through the usual interest rate channels and reducing the positive impact on real stock prices. Again, our results are very much in line with studies that focus on short run responses (i.e., Rigobon and Sack, 2003),[8] but larger than those found in the traditional VAR analysis.

How can we interpret the stock price shock? Under the "news" interpretation, the shock contains information about the future that is not yet incorporated in current macroeconomic variables leading to a delayed but permanent change in productivity (see Beaudry and Portier, 2006). If the shock is non-fundamental (sunspot), the innovation in real stock prices is driven purely by expectations with no permanent effects on output *caused by changes in technology*. There may still, however, be short-run responses to output due to

[8] Rigobon and Sack (2003) 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, while a similar-sized movement over a week has a slightly larger effect on anticipated policy actions." Similar findings are also found in Furlanetto (2008), although when focusing on the very recent time, he finds the response to have declined somewhat.

wealth effects on aggregate demand. Under both of these interpretations, the shock may contain vital information to the central bank for reasons outlined in Section 2. From Figure 3, we see that the stock market shock has only a temporary effect on output. Given, however, that we are including the output gap in the VAR, we have already effectively removed the long run trend and no permanent effects are possible. Hence we cannot draw any conclusions. In the appendix, however, we test robustness to other specifications, including measuring output in first differences (thereby allowing for a potential long run impact of shocks). The dynamic effects of the shock on output remain similar and there is no long-run effect on output. We therefore cautiously conclude that our results are consistent with the stock price shock being a sunspot shock rather than an anticipated technology shock. In this respect, our results differ from that of Beaudry and Portier. We note, however, that the confidence bands are wide and we are cautious in making any strong conclusions about the nature of the shock. The issue of as to what drives the stock market deserves further research.

One objection to our identification of the stock price shock is that the shock could have an immediate effect on other variables like production and consumption (i.e., Jaimovich and Rebelo, 2006). This was ruled out by our identification scheme. However, it can be argued that it is not unlikely that the greater part of consumer prices together with consumption and investment decisions are subject to implementation lags of length similar to the model's monthly frequency (see, Woodford, 2003, and Svensson and Woodford (2005), for arguments).[9]

The results reported so far suggest a great interdependence between the effects of the shocks.[10] How is it possible to reconcile the zero interdependence found using the Cholesky decomposition above, with that of large interdependence found in the present structural

[9] We have experimented with an alternative identification where output is ordered below real stock prices (i.e., allowing for the immediate impact of the stock price shock on output, but restricting real stock prices from responding on impact to output shocks instead). We find no significant impact effects on output of a stock price shock, taking this as support of our assumption about implementation lags in output.

[10] The error variance decomposition (not reported, but can be obtained at request) suggests that the monetary and stock price shocks together account for almost all variation in the federal funds rate and stock prices on impact, leaving the other shocks to influence these variables only in the longer run.

model? To see this, assume for simplicity a system in two variables, the interest rate (i_t) and the real stock price (s_t). The reduced form residuals will be linear relationship of the structural orthogonal shocks, that is, the monetary policy shock and the stock price shock,

$$
\begin{aligned}
u_{i,t} &= \varepsilon_t^{MP} + \alpha\varepsilon_t^{SP} \\
u_{s,t} &= \beta\varepsilon_t^{MP} + \varepsilon_t^{SP}
\end{aligned}
$$

with covariance given by $\operatorname{cov}(u_{i,t}, u_{s,t}) = E\left[(\varepsilon_t^{MP} + \alpha\varepsilon_t^{SP})(\beta\varepsilon_t^{MP} + \varepsilon_t^{SP})\right] = \beta\omega_{MP}^2 + \alpha\omega_{SP}^2$. Hence, a covariance close to zero either implies that the interdependence is zero, $\operatorname{cov}(u_{i,t}, u_{s,t}) = 0$, implying $\alpha = \beta = 0$ (as imposed using the Cholesky decomposition), or that the effects are opposite in signs and cancel out $\beta = -\left(\omega_{SP}^2 / \omega_{MP}^2\right)\alpha$. Only the structural identification scheme suggested here allows the latter to be the case.

