Changing Effects of Monetary Policy in the U.S. – Evidence from a Time-Varying Coefficient VAR

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Abstract: We estimate a time-varying coefficient VAR model for the U.S. economy to analyse (i) if the effect of monetary policy on output has been changing systematically over time, and (ii) if monetary policy has asymmetric effects over the business cycle. We find that the effectiveness of monetary policy shocks has been gradually declining over the sample period (1962-2002), as some theories of the monetary transmission mechanism imply. In addition, our results indicate that the effects of monetary policy are greater in a recession than in a boom.

JEL classification: E52, E32, C52

Keywords: vector autoregression, monetary transmission, non-linear time series models, time-varying coefficients

1 Introduction

Has the impact of U.S. monetary policy on output changed systematically over time? Moreover, are the effects of monetary policy symmetric or asymmetric over the business cycle? These issues have received increasing interest in the recent macroeconometric literature. By applying a time-varying coefficient vector autoregressive model (TVC-VAR) in the present paper we are able to tackle both these issues within one econometric framework. In comparison to other non-linear empirical models that have been used to study time-varying effects of monetary policy (e.g., the Markov-Switching model or the smooth-transition VAR model), the TVC-VAR constitutes an interesting alternative. It is comparatively flexible and it imposes as few as possible restrictions on the data. The empirical model is thereby well suited for a - to a certain extent - "unprejudiced" look at the data, which lies in the VAR-tradition of analysing the effects of policy shocks. Our results suggest a decreasing effectiveness of U.S. monetary policy over time as well as considerable asymmetries over the business cycle, with stronger effects of monetary policy during a recession.

At least two theories of the monetary transmission suggest a change of the effectiveness of monetary policy over time. The 'cost channel' presented by e.g. Barth and Ramey (2001) claims that monetary policy effects are transmitted through the supply side of the economy by affecting the working capital of enterprises. They develop three factors that may account for a weakening of the real effects of monetary policy through this channel: (i) Financial innovations and deregulation in the U.S. financial system increased the availability of working capital. (ii) The change to a floating exchange rate system after the breakdown of the Bretton Woods system. This counterbalances the directly increasing costs of working capital after a monetary tightening by a reduction in costs of imported materials. (iii) The Federal Reserve monetary policy actions in the 1960s and 1970s were often accompanied with credit control actions leading to a non-price rationing of working capital.

In addition to the cost channel, systematic changes of monetary policy effects over time can be derived from the 'credit channel', which is typically divided into the 'bank lending channel' and the 'balance sheet channel'.[1] Both channels point to changes in the private sector's financial structure as the cause of a changing effectiveness of monetary policy. In particular, as financial innovations and the integration of financial markets make it easier to raise funds

[1] See, e.g., Hubbard (1995) for an overview over the credit channel. Bernanke and Blinder (1988) present a model of the bank lending channel, whereas Bernanke et al. (1996) model the balance sheet channel. For em-

on capital markets, the dependence of the private sector on bank credit decreases and the bank lending channel likely becomes less effective.

The second issue to be addressed in the empirical analysis are potential asymmetries of monetary policy over the business cycle. On the one hand, business cycle dependent effects of monetary policy can be motivated from a convex aggregate supply curve. In the flat part of the supply curve where output is relative low as for example in a recession, a shift in the demand curve has a larger impact on output and a smaller on prices in contrast to the steeper part of the supply curve, where output is relatively high.[2] On the other hand, asymmetric effects of monetary policy can be explained by the 'balance sheet channel' focussing on the borrower's net worth.[3] A decline in net worth following a contractionary monetary policy implies that borrowers have fewer internal funds and less collateral to acquire external funds. This enhances the problems created by informational asymmetries. In a boom, when firms and households have a relatively high net worth, policy actions are less effective than in a recession when the net worth is relatively low.

As has been noted above, so far empirical studies have focussed on one of the two issues alone. Barth and Ramey (2001) and Boivin and Giannoni (2002), for example, estimate VARs for different sub-samples and find the average effect of monetary policy on output to decrease in the U.S. Moreover, concerning potential business cycle asymmetries, recent empirical evidence for the U.S. by Weise (1999) and Garcia and Schaller (2002), among others, suggests stronger effects of monetary policy in a recession than in a boom.

