The monetary transmission mechanism: evidence from the G-7 countries

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I. INTRODUCTION

The issue of the effects of monetary policy on real economic activity and the rate of inflation lies at the core of macroeconomics. However, despite the very large amount of research that has been undertaken on the monetary transmission mechanism, there is little consensus among economists regarding the exact effects of monetary policy and the extent to which these differ across countries. One reason for the lack of consensus is that it is econometrically very difficult to disentangle time series on financial variables such as interest rates and exchange rates into the parts due to monetary policy measures and the parts merely reflecting endogenous responses of financial markets to unobserved economic disturbances. Alternative empirical methodologies therefore tend to give different estimates of the role and effects of monetary policy. One consequence of the sensitivity of the results to the choice of identification strategy is that, since most studies focus on one country, it is difficult to compare estimates from different countries. Thus, relatively little is known about the extent to which the monetary transmission mechanism differs across countries.

In this paper we provide some evidence of the monetary policy transmission mechanism in the G-7 countries using a parsimonious macroeconometric model comprising output, prices and a short-term interest rate. To enhance the comparability of the results from different countries, we use similar data series, the same sample periods and an identical econometric framework for all the countries in the study. Thus, there are no obvious reasons to believe that the observed differences in the effectiveness of monetary policy are artefacts of the econometric methodology.

The paper is structured as follows. In Section II we discuss and motivate the empirical methodology, first presenting the empirical model estimated in this paper and the data series used. Next we briefly review the Structural Vector Autoregression (SVAR) methodology and discuss how we identify shifts in the stance of monetary policy. In Section III we turn to the empirical results. We use impulse response functions to evaluate the responses of output, inflation and interest rates to aggregate supply and demand disturbances and to innovations in monetary policy. Next, we study the relative importance of the different shocks using forecast error variance decompositions, and assess whether our identifying assumptions generate plausible results. We end the section by decomposing observed movements in output, prices and interest rates into the parts due to responses to supply and demand shocks, and the monetary policy shock. The purpose of this analysis is to provide an informal way of assessing whether the estimated models are sensible. Since the estimated monetary policy shocks differ in size and persistence across countries, we standardise the shock in Section IV and simulate the effects on the level of real GDP and prices of a 100 basis point increase, maintained for eight quarters, in the short-term nominal interest rate. This enables us to compare the effectiveness of monetary policy across countries. Conclusions are drawn in Section V. The paper ends with a data appendix and a technical appendix, which contains details of the econometric methodology.

II. METHODOLOGY AND DATA

In this paper we use Structural Vector Autoregressions (SVARs) to analyse differences in the effects of monetary policy in the G-7 countries. There are several reasons why SVARs are suitable for studying the monetary transmission mechanism. First, SVARs require only a minimum of restrictions in order to disentangle movements in endogenous variables such as output, prices and interest rates into the parts due to underlying shocks, such as shifts in aggregate supply and demand schedules and changes in the stance of monetary policy. The transparency of the identifying restrictions is of particular interest in a cross-country study, since it facilitates an assessment of whether the results are driven by different or implausible identifying assumptions. Second, vector autoregressions come with a number of convenient tools - impulse response functions, forecast error variance decompositions and historical decompositions - that are useful in answering a host of questions concerning the effects of the shocks and their role and importance in specific historical episodes. Third, once an identification scheme has been adopted, SVARs are easy to estimate, which makes them particularly suitable for multi-country studies.

Notwithstanding their many advantages, SVARs are also subject to limitations. While SVAR models allow us to address questions regarding the effects of monetary policy, they cannot be used to analyse the effect of changes in the monetary policy *regime* on the economy. More concretely, the SVAR techniques used in this paper decompose monetary policy into a systematic and an unsystematic part. The systematic part may be thought of as the monetary policy reaction function and corresponds to the "average" response of monetary authorities to macroeconomic disturbances such as aggregate supply and demand shocks. Because of the reduced form nature, SVAR techniques unfortunately do not allow us to distinguish between the *direct* effects of such shocks and any *indirect* effects they have by eliciting systematic responses by the central bank (as captured by the policy reaction function). The unsystematic part, which we label "monetary policy shocks" in what follows, can be interpreted as deviations from this average reaction function over the sample period. Most of the work reported below focuses on the effects of such monetary policy shocks and their role in macroeconomic fluctuation in the last decade.

A second widely recognised problem with SVARs is that the results are sensitive to the ways in which the models are identified. Thus seemingly small changes in the identifying assumptions can lead to substantial changes in the estimated effects of the shocks and in their relative importance over the sample period. This is very much the case also with our empirical results. Given this sensitivity, it is incumbent on the researcher to motivate the choice of identifying restrictions.

The rest of this section is organised as follows. We first present and motivate the simple three-variable SVAR model that we study and discuss the choice of the data set. Next, we review what is meant by identifying a SVAR and motivate our choice of identifying restrictions. Section III then turns to the results.

1. The empirical model

The purpose of SVAR analysis is to decompose movements in some *observed* time series into the parts that are due to *unobserved* underlying shocks which are structural in the sense that they can be given an economic interpretation. More concretely, in what follows we attempt to decompose movements in real income levels, prices and short-term interest rates into the parts due to shifts in aggregate supply schedules ("supply shocks"), shifts in aggregate demand schedules ("demand shocks") and changes in monetary policy ("monetary policy shocks"). To formalise the discussion and using standard notation, let $x_t^T = [\Delta y_t \quad \Delta p_t \quad r_t]$ be the vector of endogenous variables, with Δy_t denoting real GDP growth, Δp_t the rate of inflation and r_t the nominal short-term interest rate.[1]

1 The stationarity properties of the time series used are examined in the data appendix.

Furthermore, let $\varepsilon_t^T = \left[\varepsilon_t^s \quad \varepsilon_t^d \quad \varepsilon_t^p\right]$ be the vector of structural shocks, with ε_t^s denoting a supply shock, ε_t^d a demand shock and ε_t^p a monetary policy shock. Typical examples of supply shocks are exogenous changes in energy prices or the terms of trade, productivity shocks or tax and wage shocks. Demand shocks can be thought of as government spending shocks or shifts in investment and consumption functions.

The structural model can then be written as:

$$x_t = A(L)\varepsilon_t \tag{1}$$

where the matrix lag polynomial $A(L)$ contains the responses of the endogenous variables to the underlying structural disturbances.

Discussion

Given our interest in the monetary transmission mechanism, the three variables used above constitute the smallest possible SVAR model. The model can be thought of as a minimalist empirical version (of the reduced form) of a standard aggregate supply/aggregate demand macroeconomic model comprising an IS-curve, a Phillips curve and a monetary policy reaction function. While the fact that there are only three endogenous variables is an attractive feature of the model, in particular in the context of a multi-country study, this also limits the number of structural shocks that we can identify. Although this issue is typically not discussed in any great length in the VAR literature, the choice of the dimension of the SVAR should be thought of as an integral part of the identification procedure, since we can identify (at most) one structural shock for each endogenous variable. Thus, the number of variables included should be determined by the number of shocks that one thinks play a role in determining movements in the endogenous variables.

Our choice of output, prices and a short-term interest rate has two important implications which need to be noted. First, by limiting the number of endogenous variables, we implicitly assume that different supply and demand shocks (e.g. oil price shocks versus productivity shocks, or increases in government spending as opposed to shifts in the consumption function) have similar effects on income, prices and interest rates, so that they can be aggregated into a "typical" aggregate supply or demand shock.

Second, and maybe more importantly for this study, we assume that output and prices capture all the information to which monetary authorities respond when setting short-term interest rates. This assumption excludes, for example, that the central bank responds to developments in the exchange rate market that are not due to aggregate supply and demand developments. This assumption may be a good first approximation in the case of the larger economies in our sample, but appears less attractive for the smaller and more open economies. In these countries, changes in policy interest rates that are a response to exchange market tensions will appear as policy shocks (or shifts in the policy reaction function). As in such a case the response of the economy could very well differ from the effect of "pure" policy shocks, e.g. because the exchange rate responds differently, one needs to be cautious in comparing the effects of monetary policy between these two groups of countries.

The stance of policy

An important issue that arises in studying the monetary transmission mechanism is how to measure the stance of monetary policy. Implicit in our use of short-term interest rates is the hypothesis that such rates capture the stance of policy. The reasons we focus on prices, rather than quantities, as indicators of monetary conditions are twofold. First, central banks themselves typically regard themselves as pursuing monetary policy by setting the interest rate(s) at which they provide financing to the commercial banking system, which in turn implies that central banks control short-term interest quite precisely elsewhere in the economy. Indeed, all the central banks included in this study are likely to subscribe to this description of policy. Second, while monetary aggregates in principle can be used as indicators of the stance of monetary policy, they are subject in practice to a wide variety of other disturbances, including shifts in the demand for money, which often dominate the information they contain about changes in the state of policy.[2]

Conceptually, the ideal interest rate to use as a measure of the stance of monetary policy would be the official interest rate at which marginal financing is provided to the banking system. Unfortunately, it is impractical to pursue this approach for several reasons. For instance, central banks typically provide financing using a number of different interest rates, which makes it difficult to choose "the" representative rate. Furthermore, the exact interest rate that is relevant has in many countries changed over time in response to, in many cases, profound developments of central banks' monetary operating techniques. Central banks may also alter the stance of policy without changing official interest rates, for instance by varying the availability of credit at the official rates. Since market-determined interest rates typically respond very quickly to changes in monetary policy irrespective of whether they are expressed by a change in an official interest rate or by a change in the availability of credit, we use three-month interest rates as measures of the stance of policy.

2. The identification problem

Next we provide a brief overview of the identification problem as it arises in the case of SVARs, using the empirical model in (1) as an example. The purpose of the overview is to explain what is meant by identification and to explain the restrictions used to identify the model estimated in this paper.

To obtain an estimate of (1), the first step is to model the vector of endogenous variables using the following unrestricted VAR (disregarding for simplicity deterministic variables):

$$D(L)x_t = v_t \tag{2}$$

where D(L) is a finite-order matrix polynomial in the lag operator L. Equation (2) can be estimated and inverted to yield the moving average representation

$$x_t = C(L)v_t \tag{3}$$

where $C(0) = I$, and $v_t^T = \begin{bmatrix} v_t^y & v_t^p & v_t^r \end{bmatrix}$ is a vector of regression residuals, with variance-covariance matrix $Ev_tv_t^T = \Omega$, which have no economic interpretation. The lag polynomial $C(L)$ traces out the dynamic responses of the endogenous variables to the regression residuals.

By "identifying" the VAR, we map the parameters of the non-structural model (3) into the structural model (1). Note that (1) and (3) imply that

$$v_t = A(0)\varepsilon_t \tag{4}$$

and

$$A(L) = C(L)A(0) \tag{5}$$

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2 In preliminary work we incorporated monetary aggregates (M_3 or M_2) in the analysis, but found that they appear largely determined by money demand shocks that in turn have little, if any, impact on the economy. The reason for these findings is simply that monetary aggregates are dominated by disturbances unrelated to the state of monetary policy, e.g. financial deregulation or temporary external capital flows.

Equations (4) and (5) illustrate that in order to identify the model we need to find an estimate for A(0), the contemporaneous impact matrix. This is done by imposing sufficient restrictions to enable us to solve for a unique A(0), using estimates of C(L), or equivalently D(L), and Ω. To do so we assume, as is typical in VAR studies, that the structural shocks have a unit variance-covariance matrix, i.e. $E\,\varepsilon_t\varepsilon_t^T = I$.[3] Together with equation (4), this implies that:

$$\Omega = A(0)A(0)^T \qquad (6)$$

Since Ω is 3x3, it contains six unique elements, which yield six identifying restrictions on the impact matrix A(0). To identify A(0) we need three more restrictions, which can stem from assumptions regarding either the contemporaneous (short-run) or long-run effects of the structural shocks on the endogenous variables.[4] The existing literature on VARs suggests that the choice of identifying restrictions should be guided by the precise questions that we would like to address.

Bernanke and Blinder (1992) identified monetary policy shocks in the United States using the restriction that monetary policy has no instantaneous impact on output and inflation. While this assumption is appealing given the broadly held view that the effects of monetary policy take a considerable time to be felt, it does not allow us to identify shocks to aggregate supply and demand conditions for goods and services. Since monetary policy to a large extent may be interpreted as reactions by policy to the inflation and output effects of goods market disturbances, it is of substantial interest to see how such shocks affect interest rates. This, of course, requires them to be identified. Thus, while Bernanke and Blinder's restrictions may be helpful in identifying monetary policy shocks, they are not useful if we also wish to study the interest rate response to aggregate supply and demand shocks.