4.3 Robustness

We study the robustness of the results by using plausible alternative models. We first study alternative monthly specifications of the model, varying sample period, lags, allowing for dummies (for specific events like the stock crashes in 1987 and 2001), using different transformations of the variables (first differences, Hodrick Prescott filter, no detrending etc) or changing the order of the variables. We then estimate the same model using quarterly data, allowing us to substitute industrial production with GDP, as well as expanding the dimension of the model by including consumption and investment. All the results are presented and discussed in more detail in the appendix.

We find the results to remain robust to all of these variations. Regarding the monthly specifications, the baseline model has about the average response across the models. There may be some evidence that the impact effect of both shocks have decreased somewhat over time, although these results will depend on the specific VAR model specified. The responses are marginally smaller in the quarterly model, but also there robust to various transformations.

5. Conclusion

We find that there is a substantial simultaneous interaction between interest rate setting in the US and shocks to real stock prices. Just as monetary policy is important for the determination of stock prices, the stock market is an important source of information for the conduct of monetary policy. This result is found in many plausible and alternative model specifications that allows for the possibility of simultaneous interaction.

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Appendix

In this appendix we study the robustness of the result that there is strong simultaneous interaction between the stock market and monetary policy by using plausible alternative models. In the first section we study the robustness properties with respect to alternative monthly specifications of the model. We then estimate the same model using quarterly data, allowing us to substitute industrial production with GDP, as well as expanding the dimension of the model by including consumption and investment.

Robustness to alternative monthly specifications

In checking for robustness of our findings, it is important to establish whether the strong interdependence found is 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 were 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 fall. The stock market crash in October 1987 is one example and the September 11, 2001 terror attack is another. Furthermore, it is important to establish whether our results have changed in the period starting in 1987 from which Alan Greenspan took office. Regarding model specification, is the choice of lag length in the VAR model important for our results? Further, will the results prevail if the variables in the VAR are specified differently (i.e. taking first differences of the variables, using a Hodrick Prescott filter to de-trend inflation and GDP, no-detrending etc.) and finally, are the results robust to alternative ordering of the variables?