In the present paper, we take up both issues raised and analyse them in a unifying empirical framework. We use a standard VAR framework and following Neumann (2001), we allow for time-varying coefficients following a random walk. This introduces an empirical framework referred to as TVC-VAR which is able to capture a potentially changing structure of the economy over time. In particular, time-varying impulse responses are generated that visualise the nature of this structural change over time. From time-varying impulse response estimates new insights can be gained concerning the stability of monetary policy effects over time as well as potential asymmetries over the business cycle. Section 2 introduces the empirical framework. Section 3 presents our empirical findings and Section 4 concludes.

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pirical evidence on the bank lending channel in the U.S. see, e.g., Gertler and Gilchrist (1994), Kashyap and Stein (2000) and Nilsen (2002).

[2] Ball and Mankiw (1994) use a hybrid framework of time and state-contingent price adjustment rules under the assumption of menu costs to derive a convex supply curve, see also Caballero and Engel (1992).

[3] See Hubbard (1995) and Bernanke et al. (1996).

2 Empirical Methodology – The TVC-VAR Framework

In recent years, a huge amount of empirical models have been developed to account for structural breaks and potential non-linearities including regime-switching models, threshold autoregressive models as well as state-space models with time-varying coefficients.[4] Essential for the choice of the appropriate modelling framework thereby is the type of coefficient variation that is most likely for the phenomenon under investigation. Empirical findings based on simulated data from Neumann (2003) suggest that time-varying coefficient models with random walk coefficients dominate alternative approaches to time-varying estimation. Moreover, a model with random-walk coefficients may be appropriate even in the presence of time-invariant coefficients because model estimates turn out to be comparatively stable in this case.

In this paper we follow Jiang and Kitagawa (1993) and Neumann (2001) and extend univariate time-varying estimation to VAR analysis. Time-varying impulse responses derived from our model estimates allow us to investigate the real effects of monetary policy shocks over time. In the following, a brief sketch of the methodology is presented, see Neumann (2001) for a more detailed exposition.

The Model Set-Up Consider the following reduced form of a VAR with p lags and n endogenous variables:

$$Y_t = A_{0t} + A_{1,t}Y_{t-1} + ... + A_{p,t}Y_{t-p} + U_t \,. \tag{1}$$

In this set-up, for every t of the sample coefficient matrices $A_{0,t}$, $A_{1,t}$, … ,$A_{p,t}$ and a variance-covariance matrix $\Sigma_{\mathbf{U,t}}$ are estimated, where U_t is distributed as $U_t \sim N(0, \Sigma_{\mathbf{U,t}})$. Collecting the coefficient matrices in matrix $A_t = (A_{0,t}, A_{1,t}, \dots , A_{p,t})$, and defining $B_t = vec(A_t)$ and $X_t = (1 \otimes I_k, Y'_{t-1} \otimes I_k, \dots , Y'_{t-p} \otimes I_k)$, the model can be written as

$$Y_t = B_t X_t + U_t \tag{2}$$

In order to get reasonable estimates of the coefficients from the limited amount of data points available, stochastic constraints are imposed. More specifically, the time variation of the coefficients is specified by assuming that the elements of B_t follow independent random walks,

$$B_t = B_t + W_t \tag{3}$$

[4] See, e.g., Granger and Teräsvirta (1993) for a comprehensive survey.

with $W_t \sim N(0, \Sigma_W)$ and Σ_W being diagonal. This restriction constitutes the Gaussian 'smoothness prior' distribution on the time history of the VAR coefficients.[5]

In order to enable estimation of the n-dimensional system with time-varying coefficients, following Jiang and Kitagawa (1993) and Neumann (2001), a Cholesky recursive structure is imposed on the system, allowing to estimate the VAR equation by equation. Assuming that the structural form of the VAR follows a recursive structure, equation (1) can be written as

$$\Gamma_t Y_t = C_{0,t} + C_{1,t} Y_{t-1} + \ldots + C_{p,t} Y_{t-p} + V_t, \tag{4}$$

where the structural residuals are distributed as $V_t \sim N(0, \Sigma_V)$, and Σ_V being diagonal. The lower triangular matrix Γ_t captures the recursive contemporaneous interactions of the endogenous variables. As Σ_V is a diagonal matrix, the equations of model (4) can be estimated equation by equation yielding estimates of the structural coefficient matrices $C_{0,t}$, $C_{1,t}, \ldots, C_{p,t}$ as well as Γ_t, and the variance-covariance matrix Σ_V.