Long-run restrictions can also be used to identify SVARs. However, again their usefulness depends on the shocks we would like to identify. Indeed, long-run restrictions have typically been used in the literature to distinguish between aggregate supply and demand disturbances which are poorly identified using short-run restrictions. However, there are only a few examples of long-run restrictions being used to study monetary policy shocks. One reason for this is that it is difficult to think of long-run restrictions that uniquely identify monetary policy shocks. Keating (1992) and Walsh (1993) use the restriction that monetary policy actions can have no long-run effects on real variables such as real output, the real interest rate or the real money stock. While this assumption is plausible, temporary demand shocks are likely to satisfy the same long-run restrictions, so that it is difficult to distinguish between these and monetary policy actions.

Given the relative advantages of short or long-run restrictions, in this paper we follow Galí (1992), who employs a combination of short and long-run restrictions to identify a SVAR.[5] First, in order to identify the aggregate supply shock, we assume that the aggregate demand and monetary policy shocks do not have permanent, but perhaps persistent, effects on the *level* of real

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3 The assumption that the shocks have a unit variance is just a normalisation. If there are only three fundamental shocks to the system, then the orthogonality assumption is not particularly stringent, as one can always redefine the shocks to be uncorrelated. To the extent that other unidentified shocks are important and affect each of the endogenous variables contemporaneously, the orthogonality assumption will lead to a misspecification of the three shocks. In this case the suggested solution would, however, be to increase the dimension of the system.

4 Sims (1980) in his seminal work on VARs assumed that the instantaneous impact matrix was lower triangular. Bernanke (1986), Blanchard and Watson (1986) and Sims (1986) proposed contemporaneous zero restrictions that are more general than the recursive restrictions, and which can be given a structural interpretation. Blanchard and Quah (1989) and Shapiro and Watson (1988) pioneered the use of long-run restrictions to identify SVARs.

5 In preliminary work, we experimented with using only short-run or long-run restrictions, but found that such restrictions did not plausibly identify the underlying shocks. For some further discussion, see Section III.3.

GDP.[6] This implies that the aggregate supply shocks are identified by the restriction that only they affect the level of real GDP in the long run. This restriction, which essentially says that the long-run Phillips curve is vertical, is implicit or explicit in much of macroeconomic theory.

In order to discriminate between the aggregate demand and the monetary policy shocks, we follow Bernanke and Blinder (1992) and Galí (1992) and use the restriction that monetary policy has no contemporaneous effect on output.[7] An alternative assumption would be that monetary policy has no contemporaneous effect on the rate of inflation. However, given that we use quarterly data, changes in monetary policy could well have an effect on the price level, either by affecting the exchange rate and import prices or by affecting the price index directly through mortgage interest rates. Thus, the assumption of no instantaneous pass-through to prices seems less plausible. It would also be possible in principle to assume that monetary policy has no contemporaneous effect on either inflation or real output. However, such over-identifying restrictions are more difficult to use since the "separation" between estimation and identification that is possible in the case of just-identified models breaks down.[8]

The three additional restrictions discussed above, together with equation (6), allow us to find an estimate of A(0) and to identify the structural model. The actual implementation of these restrictions is somewhat complicated and is therefore relegated to the technical appendix.

III. RESULTS

Next we turn to the econometric results, which stem from estimates of the SVAR model discussed above on quarterly data for the period 1979:1-1993:4, using real GDP to measure economic activity and consumer price indices to measure the rate of inflation. Exact descriptions of the data are provided in the data appendix.

The purpose of this section is to assess whether our identification scheme generates plausible estimates of the structural shocks, particularly the monetary policy shocks, and of the effects of such shocks on the different economies in the sample.[9] Comparison of the results across countries plays an important part in this assessment: since we believe that monetary policy shocks have the same *qualitative* effects in different countries, we would have little faith in the restrictions unless they yielded sensible estimates for a number of countries.

The discussion is organised as follows. We first use impulse response functions to study the reactions of short-term interest rates, output and prices to monetary policy shocks, and aggregate supply and demand disturbances.[10] Since it is not clear whether real or nominal interest rates play a more important role in the transmission process, we provide results for both. Second, we study the relative importance of the different shocks using variance decompositions. We end the section by briefly discussing the historical decompositions of movements in interest rates, output and prices into the parts due to aggregate supply, aggregate demand and monetary policy shocks.

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6 This implies that the second and third elements in the first row of A(1) are zero. From equation (5) it follows that this also implies two linear restrictions on the elements of the A(0) matrix.

7 Thus, the third element in the first row of A(0) is zero.

8 See Roberts (1993) for details.

9 By "plausible" we mean that the signs (and also the size and persistence) of the effects are realistic: e.g. a monetary policy tightening should increase nominal and real interest rates, depress output and reduce prices.

10 The real interest rate is defined as the nominal interest rate minus the inflation rate over the last four quarters.

Figure 1.1

Canada: Estimated impulse response functions (1979:1-1993:4)

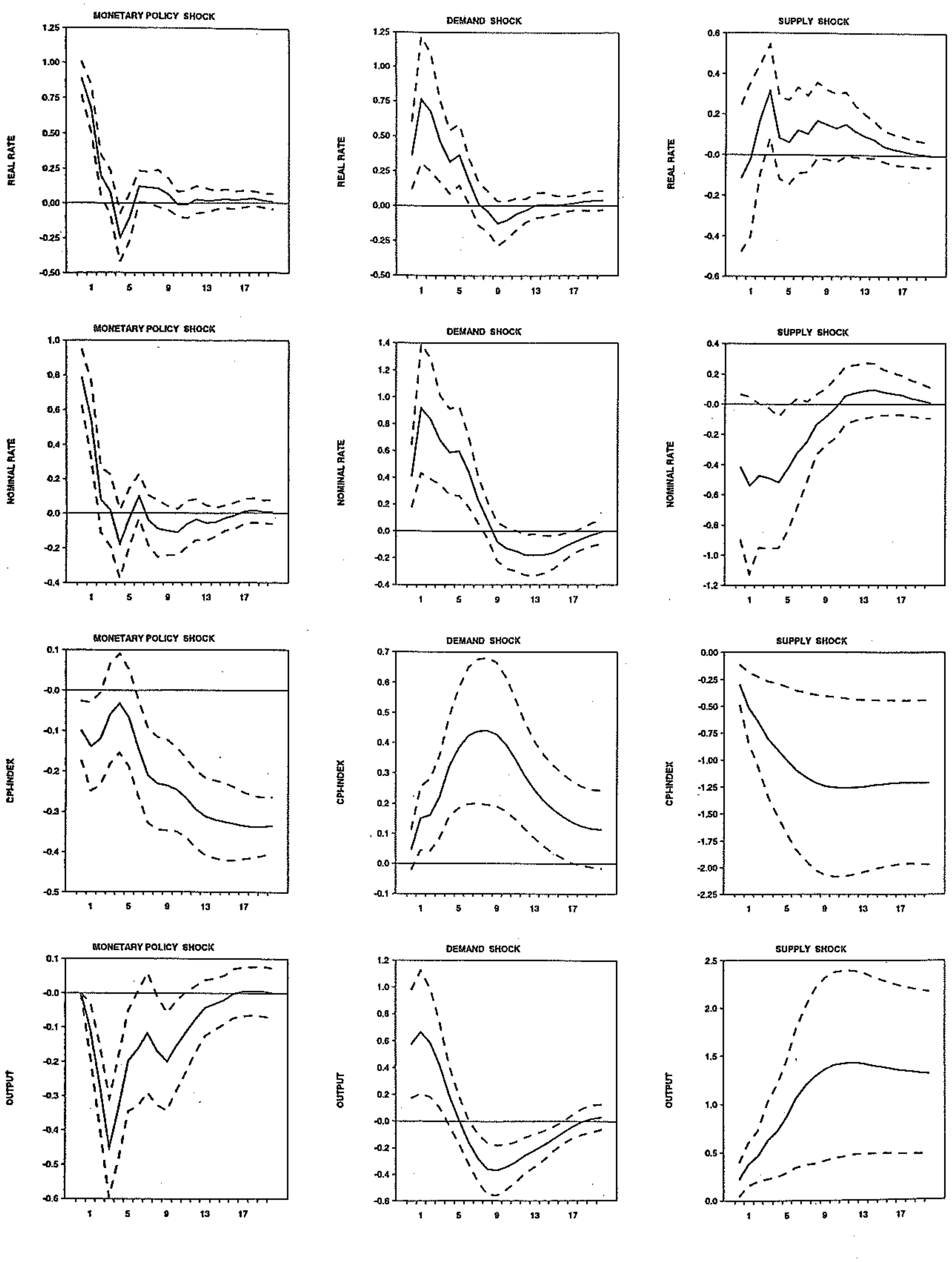


Figure 1.2

France: Estimated impulse response functions (1979:1-1993:4)

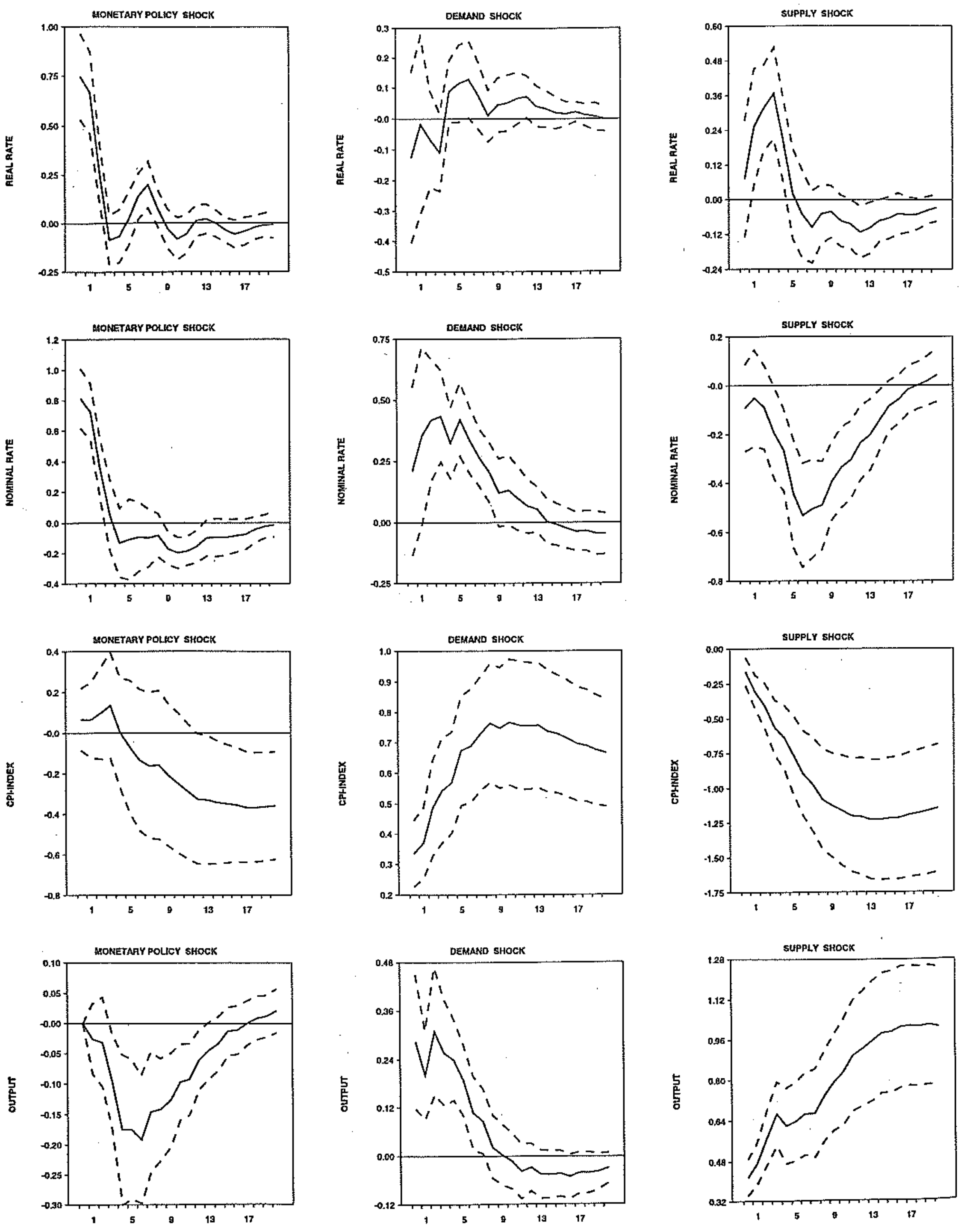


Figure 1.3

Germany: Estimated impulse response functions (1979:1-1993:4)