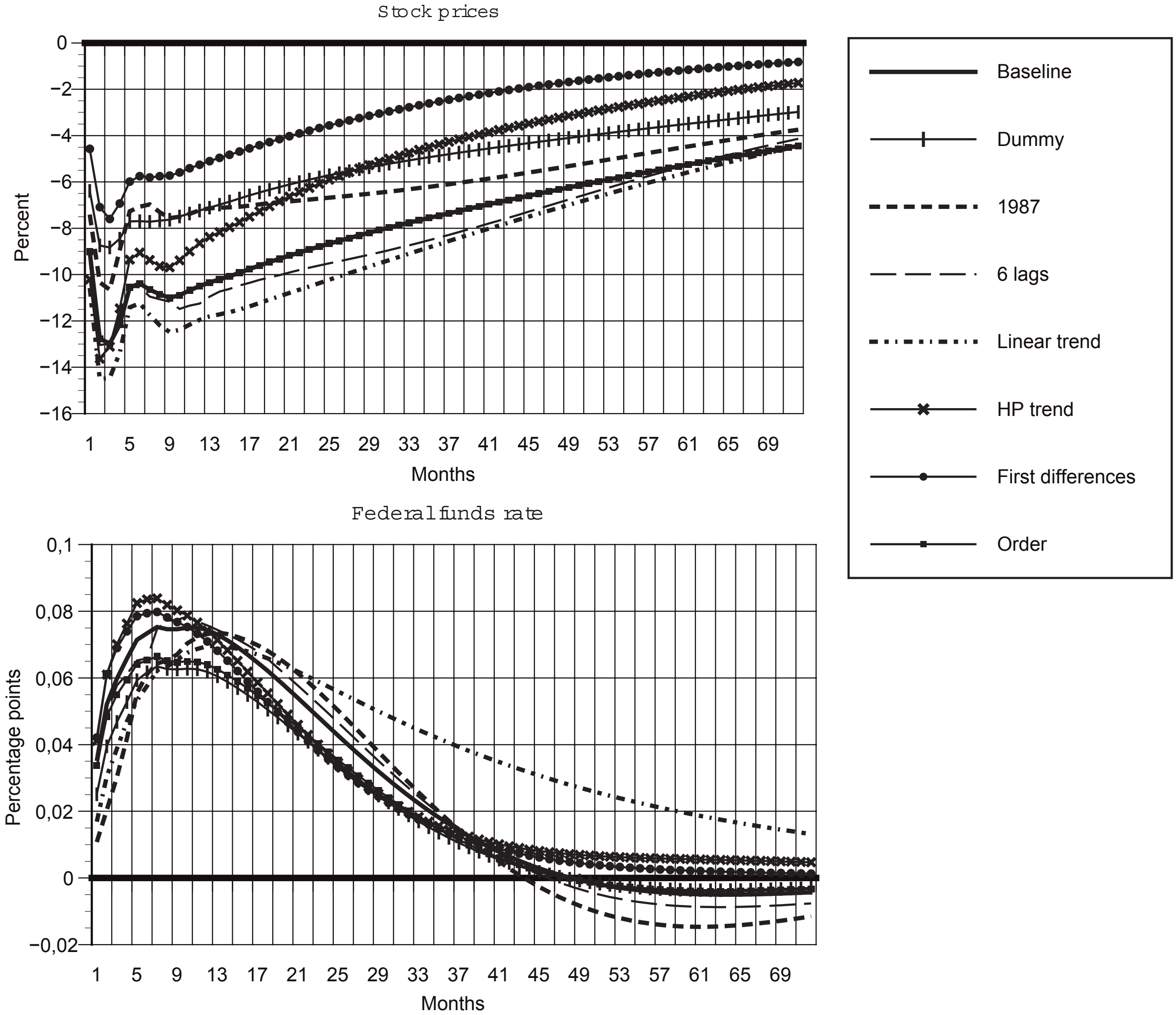
To investigate the robustness of our results along these dimensions, the upper panel of Figure A1 reports the impulse responses of a normalized monetary policy shock (that increases the interest rate with 100 basis points) on stock prices when the baseline VAR is re-estimated (*i*) with two dummies for the suggested stock price collapses (*Dummy*) (*ii*) using more recent time, i.e. the Greenspan period 1987M1 to 2002M12 (*1987*) (*iii*) with 6 instead of 4 lags (*6 lags*) (*iv*) first differencing all variables but the interest rate (First differences) (*v*) using Hodrick Prescott (HP) filter to detrend inflation and output (*HP trend*) (*vi*) using a linear trend to de-trend output and inflation (*Linear trend*), and, finally, (*vii*) using an alternative order of the first four variables in the VAR. That is, we order output below the real stock price, i.e. we allow for an immediate impact of the stock price shock on output, but restricting instead real stock prices from responding on impact to output shocks (*Order*). The lower panel of Figure A1 reports the effect of a normalized stock price shock (that increases stock prices by one percent) on the federal funds rate to the same robustness tests.