The matrices $A_{i,t}$ and $\Sigma_{U,t}$ as well as the residuals U_t of the reduced form can be recovered using the following equations:

$$\begin{aligned} A_{i,t} &= \Gamma_t^{-1} C_{i,t}, \\ \Sigma_{U_t} &= \Gamma_t^{-1} \Sigma_V (\Gamma_t^{-1})', \qquad i = 1, \ldots, p \\ U_t &= \Gamma_t^{-1} V_t. \end{aligned}$$

Estimating the Model For estimating (4) equation by equation each equation of the model is written as

$$y_t = x_t' ß_t + v_t, \tag{5}$$

where y_t is the dependent variable and x_t and b_t are vectors collecting the variables and the coefficients of a single equation of model (4). (5) constitutes the measurement equation of the state-space representation of the model, where the respective transition equation is given by

$$b_t = b_{t-1} + w_t, \tag{6}$$

with $w_t \sim \mathrm{N}(0, s_w^2)$.

[5] Alternatively an autoregressive structure like $b_t = a b_{t-1} + W_t$ could have been imposed, where $0 < \alpha < 1$. Simulations however show that the random walk model as a general specification captures several potential time paths of gradual coefficient changes quite well. Note, however, that the specification by construction imposes a smooth path for the coefficients. As a consequence, the model behaves badly when the underlying coefficient process exhibits discrete single shifts. An appropriate model to capture discrete stochastic shifts may be the Markov-Switching model, see, e.g., Garcia and Schaller (2002).

Then, sequential estimates of the coefficients $b_1,\ldots,b_T$ can be generated by applying the Kalman filter routine to every single equation given by (5), see Jiang and Kitagawa for an exposition of the Kalman filter for the TVC–VAR application. The model is estimated as outlined in detail in Neumann (2001), using the EM algorithm to find maximum liklihood estimates of the hyperparameters to initialise the Kalman filter. Time-varying impulse responses are derived using the Generalised Impulse Response approach of Koop et al. (1996). In contrast to Koop et al. the present analysis assumes that once a shock has occurred there is no feedback of this shock to the coefficients of the model, coefficient variation thus is exogenous.

3 Empirical Results

We apply the TVC-VAR methodology to a standard three variables VAR model of the U.S.-economy, consisting of GDP (deflated with the consumer price index and in logs), consumer prices (in logs) and the federal funds rate. All series are at the quarterly frequency, running from 1962:1 to 2002:2.[6] The federal funds rate is used as a measure of monetary policy for the whole sample range. This approach is widely used in the empirical literature, for a discussion see, e.g., Bernanke and Mihov (1998).[7]

Unit root tests indicate that output and prices are I(1), whereas the federal funds rate is I(0), see Table 1 for details. Therefore, except for the federal funds rate the model is estimated in first differences. With this specification we follow, among others, Rudebusch and Svensson (1999). No statistical criterion is available yet for the choice of the lag order in the TVC-VAR case. The results, however, are comparatively robust to alternative choices. Hence, we restrict the presentation of estimation results to a lag order of four. Finally, as the estimation and identification of the model relies on the recursive Cholesky structure, we follow the standard procedure to order the monetary policy instrument last in the VAR, after GDP and prices.

From TVC-VAR estimates we derive an impulse response function for every point of time over the whole sample period. Figure 1 plots the complete accumulated impulse response of real GDP to a monetary policy shock as it evolves over the estimation period in a three dimensional space. This gives a complete picture of the time variation of the accumulated impulse responses, details are yet somewhat less clear to grasp. Figure 2 presents the results in a

[6] All data are from the IMF's "International Financial Statistics": Gross Domestic Product, series code 11199b.c. Consumer Price Index, series code 11164. Federal Funds rate, series code 11160b.

[7] Even though the Federal Reserve changed it's operating procedure in the period of 1979-1982, the funds rate was still closely connected with the Federal Reserve monetary strategy, on this see, e.g., Cook (1989), Good-

more accessible way. It contains four graphs (a) to (d) that indicate how the accumulated impulse responses at a horizon of 4, 8, 12 and 16 quarters evolve over the sample period, respectively. For reasons of an illustrative comparison every graph also plots as a dashed line the accumulated impulse response at the respective horizon from the *linear* VAR specification as well as 10% error bands from the latter specification. This is intended to serve as a rough guideline to judge the degree to which the time-varying specification departs from the linear one. Yet, it is important to stress that this does not constitute a formal test for non-linearity, as the estimates from the linear specification are biased in the presence of structural change.[8] Figures 2(a) to (d) present the time-varying accumulated impulse responses of real GDP to a monetary policy shock at the four different horizons. Concerning the first issue to be analysed in this paper, namely the change in the effectiveness of monetary policy over time, the results tentatively suggest that monetary policy has become less effective over time. Most clearly this 'trend' is visible in the reaction of GDP to the monetary policy shock after four quarters. The impact today is almost half as strong as it was in the 1970s: While at the beginning of the 1970s a one percentage point increase in the federal funds rate led to a decrease in real GDP after four quarters of roughly 0.5 percent, in the second half of the 1990s this effect was down to around 0.2 percent, though increasing again at the end of the sample period. It is also interesting to note that at the four quarter horizon the impulse response moves out of the linear error bands at the beginning of the 1980s. As has been noted above, this may tentatively indicate a structural break at the beginning of the 1980s. A linear specification over the whole sample period hence may systematically overestimate the effect of a monetary policy shock on output.