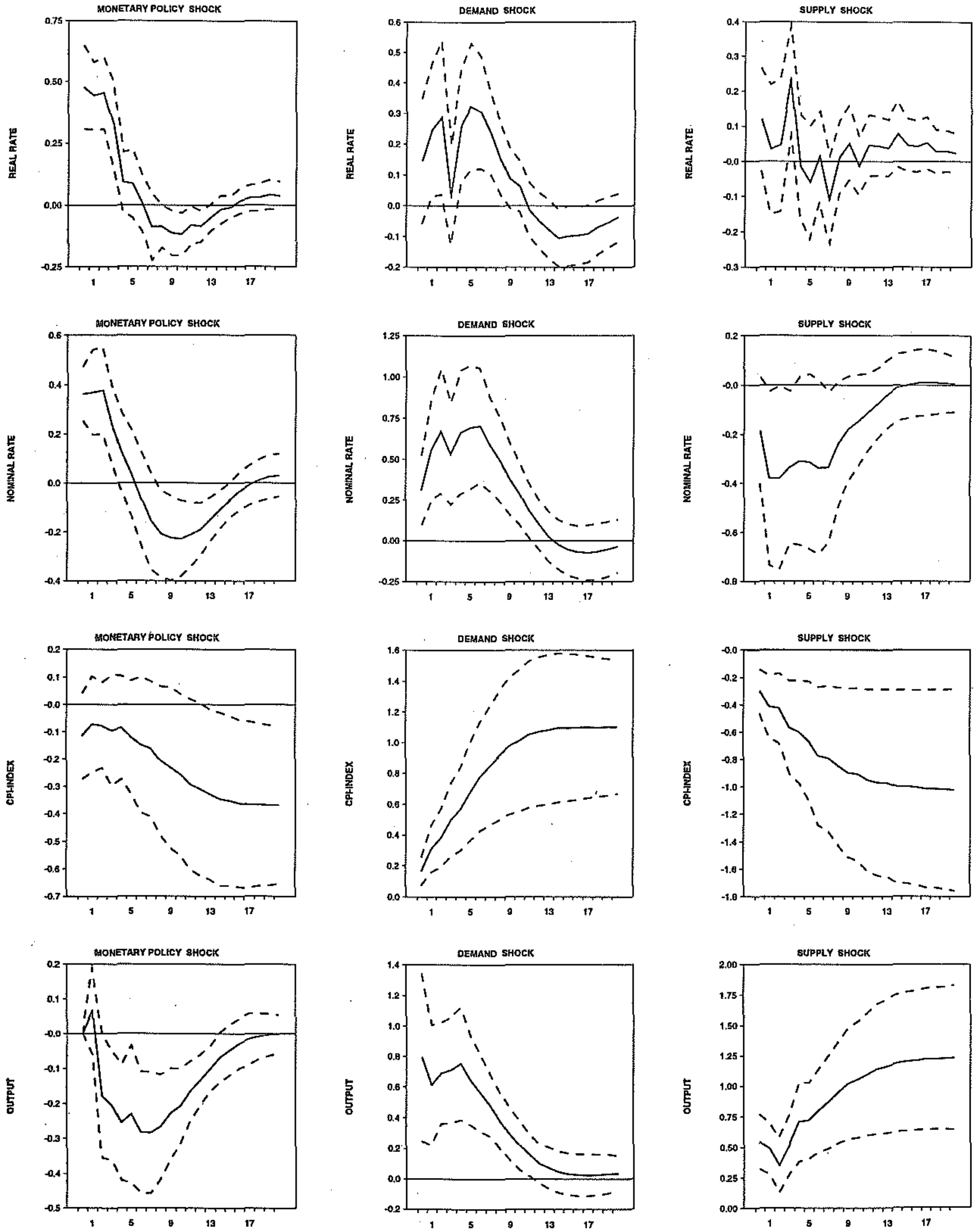


Figure 1.4

Italy: Estimated impulse response functions (1979:1-1993:4)

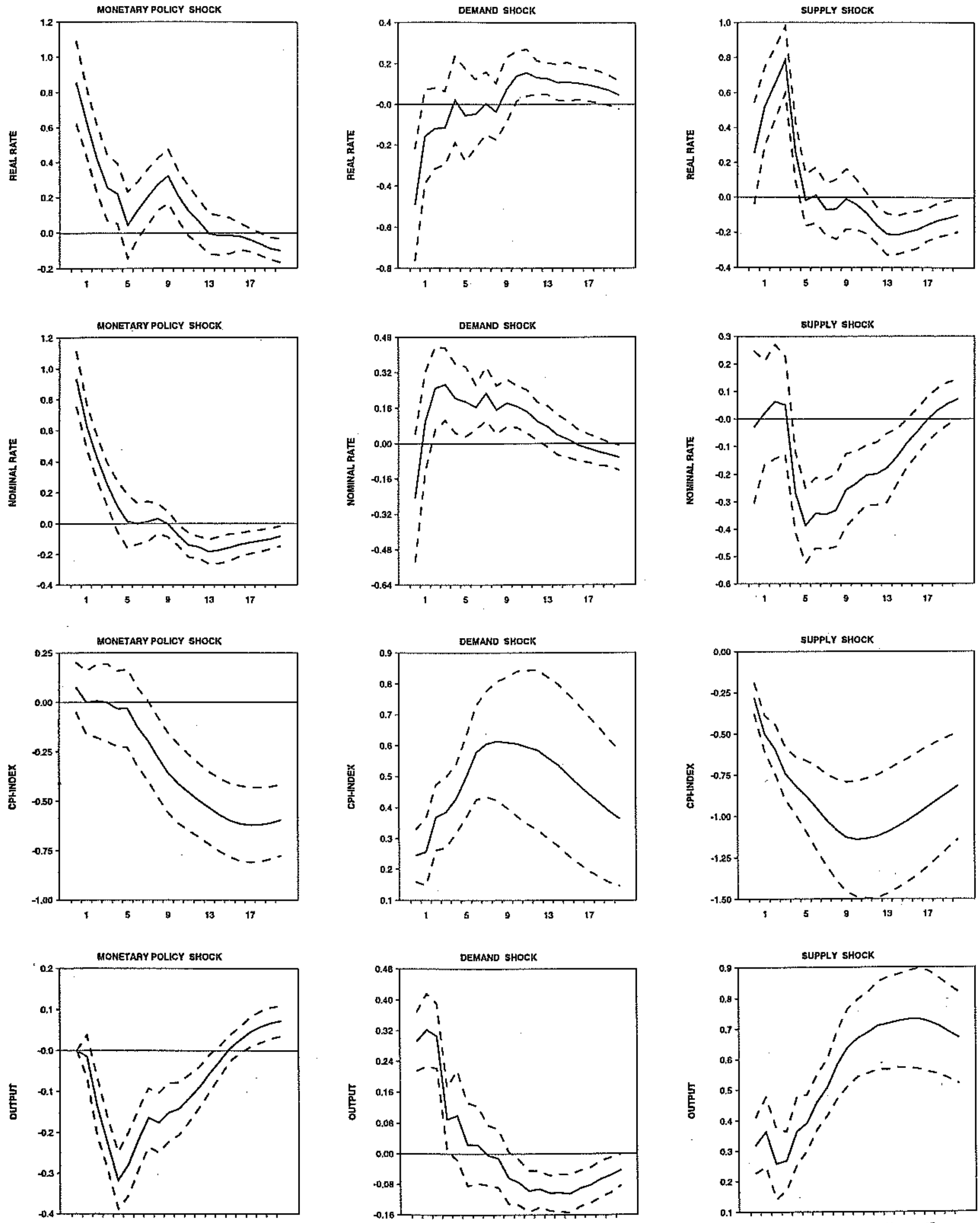


Figure 1.5

Japan: Estimated impulse response functions (1979:1-1993:4)

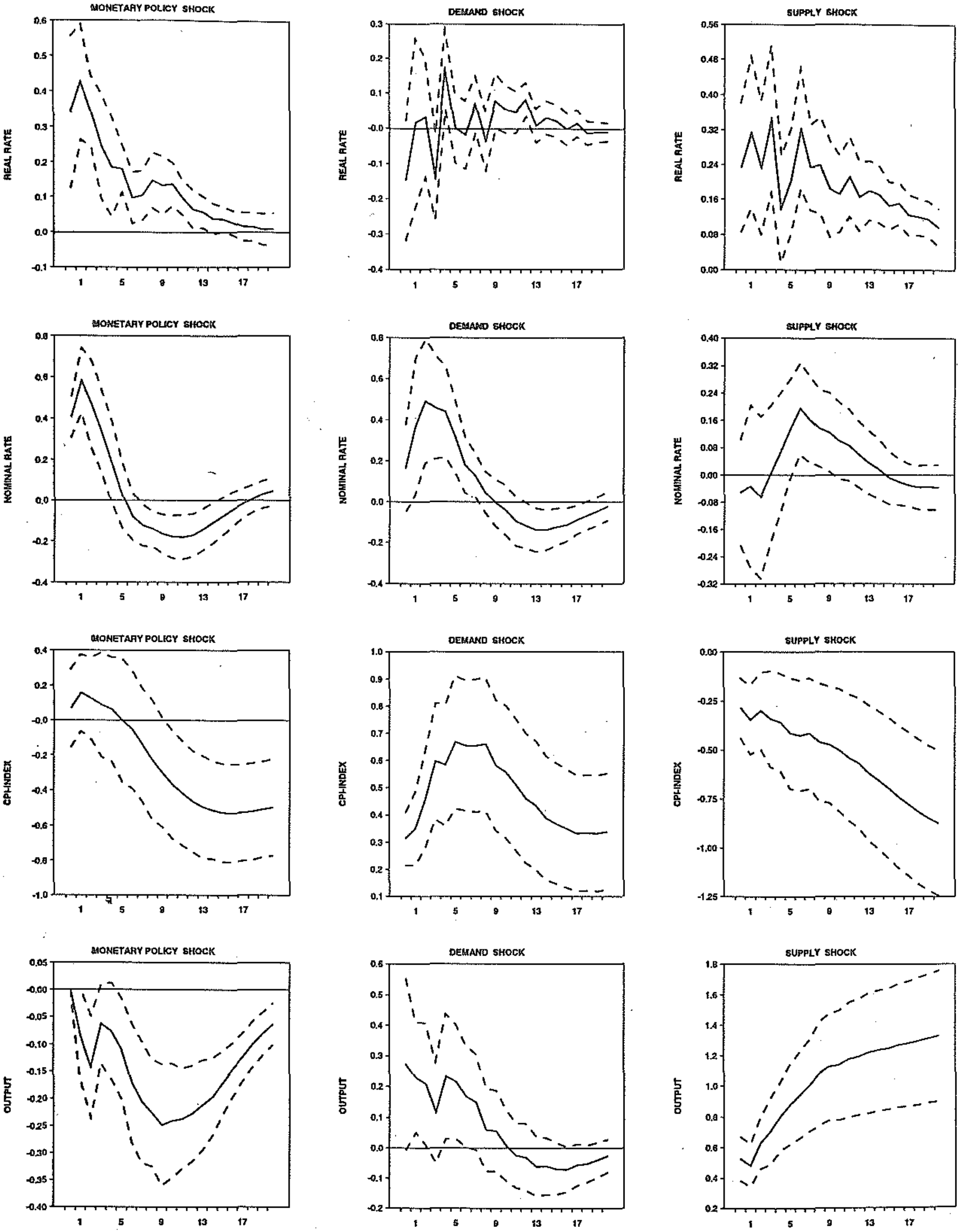


Figure 1.6

United Kingdom: Estimated impulse response functions (1979:1-1993:4)