Starting with the top panel, we see that across the models, there is a substantial and immediate reduction in stock prices due to the monetary policy shock. The baseline model has about the average response across the models. In particular, removing the first part of the sample, re-estimating with a dummy for major events or using first differences, all reduce the impact; whereas alternative de-trending or using more lags increase the impact. All models suggest that real stock prices return to the steady state at approximately the same speed. Finally, note that the impulse responses using an alternative order remains indistinguishable from baseline, as the effect of the monetary policy shock on stock prices remains exactly identical. The results allows for a generalizing of Christiano et al. (1999; Proposition 4.1) to also include a variable that is identified using a (zero) long run restriction.[11]

Turning to the response of a stock price shock, the lower panel emphasizes that there is a robust picture with respect to how the federal funds rate reacts to the stock price shock. The baseline model has about the average response across the models. Again, removing the first part of the sample, re-estimating with a dummy for major event or using first differences

[11] Christiano et al. (1999; Proposition 4.1) states that using a Cholesky decomposition with the monetary policy variable (the interest rate) ordered last, the responses to the monetary policy shock will be invariant to the ordering of the variables above the interest rate. The real bite here is the assumption that the variables in the VAR don't respond contemporaneously to a monetary policy shock.

Figure A1. Impulse responses under alternative monthly model specifications to a monetary policy shock (upper panel) and a stock price shock (lower panel).



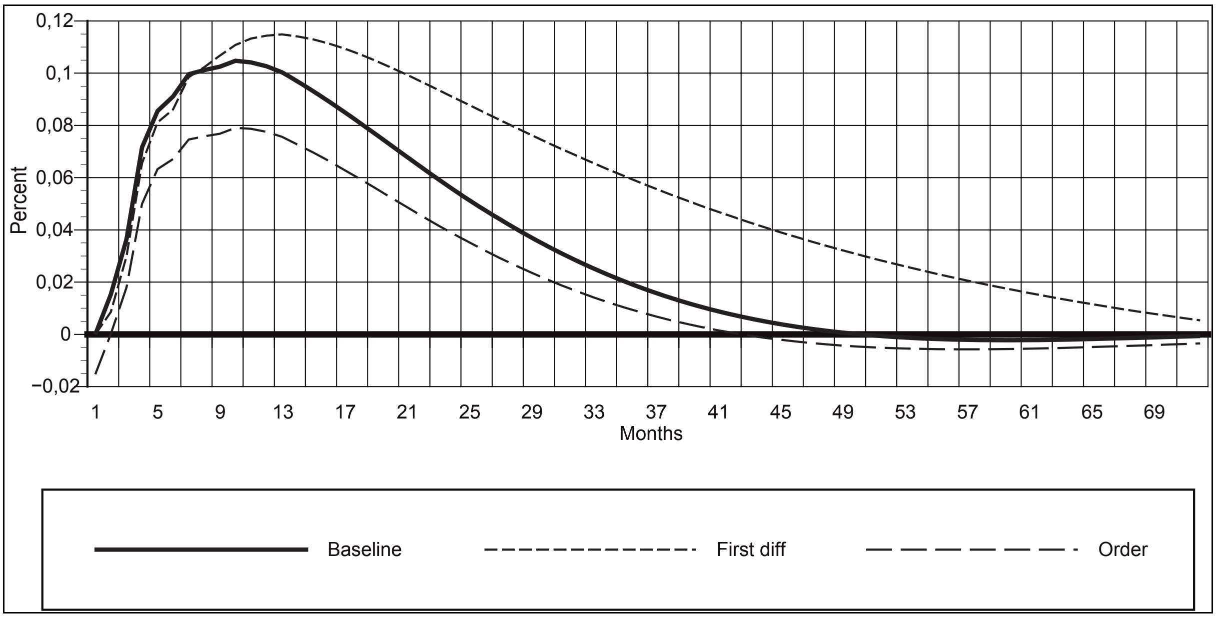
Note: The upper panel shows the impulse response of real stock prices to a normalized monetary policy shock that increases the nominal interest rate on impact by one percentage point. The lower panel shows the impulse response of the federal funds rate to a normalized stock price shock that increases stock prices by one percent. See the main text for an explanation of the different monthly specifications.