The finding of a declining effectiveness of monetary policy over time supports the cost channel and the credit channel of monetary transmission. Both refer to changes in the financial structure that translate into a weakening of monetary policy effects. Our empirical results are is consistent with the evidence found in Boivin and Giannoni (2002) and Barth and Ramey (2001). Boivin and Giannoni estimate a linear VAR with different sub-samples and find that the response of output to a monetary policy shock has become weaker since the beginning of the 1980s, similar results at the industry level can be found in Barth and Ramey.

The second issue we are interested in is whether there is a business-cycle dependency in the effects of monetary policy. Therefore, we compare our results with the U.S. recession periods, in

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friend (1991) and Bernanke and Mishkin (1992). Among others Sims (1992) and Clarida et. al (2000) have used the funds rate for comparable sample ranges in a VAR-analysis as monetary policy instrument.

[8] Computing error bands for the time-varying impulse responses on the other hand is still an unresolved issue.

Figure 2 the shaded areas correspond to the NBER recession periods. It is clearly visible from the figure that discretionary monetary policy tends to have stronger effects during recessions. This result is particularly pronounced at the longer impulse response horizons, most strongly during the recessions 1973:4 until 1975:1 and in the early 1980s. In addition, we observe that this asymmetry became much weaker since the mid-80s. One possible explanation is that the Federal Reserve gained more experience in steering the economy through the business cycle. Taylor (1999) shows with the help of a monetary policy rule for the interest rate that in comparison to the 1970s monetary policy in the last 20 years became less accommodative to output and more active in inflation fighting. In his opinion this results from a learning process within the Federal Reserve related to the experience of the inflationary periods of the 1970s as well as academic research on the Phillips trade-off.

The second part of our empirical findings are again in line with economic theory, namely with the credit channel and with models of convex supply curves. Moreover, our study confirms the results of other empirical studies that analyse asymmetries of the effects of monetary policy. To mention only two important studies, Garcia and Schaller (2002) find that monetary policy is stronger during recessions using the Markov-Switching framework introduced by Hamilton (1989), while Weise (1999) finds the same result applying a non-linear smooth transition VAR framework.

4 Conclusion

In the present paper we address two questions: (i) Have the real effects of US monetary policy changed over the last 40 years? (ii) Are the real effects of monetary policy asymmetric over the business cycle? To investigate these two issues, we apply a standard three-variable VAR while allow for time-varying coefficients in this model. From this we derive time-varying impulse responses to investigate the response of output to monetary policy shocks over time.

Two findings emerge from our empirical analysis. First, the impact of monetary policy steadily decreased since the 1960s. This finding supports the cost channel and the credit channel of monetary transmission. Second, we find that monetary policy effects are asymmetric over the business cycle, where monetary policy is more effective during recessions. This is in support of the credit channel, but also of models with convex supply curves. Finally, our findings suggest that the asymmetry of monetary policy effects over the business cycle has decreased since the mid 1980s. Note, however, that in the general statistical framework of our paper it is certainly not possible to differentiate between the different structural explanations.

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Figure 1: Complete Accumulated Impulse Responses, 1968 – 2002