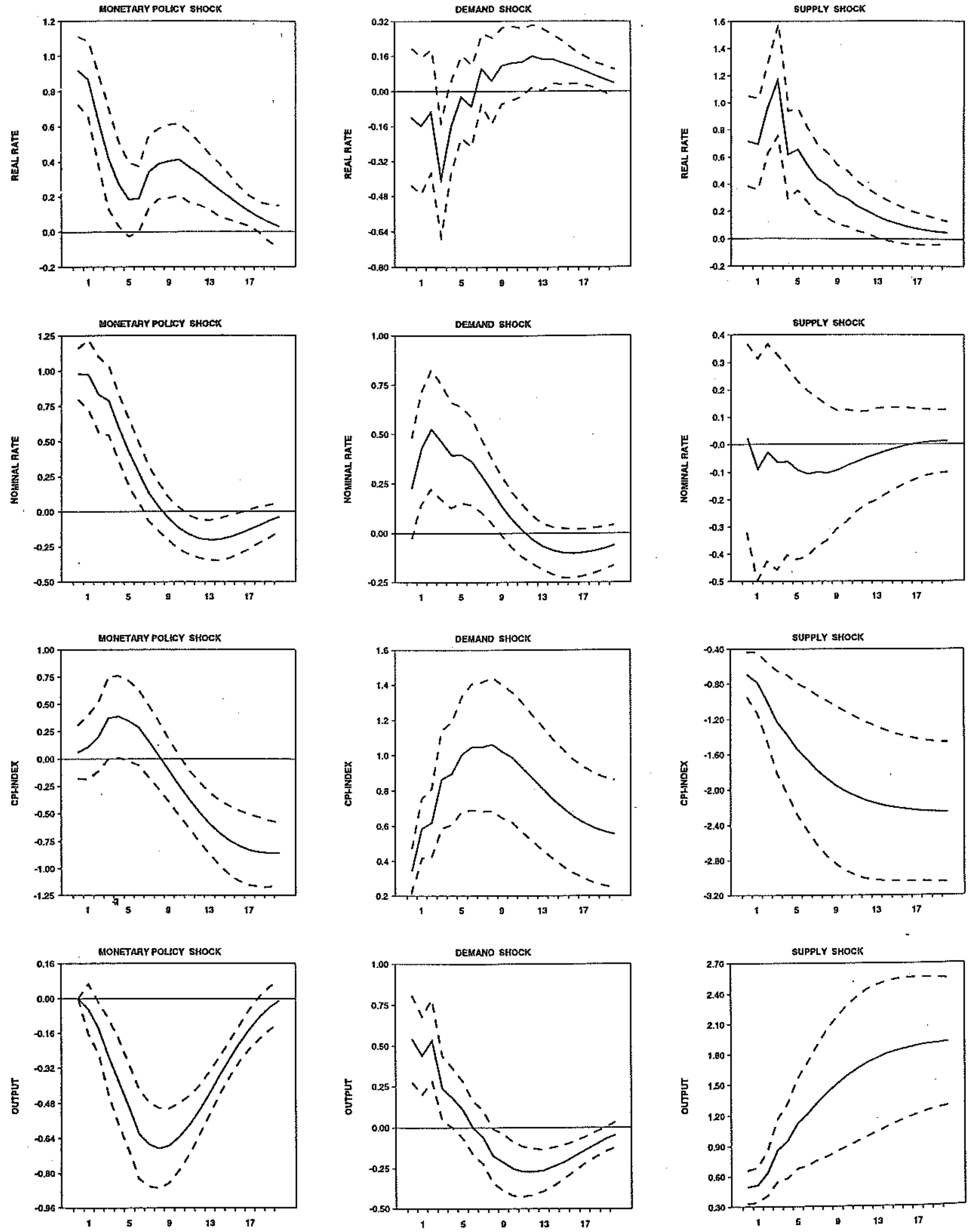
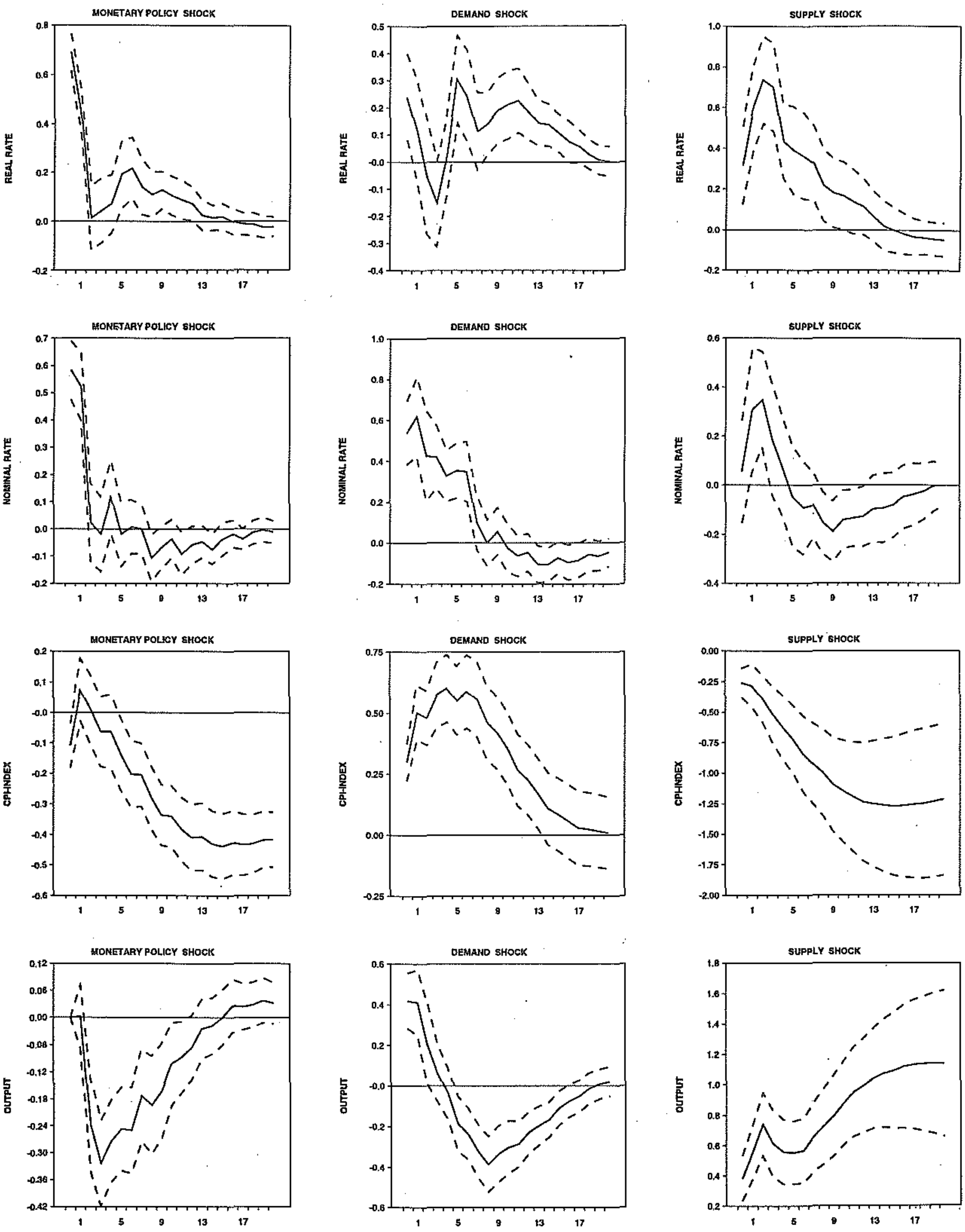


Figure 1.7

United States: Estimated impulse response functions (1979:1-1993:4)



1. Impulse responses

Figures 1.1-1.7 provide the estimated responses of the levels of real and nominal short-term interest rates, the level of real GDP and - with the exception of the United Kingdom - the consumer price level in the G-7 countries to the three structural shocks. For the United Kingdom, we found that monetary policy shocks consistently led to increases in both the consumer price index, and the consumer price index adjusted for mortgage interest payments. In what follows, we therefore use the GDP deflator in the case of the United Kingdom.

Monetary policy shocks

The first column of graphs displays the responses of the economy to monetary policy shocks together with ± 1 standard deviation confidence intervals.[11] The second graph in the first column shows the effect of a tightening on the short-term interest rate. A one standard deviation monetary policy shock increases short-term interest rates by between 60 and 100 basis points, depending on the country considered. Exceptions to this general pattern are Germany and Japan, where the typical tightening is about 40 basis points. The persistence varies substantially across countries: in Canada and the United States nominal interest rates return to the starting level after about three quarters while in the United Kingdom eight quarters or so elapse before the nominal interest rate returns to baseline. One finding is that nominal interest rates fall for a while below their initial level in a number of countries. However, the real short-term interest rate, plotted in the first graph, does not display this "J-curve" behaviour, which suggests that the undershooting of the nominal rate is an endogenous response to the fall in prices caused by the initial tightening of monetary policy.

The third graph in the first column shows the responses of consumer prices to the monetary policy shock. The graphs illustrate that in all countries the price level falls following a tightening of monetary policy and it appears 12-16 quarters elapse before the fall in the price level is arrested. The impact effect of a monetary policy tightening on consumer prices might differ somewhat, but does not seem to be significantly different from zero except in Canada. The immediate response on prices might be due to the effects of a tightening of monetary policy on the exchange rate and import prices. This may also explain why consumer prices in Germany fall contemporaneously with the monetary policy shocks, while prices in France and Italy, which operated under fixed exchange rates during a large part of the sample period, and in Japan and the United States, which are large and relatively closed economies, are initially unaffected by the monetary policy shock.

The fourth graph in the first column shows that the increase in interest rates depresses output in all countries. It is striking that the output effects are very similar across countries: except in the case of the United Kingdom, where the effect is somewhat larger, monetary policy shocks reduce output by approximately 0.2 to 0.4% relative to baseline. The time paths of the GDP responses are quite similar across countries, although in Canada the peak effect is quite abrupt. In most countries the negative effect on output peaks after about five to six quarters and is undone after about two to three years. The point estimates for the within-the-year response of output in Japan are essentially zero and insignificant. Consequently, our results for Japan suggest that the impact effect of monetary policy is relatively muted and that the effects are somewhat delayed.

Aggregate demand shocks

The second column in Figures 1.1-1.7 provides the responses of real and nominal interest rates to expansionary aggregate demand shocks. Such demand shocks could stem from increases in government spending or shifts in the consumption or investment functions. Note that nominal interest rates increase in all countries following a demand shock. The responses of real interest rates, however, vary across countries. In Canada, Germany and the United States demand shocks increase

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11 The confidence bands are bootstrapped with 100 draws. Some experimentation suggested that using more than 100 draws had no impact on the results.

real interest rates. However, in France, Italy and Japan the real interest rate is essentially unaffected by the demand shocks, and in the United Kingdom real rates fall.

The third graph in the second column shows that a typical aggregate demand shock increases the price level by between 0.5 to 1.0%, with the peak effect typically reached after about six quarters. In France, Germany and the United Kingdom, the effect on the price level appears very persistent or permanent, while in the other countries the price level tends to fall back towards its initial level.

The output responses are provided in the fourth graph in the column. In all countries the demand shock expands output instantaneously. The size of the impact effect varies across countries, from about 0.3% in France to as much as 0.8% in Germany. Furthermore, the results indicate that output falls back *below* baseline for a while in Canada, Italy, Japan, the United Kingdom and the United States, so that our estimates point to some cyclical behaviour following demand shocks.

Aggregate supply shocks

Finally, we turn to the effects of aggregate supply shocks, which are provided in the third column of Figures 2.1-2.7. As before, we first analyse the responses of real and nominal interest rates and then turn to prices and output.

The first and second graphs in the last column show the responses of interest rates to supply shocks. As can be seen, the reactions of the real and nominal interest rates continue to be quite different. In France, Germany, Italy and Japan, nominal interest rates typically fall, but real rates rise, in response to expansionary supply disturbances. This finding is not difficult to reconcile with theory. Expansionary supply shocks increase the return to capital and therefore real interest rates. At the same time, they reduce inflationary pressures and nominal interest rates. In the United Kingdom and the United States, both rates rise following the disturbance, although the nominal interest rates very quickly return to their original level. In Canada, real rates are essentially unaffected by the supply shock, while nominal rates fall.

Turning to the effects of supply shocks on prices and output, the results indicate, not surprisingly, that supply shocks expand income and depress prices by about 1% (in the United Kingdom the effects appear larger: about 2%). The long-run effects are also relatively slow to appear: in most cases the adjustment to the new equilibrium takes at least 12 quarters.

2. Variance decompositions

We next assess the relative importance of the three structural shocks for the behaviour of real and nominal interest rates, output and the price level. Table 1 gives an overview of how large a fraction of the variance of the forecast error of the endogenous variables is due, at different forecast horizons, to the three structural shocks.

Monetary policy shocks

The table illustrates that monetary policy shocks tend to explain only a very small part of the forecast errors on output and inflation.[12] We view this as an encouraging finding, since it suggests that innovations in monetary policy play only a minor role in macroeconomic fluctuations. Of course, the finding that monetary policy shocks - or the unsystematic part of monetary policy - is relatively unimportant does not contradict the notion that the monetary policy reaction function plays a significant role in offsetting or propagating the effects of aggregate supply and demand shocks.

12 Cochrane (1994) uses a number of approaches to identify monetary policy shocks in the United States. One interesting finding is that the importance of monetary policy shocks shrinks as the identification of such shocks becomes more credible, judged by the shape of the impulse response functions.

Table 1

Variance decompositions

Canada				
Variable	**Quarters**	**Shocks**		
		policy	**supply**	**demand**
Nominal interest rate	1	64	18	17
	4	23	23	54
	20	17	27	56
Real interest rate	1	84	1	14
	4	46	5	49
	20	41	9	50
Real GDP	1	0	13	87
	4	12	34	54
	20	2	91	7
Consumer prices	1	10	88	2
	4	3	91	6
	20	4	89	6

France				
Variable	**Quarters**	**Shocks**		
		policy	**supply**	**demand**
Nominal interest rate	1	93	1	6
	4	69	3	28
	20	36	38	26
Real interest rate	1	96	1	3
	4	76	22	2
	20	69	25	6
Real GDP	1	0	68	32
	4	1	80	19
	20	1	96	3
Consumer prices	1	3	19	78
	4	3	42	55
	20	4	66	30

Germany				
Variable	**Quarters**	**Shocks**		
		policy	**supply**	**demand**
Nominal interest rate	1	50	13	37
	4	23	21	56
	20	15	19	66
Real interest rate	1	87	5	8
	4	76	7	17
	20	54	7	38
Real GDP	1	0	32	68
	4	3	31	66
	20	2	81	16
Consumer prices	1	10	69	21
	4	3	58	39
	20	4	44	51

Table 1 (cont.)