reduce the immediate response somewhat; whereas more lags and alternative de-trending increase the response. Using an alternative order of the variables reduce the impact somewhat Hence, we are confident in reporting that all models suggest that the interaction is quantitatively important.[12] There may be some evidence that the impact effect of both shocks

[12] Several other model specifications were also tried out. For instance, specifying all variables in levels or adding a trend to the VAR increased the impact somewhat. However, these responses are not reported as we believe this to yield an improper representation of data. We also tested robustness to substituting some of the variables with plausible alternatives in the VAR. We found that this did not change the results much. The most effect was when we included oil prices instead of a commodity price index in the VAR, which magnified all the results. All results can be obtained at request from the authors.

have decreased somewhat over time, although these results will depend on the specific VAR model specified.

Figure A2. Industrial production: Effect of a stock price shock using an alternative ordering or first differences



Note: The effect of a stock price shock comparing baseline model with the models using an alternative order (industrial production is ordered *after* real stock price) and using first differences.

Before turning to the quarterly model, Figure A2 reports robustness of the effect of a stock price shock on industrial production, using two alternative specifications; Using (*i*) first differences (*First diff.*) or using (*ii*) the alternative order (*Order*) discussed above (where the real stock price is ordered above output). The two robustness tests are chosen to cast some more light on the interpretation of the stock price shock. In particular, when output in measured in first differences, we allow for a potential long run impact of shocks. However, as can be seen, the dynamic effects of the shock on output are similar and there is no long-run effect on output.

The alternative order is chosen to allow the stock price shock to have an immediate effect on production (i.e., Jaimovich and Rebelo, 2006). This was ruled out by our original identification scheme. However, as discussed in the paper, it can be argued that it is not unlikely that the greater part of consumer prices together with consumption and investment decisions are subject to implementation lags of length similar to the model's monthly frequency. A possible way to test for implementation lags in output is to allow for the immediate impact of the stock price shock on output, but as a requirement for identification, restricting real stock prices from responding on impact to output shocks. However, Figure A.2 emphasizes that the impact effect is close to zero as in the baseline model. This gives some support to our assumption about implementation lags in output. However, we acknowledge that this is only an imperfect test since we might have imposed an implausible assumption when restricting real stock prices from responding on impact to shocks in output.