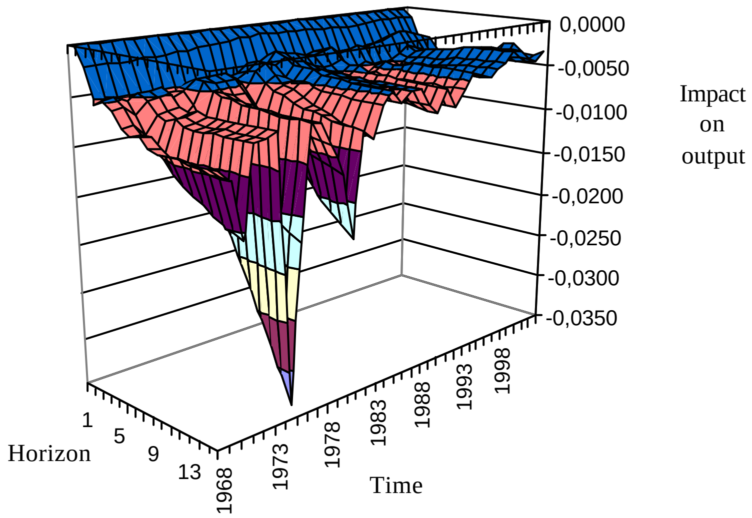
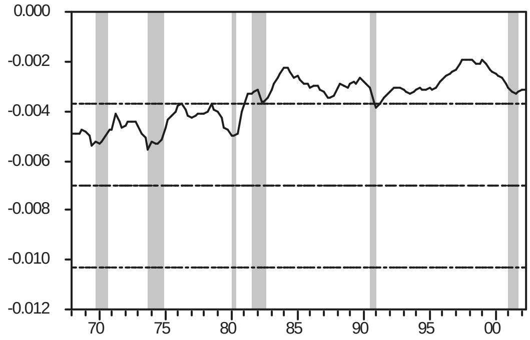
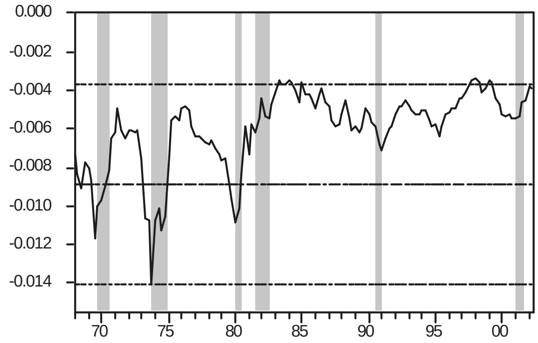


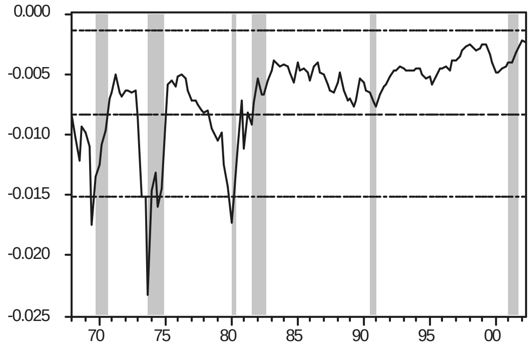
Figure 2: Accumulated Impulse Responses of GDP to a Monetary Policy Shock



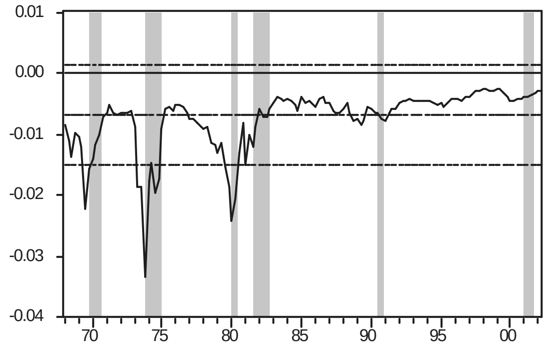
(a) Response over time after 4 quarters



(b) Response over time after 8 quarters



(c) Response over time after 12 quarters



(d) Response over time after 16 quarters

Note: Graphs (a) to (d) are profiles along the time axis of Figure 1. Shaded areas are NBER recessions. The y-axis gives the percentage impact on output of a one unit shock.

Table 1: Unit Root tests

Variable	ADF Test[a]	KPSS Test[b]
	Test statistic (Specification[c])	Test statistic (Specification[c])
GDP	-3.436* (c,t)	0.159** (c,t)
ΔGDP	-8.585*** (c)	0.216 (c)
CPI	-1.618 (c, t)	0.290*** (c,t)
ΔCPI	-2.189 (c)	0.326 (c)
Interest rate	-2.654* (c)	0.264 (c)
	H_0: Existence of a unit root	**H_0: Stationarity**
	* denotes signifcance at 10% - level ** denotes signifcance at 5% - level *** denotes signifcance at 1% - level	

[a] Augmented Dickey-Fuller Test with lag selection according to the Schwartz criterion; [b] Kwiatkowski-Phllips-Schmidt-Shin Test; [c] c =constant, t = trend.