Variance decompositions

Italy				
Variable	**Quarters**	**Shocks**		
		policy	**supply**	**demand**
Nominal interest rate	1	93	0	6
	4	88	0	12
	20	56	28	16
Real interest rate	1	71	6	23
	4	45	45	10
	20	45	44	11
Real GDP	1	0	54	46
	4	10	51	40
	20	6	89	5
Consumer prices	1	4	55	41
	4	0	75	25
	20	13	68	19

Japan				
Variable	**Quarters**	**Shocks**		
		policy	**supply**	**demand**
Nominal interest rate	1	85	1	14
	4	57	1	42
	20	47	7	47
Real interest rate	1	60	28	11
	4	56	39	5
	20	39	55	6
Real GDP	1	0	79	21
	4	2	87	11
	20	2	96	2
Consumer prices	1	2	44	53
	4	4	33	63
	20	19	45	36

United Kingdom				
Variable	**Quarters**	**Shocks**		
		policy	**supply**	**demand**
Nominal interest rate	1	95	0	5
	4	81	0	18
	20	74	1	25
Real interest rate	1	61	38	1
	4	38	58	4
	20	38	58	5
Real GDP	1	0	45	55
	4	4	64	32
	20	8	90	3
Consumer prices	1	1	80	20
	4	4	67	29
	20	6	78	16

Table 1 (cont.)

Variance decompositions

United States				
Variable	**Quarters**	**Shocks**		
		policy	**supply**	**demand**
Nominal interest rate	1	54	0	46
	4	32	13	54
	20	26	16	57
Real interest rate	1	75	16	9
	4	30	66	4
	20	24	62	14
Real GDP	1	0	46	54
	4	8	71	20
	20	3	90	7
Consumer prices	1	7	40	53
	4	1	38	61
	20	8	81	11

Note that variance decompositions for the short-term interest rate indicate that monetary policy shocks account for a significant part of their forecast error variance, especially in the short run. However, the fraction explained decreases significantly over the long run, when less than one-third of the variation in interest rates is accounted for by monetary policy shocks. Italy and Japan are exceptions, where about half of the forecast error variance can be attributed to monetary policy shocks.

Aggregate supply and demand shocks

The variance decompositions of forecast errors on output indicate that in the short run most of the variation is due to a mixture of aggregate supply and demand shocks. By construction, supply shocks start to dominate demand shocks as increasingly longer forecast horizons are considered. Turning to the relative importance of aggregate supply and demand shocks for the forecast error variance of consumer prices, the results suggest that these vary quite substantially across countries. In Canada, for instance, supply shocks explain approximately 90% of the forecast error on the price level, while in France demand shocks explain about 80% in the short run, and as much as 30% over five years. Finally, aggregate demand shocks typically explain a larger fraction of the variance of the forecast error on short-term interest rates, in particular at horizons of more than one year, than aggregate supply shocks.

3. Does the identification scheme work?

Several aspects of the above results warrant comment. First, the estimated impulse responses are broadly similar across countries and the size and duration of the estimated effects are plausible. Furthermore, there are no cases in which the estimated impulse responses have the "wrong" sign and are significant. We view these findings as encouraging and as suggesting that the mixture of long and short-run restrictions we use produces plausible estimates of the different shocks.

Second, it is interesting to compare the results discussed above with the results in studies using solely short or long-run restrictions. A common finding in VAR studies that solely use short-run restrictions to identify the monetary policy shocks is that a tightening of monetary policy increases inflation rates temporarily.[13] This finding, which is sometimes referred to as the "price puzzle", is typically rationalised as being due to the central bank raising interest rates in response to expectations of increases in the rate of inflation. For this hypothesis to explain the price puzzle, central banks must react to information that is not included in past inflation and real income growth rates and must systematically and correctly predict changes in inflation rates. Using short and long-run restrictions, however, we find that estimated monetary policy shocks reduce inflationary pressures in all the countries we study. The finding that the price puzzle does not arise when aggregate supply shocks are identified by long-run restrictions suggests that the puzzle is due to the fact that the short-run identifying restrictions alone do not properly discriminate between contractionary aggregate supply shocks and monetary policy shocks.[14]

An alternative method to identify monetary policy is to use solely long-run restrictions. Keating (1992) and Walsh (1993) identify monetary policy shocks by assuming that they have no permanent effects on real GDP, the real interest rate or the real money stock. While this restriction is appealing from a theoretical standpoint, we found that using similar long-run restrictions in the three-variable system estimated above does not allow us to discriminate between monetary policy shocks and temporary demand shocks, which also do not have long-run effects on real output and the real interest rate.[15] While the identification strategy used by Keating (1992) and Walsh (1993) provides plausible results in the United States and Canada, a tightening of monetary policy in the four European countries is associated with a reduction of interest rates. This suggests that the monetary policy innovations are misidentified. Furthermore, in the United States and Canada the results also point to a large undershooting of the interest rate following the initial positive shock. This appears to indicate that the impulse response parameters are the results of an interaction of monetary policy and other temporary demand shocks. These results suggest that using only long-run restrictions to identify monetary policy shocks is hazardous.

4. Historical decompositions

Next we provide estimates of the three structural shocks and ask what role the different shocks played in the sample period. Figures 2.1-2.7 present, in the first row, estimates of the three disturbances in the seven countries. These graphs are quite difficult to interpret since, by construction, the disturbances are serially uncorrelated, orthogonal and have unit variance. To better assess their importance, we decompose the time paths of the nominal short-term interest rate (row 2), the real short-term interest rate (row 3), the output level (row 4), and the consumer price index (row 5) into the parts due to the policy (column 1), aggregate demand (column 2) and aggregate supply shock (column 3).

In interpreting the graphs two points should be kept in mind. First, the purpose of this exercise is to see whether the estimates of the three shocks, and the role the SVAR model attributes to them in different historical episodes, are compatible with the established view of monetary policy events in the countries in question. However, since the decompositions are *point estimates* of the role of the three disturbances in different time periods (and thus subject to uncertainty), one should be careful not to overinterpret the smaller movements in these graphs.

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13 We estimated the same three-variable VAR system (ordering the interest rate last) and used the traditional Choleski-decomposition to impose the short-run restriction that changes in monetary policy have no contemporaneous effects on either output or inflation. In all countries the "price puzzle" appears. See also the discussion in Sims (1992).

14 Another unattractive feature of VARs that solely use short-run restrictions is that the impulse response functions imply that monetary policy does have permanent effects on output (if output is modelled as exhibiting a unit root). Our identification strategy plausibly restricts these effects to be zero in the long run.

15 Following Walsh (1993) and Keating (1992), we modelled the interest rate as being non-stationary (see the mixed evidence on this in Table 1 in the data appendix) and assume that monetary policy shocks can have no long-run effects on real output and the real interest rate. This provides a triangular system of long-run zero restrictions, which can easily be implemented using the Blanchard and Quah (1989) methodology.