Robustness to alternative quarterly specifications

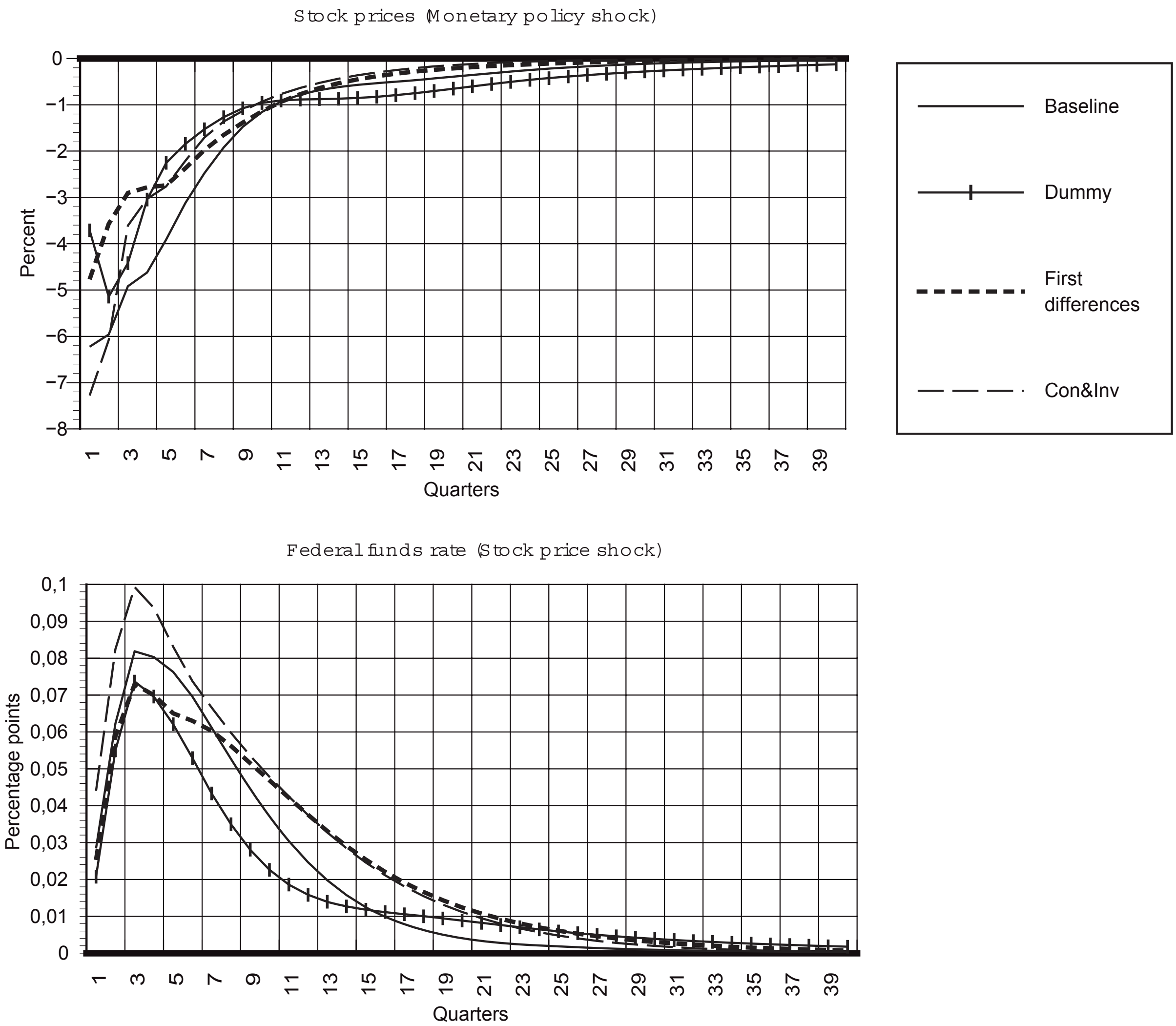
Although we believe that the interaction between monetary policy and asset markets is best modeled at a rather high frequency, a quarterly specification allows us to use other macroeconomic series arguably more important for monetary policy and aggregate stock prices. Our results are, however, confirmed in a robust manner also at this frequency. We consider several specifications of the quarterly model. First, as the baseline model, we estimate the quarterly model from 1983 with GDP replacing industrial production (*Baseline*).[13] In a second specification we augment the VAR using the same dummies as above, albeit at a quarterly frequency, i.e. 1987Q4 and 2001Q3 (*Dummy*), then we augment the baseline model transforming the variables to first differences (*First differences*) and, finally, in the last specification we augment the VAR by replacing GDP with consumption and investment (*Con&Inv*).[14]

The upper panel of Figure A3 shows the impulse responses of a normalized monetary policy shock (that increases the interest rate with one percentage points initially) on real stock prices for these model specifications, whereas in the lower panel of the same figure, we graph

[13] In all specifications, GDP replaces industrial production, whereas the other variables remain the same, but are aggregated up to a quarterly frequency. The variables are transformed the same way as in the monthly model (i.e. GDP is linearly detrended), and we use two lags (2 quarters) in the VAR.
[14] When the VAR is augmented with consumption and investment, all variables but the interest rates are first differenced.

the responses in the federal funds rate of a normalized stock price shock (that increases real stock prices initially with one percent) for the same model specifications. Finally, in figure A4 we graph the response in consumption and investment to the stock price shock.