Figure 2.1

Canada: Historical decomposition of output, prices and interest rates

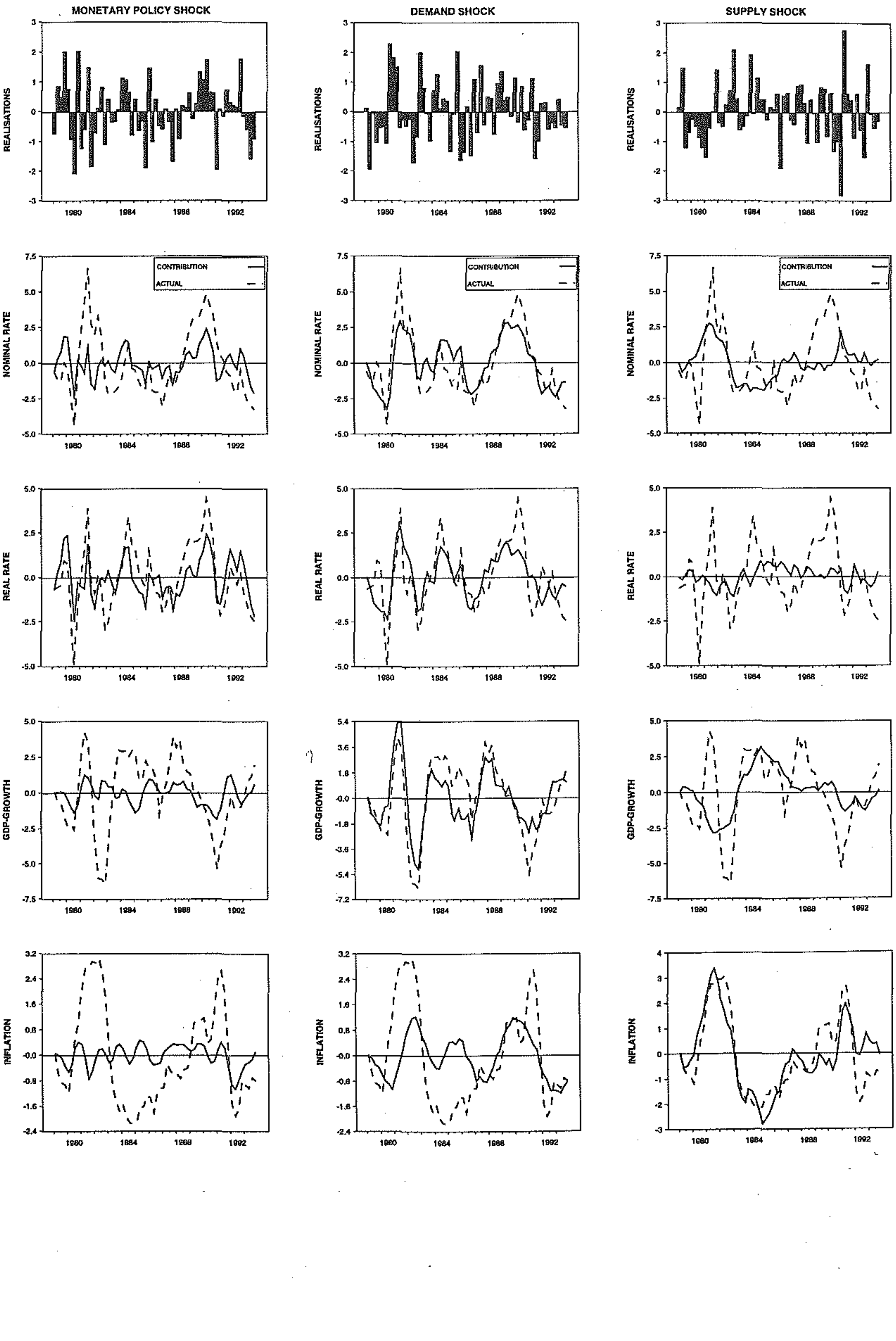


Figure 2.2

France: Historical decomposition of output, prices and interest rates

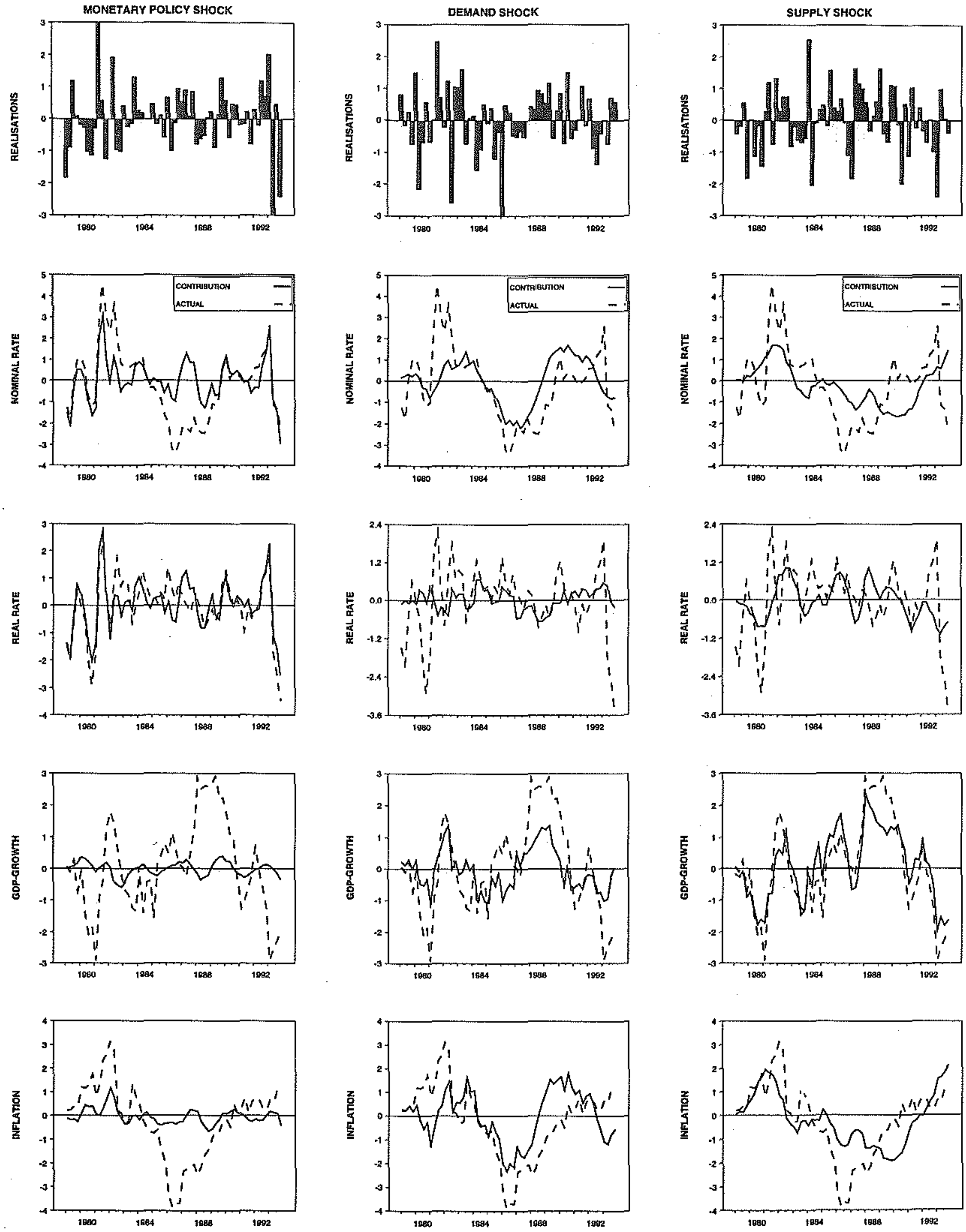


Figure 2.3

Germany: Historical decomposition of output, prices and interest rates

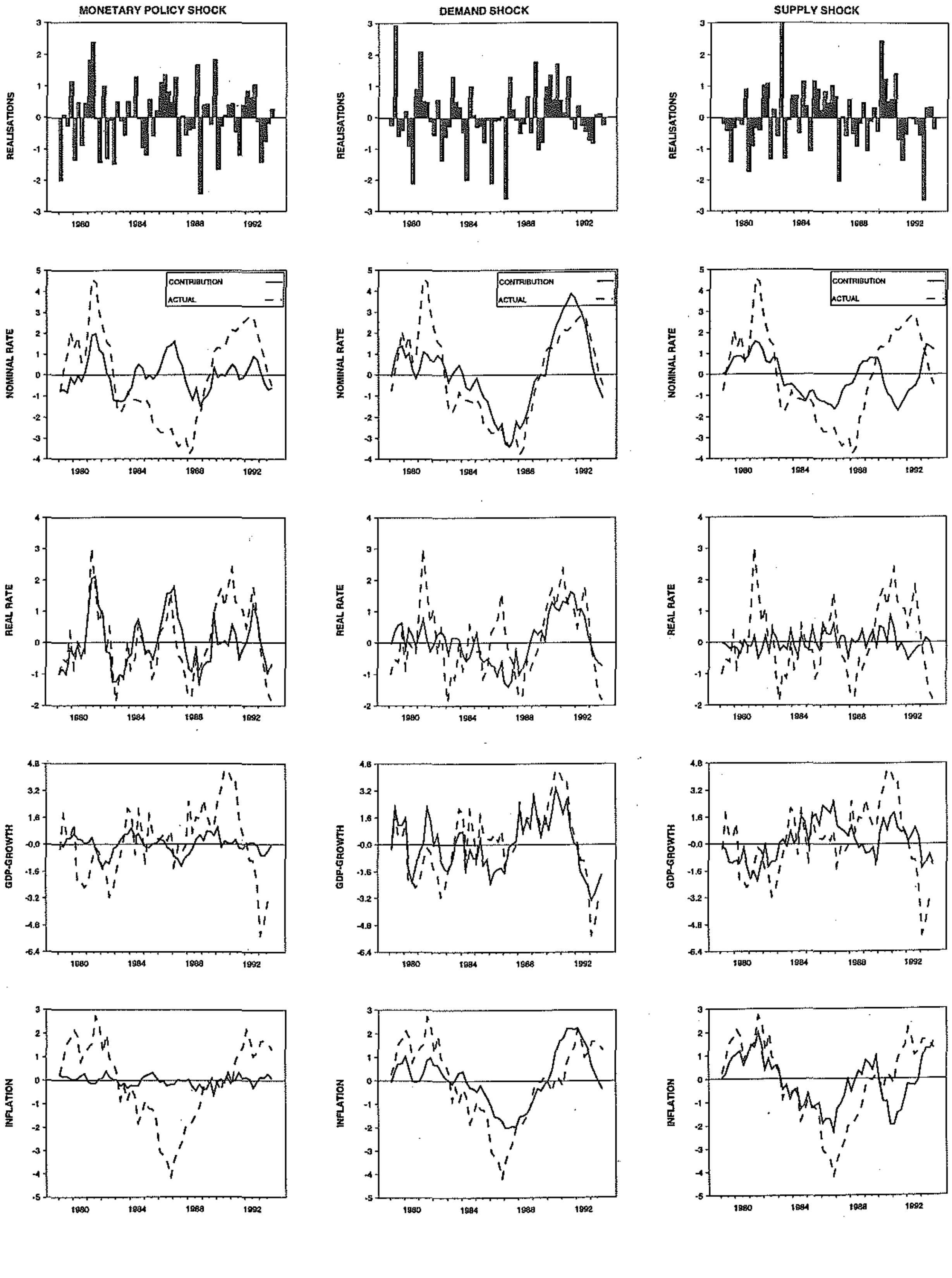


Figure 2.4

Italy: Historical decomposition of output, prices and interest rates

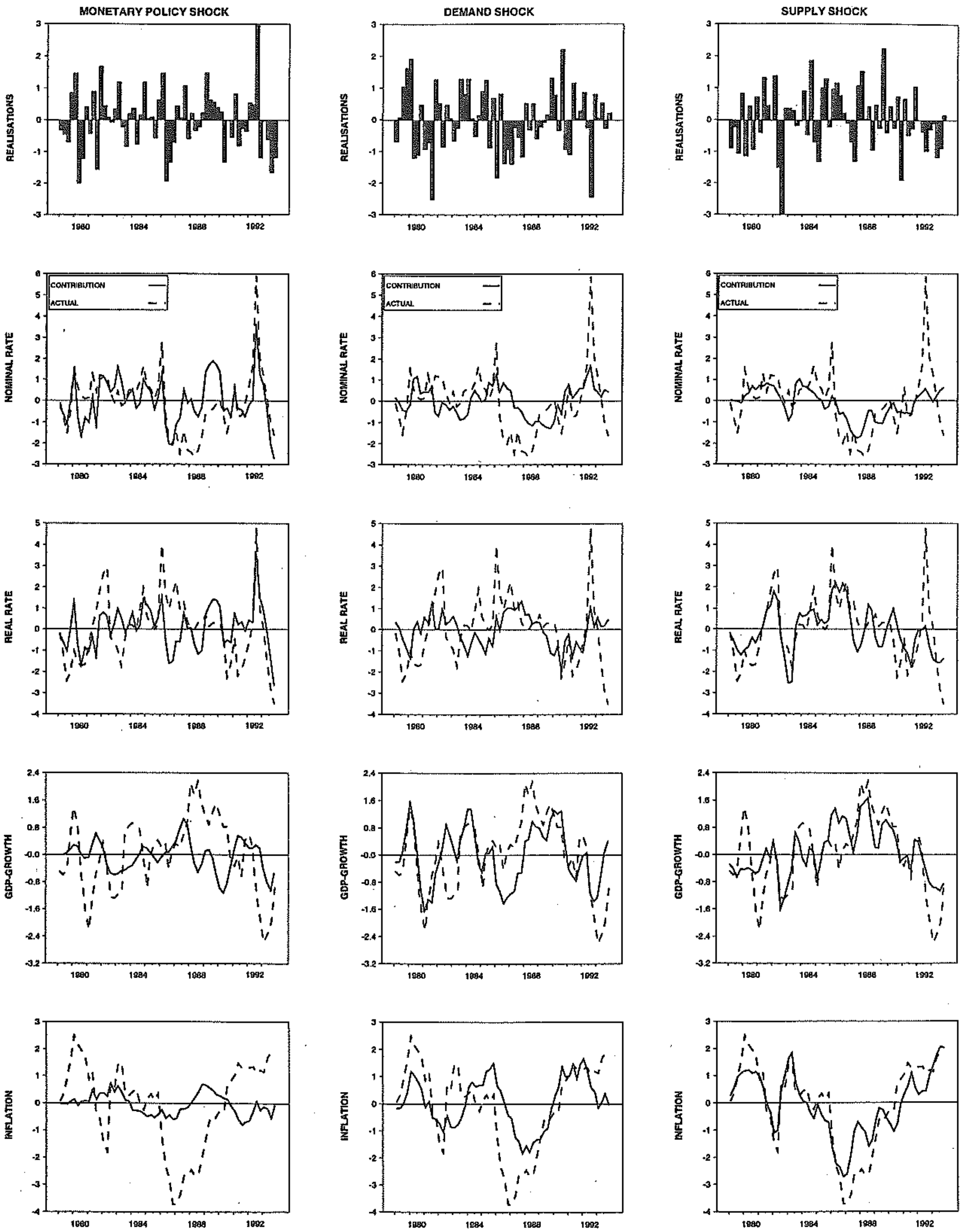


Figure 2.5

Japan: Historical decomposition of output, prices and interest rates

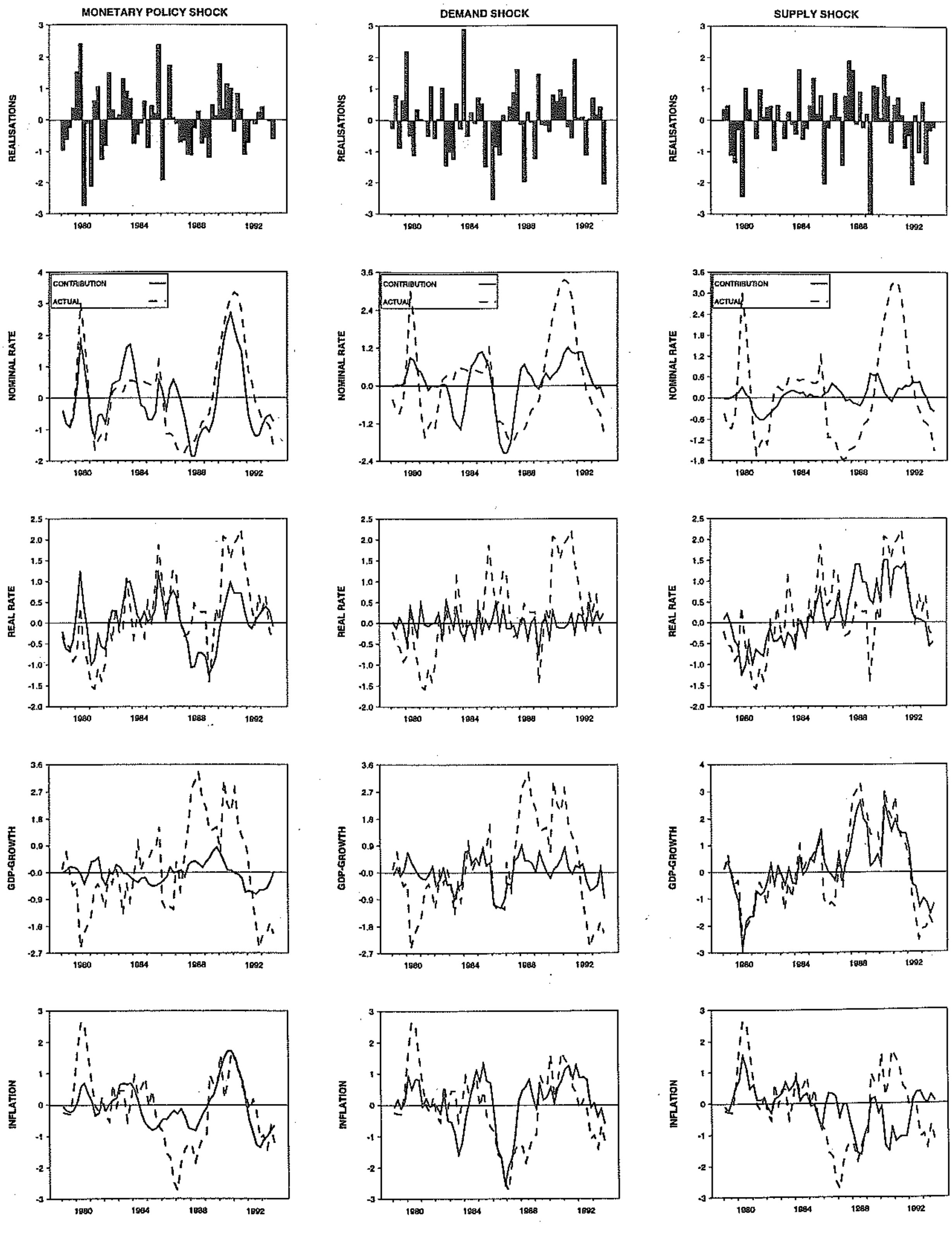


Figure 2.6

United Kingdom: Historical decomposition of output, prices and interest rates

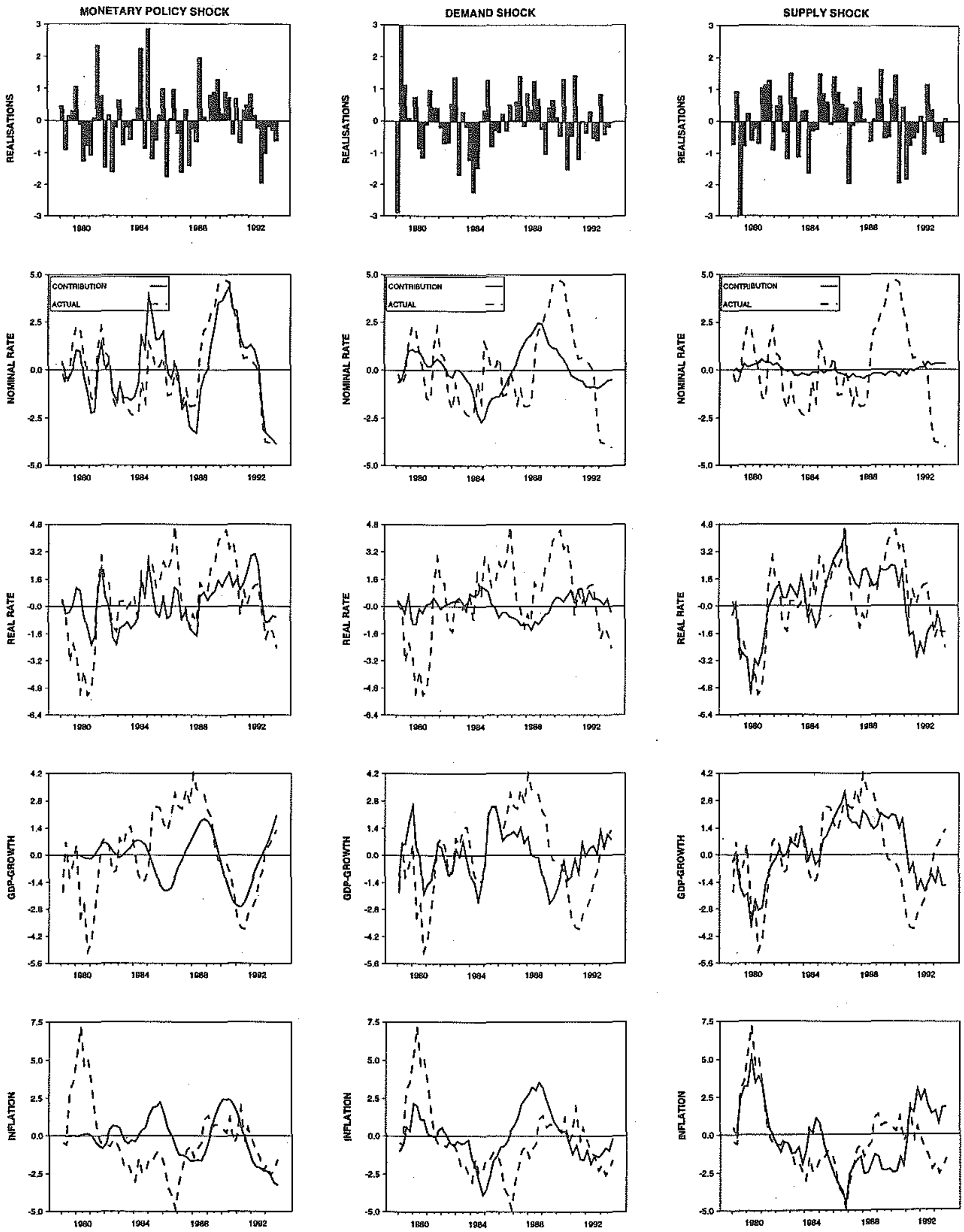
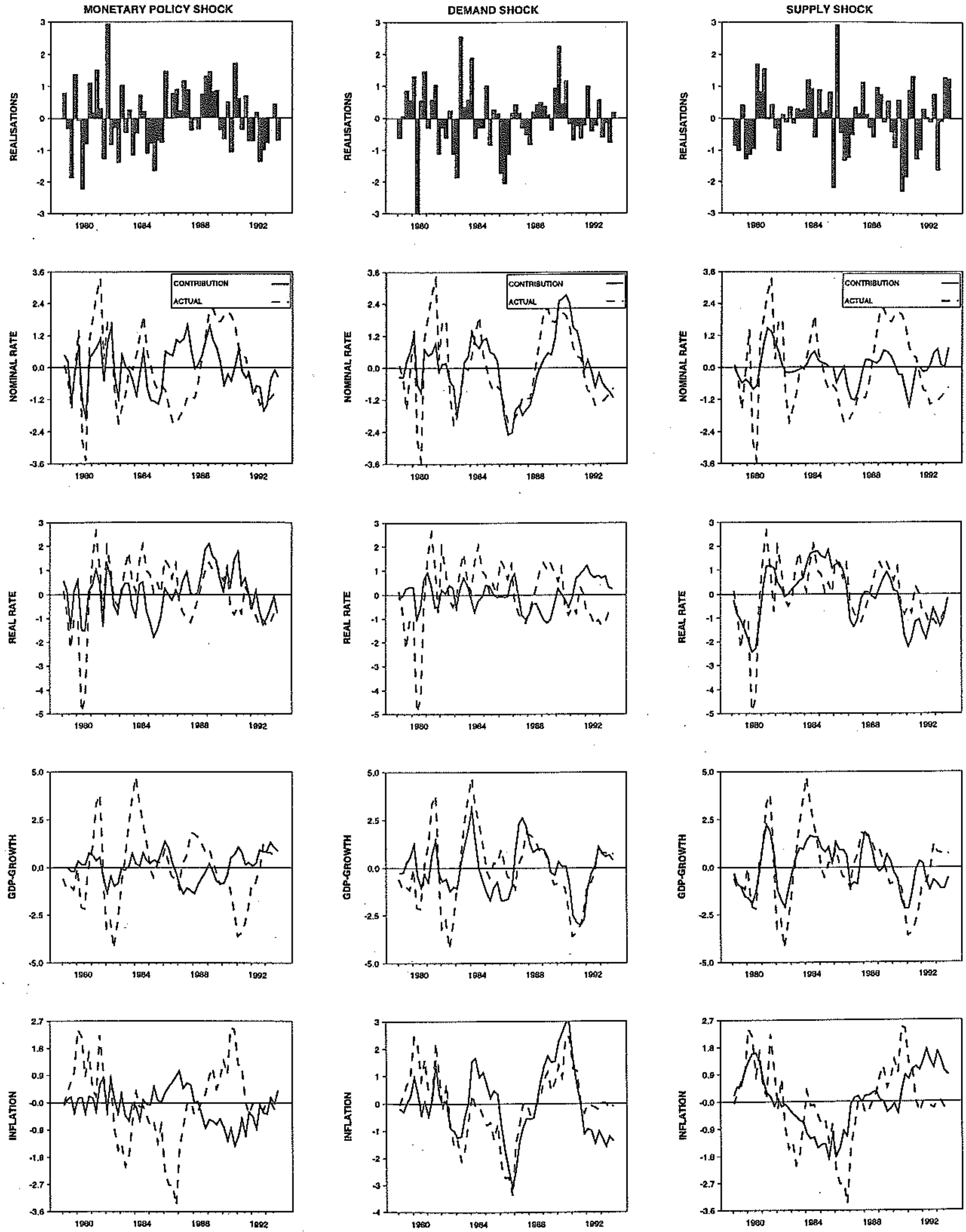


Figure 2.7

United States: Historical decomposition of output, prices and interest rates



Second, the so-called monetary policy shocks may be interpreted as deviations from the "average" response of monetary authorities to the estimated aggregate supply and demand disturbances in the sample period. However, the SVAR techniques do not allow us to identify the central banks' (implicit) reaction functions: the effects of aggregate supply and demand shocks are thus a convolution of their "direct" effect and any "indirect" effect they have by eliciting a tightening or relaxation of monetary policy by the central bank. One implication of this is that the effects and importance of the different disturbances are sensitive to any shifts in the reaction function during the sample period. For example, to the extent that the response of monetary policy to the first and second oil shock differed, as has frequently been argued, including the first oil shock in our sample period would change the estimated impulse response functions to a supply shock. This would in turn change the estimates of monetary policy shocks during the second oil shock.

With these caveats in mind, we next briefly comment on the results for each country. For reasons of space, we focus on business cycle developments since 1985.

Canada

The results for Canada are shown in Figure 2.1. Most of the variation in output since 1987 seems to be due to aggregate demand developments. These aggregate demand movements contributed to a large extent to the rise and decline of nominal and real interest rates and the rise and collapse in inflation since 1988.

However, both monetary policy and supply shocks also play a role during the recent cycle. Striking is that the tax changes in 1991 are attributed to aggregate supply shocks, which lead to a contraction in output and a quite dramatic rise in inflation.

In comparison to the average monetary policy response to economic disturbances during this period, the estimated monetary policy shocks indicate that policy was tightened considerably in 1990, increasing both nominal and real interest rates by about 250 basis points. This seems to have exacerbated the fall in output in 1990 and also contributed to a drop in inflation.

France and Italy

The results for France and Italy are reported in Figures 2.2 and 2.4 and are in many ways very similar. In both countries most of the movements in output and inflation are attributed to longer-run supply developments. Aggregate demand developments also play, however, a role in the recent business cycle and have in France, in particular, contributed to the recent rise and fall in nominal interest rates.

Furthermore, the role of monetary policy innovations in determining output and price movements is limited in France and Italy. The movements in the short-term interest rates over the 1992-93 period, which were caused by monetary policy responses to speculative capital flows, are quite appropriately viewed as discretionary monetary policy by the model, but have especially in France only negligible effects on output and prices.

Germany

Figure 2.3 shows that, as in France and Italy, discretionary shifts in German monetary policy have played only a very limited role in determining recent output and price developments. One notable difference with the results reported for France and Italy, however, is the clear role of aggregate demand movements in accounting for the expansion in 1990 and 1991 and the subsequent contraction in economic activity. The increase in interest rates between 1988 and 1992, and the subsequent relaxation of monetary policy, is viewed as largely due to the response of interest rates to the behaviour of aggregate demand over the period. The results are thus compatible with the view that the Bundesbank tightened monetary conditions in order to reduce the inflationary pressures associated with German unification.

Japan

The results for Japan are provided in Figure 2.5. One surprising feature is that the movements in the nominal interest rate are, to a comparatively large degree, attributed to monetary policy shocks. In particular, the large increase and subsequent decrease in interest rates since 1988 appear only to a modest degree due to central bank responses to aggregate demand shocks, and not at all to supply shocks. Turning to the real interest rates in row 3, it appears that monetary policy was relatively loose during 1987-88 with real interest rates more than 100 basis points below baseline and was subsequently tightened in 1989, leading to positive real interest rates since then. This tightening captures the "bursting of the bubble economy" by the Bank of Japan in 1989. This period of relatively loose monetary policy, followed by a relative tightening, contributed to the recent rise and decline in prices and output. Most of the recent collapse in output is, however, attributed to negative supply developments.

United Kingdom

In Figure 2.6 we provide the results for the United Kingdom. A striking finding is that also in the United Kingdom a very large fraction of the movements in nominal interest rates is due to monetary policy shocks; thus, only a very small part of changes in interest rates can be forecast by past inflation and output.[16] Perhaps even more striking is the finding that the estimates suggest that the monetary policy shocks have played an increasingly important role in accounting for fluctuations in real GDP growth and inflation. In particular, the fluctuation in GDP growth and inflation since 1988 are, according to our estimates, essentially entirely due to the monetary policy shocks.