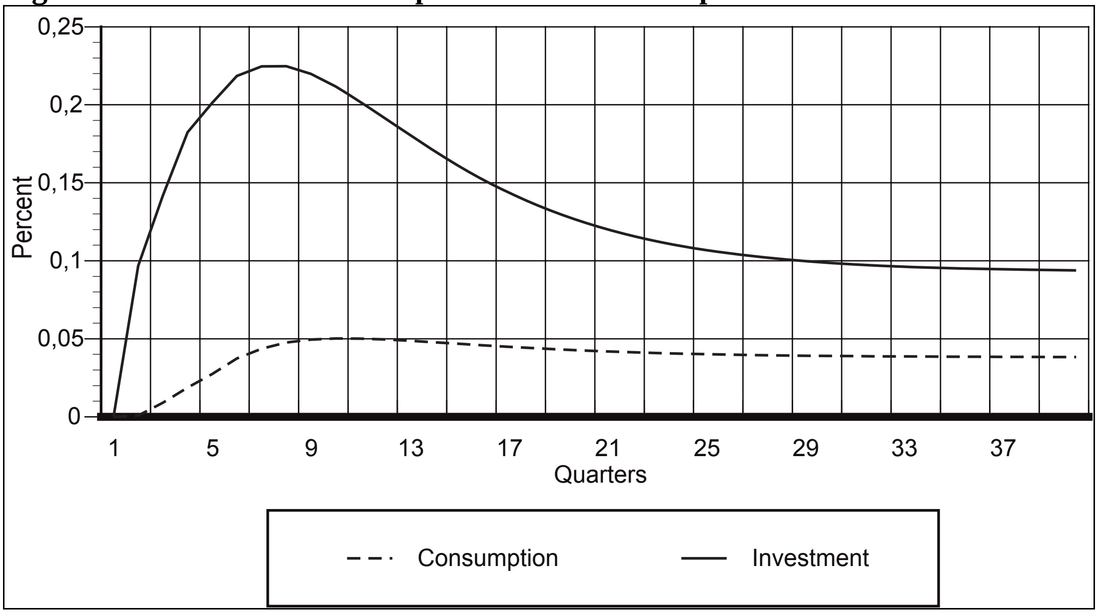
Figure A3. Impulse responses under alternative quarterly model specifications to a monetary policy shock (upper panel) and a stock price shock (lower panel).



Note: The upper panel shows the impulse response of real stock prices to a normalized monetary policy shock that increases the nominal interest rate on impact by one percentage point. The lower panel shows the impulse response of the federal funds rate to a normalized stock price shock that increases stock prices by one percent. See the main text for an explanation of the different quarterly specifications.

The upper panel of Figure A3 emphasizes again that there is a substantial and immediate fall in stock prices due to the monetary policy shock. A monetary policy shock that increases the interest rate with 100 basis points, reduce the stock price with 6-7 percent. As in the monthly models, the baseline model has about the average response across the models. Using first differences reduces the impact the most, whereas when we augment the model with consumptions and investment (instead of GDP) the impact effect increases. Further, the lower panel emphasizes that a stock price shock that increases the real stock price by one percent increases the Fed rate with three basis points and increasing to eight basis points within a year. Also here, the baseline model has about the average response across the models.

Figure A4. The effect of a stock price shock on consumption and investment



Note: Impulse response of consumption and investment from a normalized stock price shock (that increases stock prices with one percent initially) in the quarterly model (Con&Inv).

Finally, Figure A4 shows that a positive stock price shock increases both consumption and investment in the short run. This confirms the results found in the monthly model; a rise in real stock prices increases consumption through a wealth effect and investment through a Tobin Q effect, thus affecting aggregate demand. Under either the news or the sunspot interpretation, the shock may contain vital information to the central bank for reasons outlined in Section 2. However, Figure A4 also emphasizes that there may be some more persistent effects from a stock price shocks than in the benchmark model, although low point estimates and wide standard error bands (not reported) suggest that the effects of the shock eventually die out.

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