United States

Finally, in Figure 2.7 we present the estimates for the United States. Turning to the decomposition of real income, we note that aggregate demand shocks have played a critical role in accounting for the recent recession, with aggregate supply developments playing a smaller but reinforcing role. The increase in nominal interest rates between 1986 and 1990, and the subsequent reduction, appear almost entirely due to these aggregate demand shocks, although their effects on the real interest rate are relatively subdued.

Interestingly, the estimated monetary policy shocks suggest that, in comparison with the average response to economic disturbances during this period, monetary policy has followed a pronounced counter-cyclical pattern since 1986: first by raising interest rates relatively early in the upturn, and subsequently by lowering them. In particular, the reduction in real rates between 1989 and 1993 is mainly attributed to a discretionary easing of monetary policy, with slack aggregate demand playing a contributing role. Rows 4 and 5 show that the implied contributions to output and prices offset part of the negative demand and supply developments.

IV. THE EFFECTS OF MONETARY POLICY: SOME SIMULATIONS

In this section we compare the effects of monetary policy across countries. A direct comparison of the impulse responses is made difficult by the fact that a typical monetary policy shock varies in size and duration across countries. For example, in Germany and Japan the typical shock is small in terms of basis points but quite persistent, while in Canada and Italy a typical shock is large but transitory. In order to render the results comparable, we standardise the monetary policy shocks

16 One possible explanation for this finding is that the monetary policy reaction function may have shifted repeatedly over the sample.

by assuming that the central bank raises the nominal short-term interest rate by 100 basis points for eight quarters, after which the interest rate is returned to baseline.[17]

Of course, it is conceptually unappealing to perform simulation experiments by fixing endogenous variables. In this case, however, the increase in the short-term interest rate is of moderate size and only temporary, and it is not grossly at odds with the actual behaviour of interest rates during the estimation period.

In most countries this standardised simulation leads to a new long-run equilibrium, with output returning to baseline and prices converging to a new long-run level.[18] However, in Germany, Japan and to a lesser extent in France, the results display some instability with prices continuing to fall even 20 quarters after the initial increase in interest rates. The reason for this is that, as indicated by the earlier discussion, a typical monetary policy tightening in Germany and Japan is followed by a period of undershooting of the nominal interest rates. This phenomenon, which was also noted to a lesser degree in the other countries, is explained by the fact that nominal interest rates endogenously respond to the fall in prices caused by the initial monetary tightening. Since nominal interest rates tend to fall after the initial monetary policy shock, additional positive (tightening) monetary policy shocks are required to maintain the nominal rate at baseline, even after the initial policy tightening is undone. While in the other countries these additional shocks eventually die out, in the German and Japanese case ever larger policy shocks are needed to maintain the baseline path of the nominal interest rate. This results in output and inflation declining at an increasing rate, while the real interest rate is increasing.[19]

These problems could be alleviated in two ways. We could let the nominal interest rate adjust automatically after fixing the first eight quarters. Depending on how important the endogenous undershooting is, this could then lead to quite different nominal interest rate paths thereafter. Alternatively, we could fix the path of the real interest rate. In panel (b) of Figure 3 we chose the latter solution, as it might be theoretically more appealing to standardise the effect on the real interest rate.

In Figure 3 we compare the results of the standardised monetary policy simulation experiment across countries for both a fixed nominal interest rate path (first column) and a fixed real interest rate path (second column). It should be stressed that the plotted responses are point estimates. Focusing initially on the first column, several comments can be made. As discussed above, forcing the nominal interest rate path to return to baseline results in a prolonged period of high real interest rates and thus tight monetary policy. This is particularly the case in the United States, where prices respond quite vigorously to the monetary policy tightening. As discussed above, it is also the source of the instability in the German and Japanese case, explaining the persistent effects on output and prices towards the end of the simulation period.

In most countries the effect of the monetary tightening on output is quite rapid. The effect on output in Germany, Canada and the United States is quite similar and reaches a peak effect of about 1.5% below baseline after nine quarters. The effects in France and Italy, on the other hand, are also similar, but the peak effect is only half of this. One obvious explanation for the difference is that, as discussed in Section III.4, part of the monetary policy shocks were related to counteracting the effects of speculative capital flows on the nominal exchange rate as both Italy and France were members of the ERM during most of the estimation period. The difference in effectiveness of

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17 The actual time path of the short-term nominal interest rate is chosen to facilitate a comparison with the simulation results of the central bank macroeconometric models.

18 This is an implication of our identifying assumption that the long-run Phillips curve is vertical.

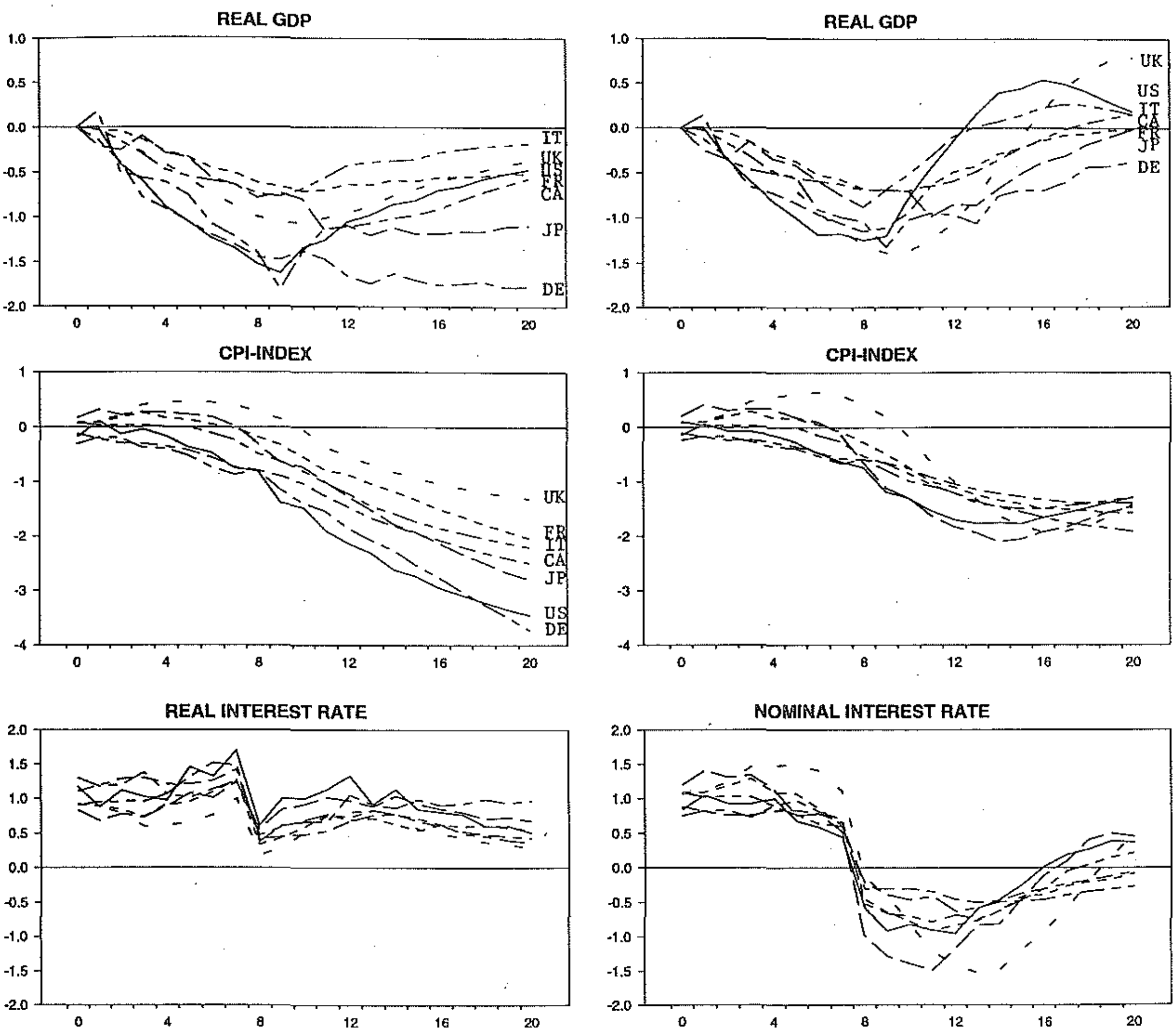
19 It is interesting to note that this is exactly the same problem some of the large-scale macroeconometric models have when they perform this simulation experiment.

Figure 3

The effect of a monetary tightening on output, prices and interest rates: a cross-country comparison

(a) 100 basis points increase in the nominal short-term interest rate during eight quarters

(b) 100 basis points increase in the real short-term interest rate during eight quarters



monetary policy could thus be related to the lack of an exchange rate channel in France and Italy.[20] The effects on output in Japan and the United Kingdom fall in between these two extremes, with the effect of a Japanese monetary tightening being somewhat more persistent than in other countries.

Output in most countries returns back to its baseline level after six to seven years. Exceptions in Figure 3 are Germany, Japan and France, where the policy experiment leads to very prolonged effects on both output and inflation because of the instability problems discussed above.

The second row of Figure 3 shows the effects on the consumer price index. Apart from (mostly insignificant) contemporaneous price jumps, the monetary policy tightening takes some time to affect prices. This is most clearly the case in the United Kingdom, Japan, France, and Italy, where prices only start falling after more than a year. In part this probably reflects the smaller effects on output in these countries. For France and Italy it could again also be explained by the lack of an exchange rate channel. The longer-run effect on the price level is more pronounced in the United States than in most of the other countries. This could, however, be related to the higher real interest rate after eight quarters.

In the second column of Figure 3 we report the effects on output, prices and the nominal interest rate of increasing the real interest rate by 100 basis points during eight quarters. To the extent that it is the real rather than the nominal interest rate that matters more for spending decisions, this simulation may provide a more comparable policy experiment. As can be seen from comparing the first and second columns in Figure 3, the range of outcomes is smaller in this case. Furthermore, the results for output and prices during the first eight quarters are very similar to the results in the first column. The third graph of the second column shows that, after the initial tightening for eight quarters, nominal interest rates undershoot in all countries to account for the declining prices caused by the initial monetary tightening. Nominal interest rates return to baseline, as prices stabilise around their new long-run level towards the end of the simulation period. This undershooting accounts for the somewhat different dynamics of output and prices after the initial shock. The problems of instability in Germany, Japan and France disappear, and in most countries output returns to baseline before the end of the simulation period. One exception is Germany, where the effects of a monetary tightening on output are again more persistent than in the other countries. It is quite striking how similar the effects on prices are in this case.

V. CONCLUSIONS

In this paper we provide some evidence of the monetary policy transmission mechanism in the G-7 countries using a parsimonious macroeconometric model of output, prices and a short-term interest rate. To enhance comparability, we use similar data series, the same sample period and the same econometric methodology for all the countries in the study. In what follows we sum up some of the main conclusions we have drawn from the research underlying this paper.

Although in many respects SVARs are an appealing methodology to use in cross-country analysis, it should be stressed that the estimated effects of monetary policy shocks are in general sensitive to the choice of identifying restrictions. Indeed, what would appear to be small changes in the identifying restrictions can lead to drastic changes in the estimated impulse responses.

Despite this, we are relatively confident that our results capture fundamental relationships in the data for three reasons. First, the results using our proposed identifying scheme are broadly

20 Preliminary results from estimated models in which we include the exchange rate confirm this hypothesis. In contrast to what one would expect, the exchange rate actually depreciates following a monetary policy tightening in France and Italy. Presumably this undoes some of the negative effects of the policy tightening on output.

stable across countries and over time.[21] Second, they compare quite well with the results from structural macroeconometric models and avoid the so-called "price puzzle" found in many other VAR studies of the transmission mechanism: i.e. the tendency of a monetary policy tightening to, at least temporarily, increase prices. Third, they provide plausible accounts of different historical episodes.

The estimates of the effects of monetary policy provide little evidence of large differences in the transmission mechanism across countries, particularly not when estimated confidence bands are taken into account. We find that over the estimation period the effects of a standardised monetary policy tightening on output and inflation are very similar in Canada, Germany and the United States. The point estimates of the effect on output in France and Italy are somewhat smaller, but may be due to the absence of a significant exchange rate channel in these countries during the estimation period. The effects on output in the United Kingdom and Japan fall somewhere in between. The finding that differences in monetary policy effectiveness across countries are limited does not necessarily imply that there are no such differences, only that they are difficult to document econometrically, at least using VAR techniques.

One of the obvious limitations of using a minimal macroeconometric model is that it is hard to document the channels of monetary policy transmission. One possible extension is to include the exchange rate in the model. This would make it possible to control for differences in the exchange rate channel and would also enable us to identify the effects of exchange market turbulence on the short-term interest rate. We leave this for future research.

21 Except for the United Kingdom, the qualitative results were very similar when we estimated the model over a longer sample period which included the first oil shock.

DATA APPENDIX

Real income is measured by real GDP[22] and prices by the consumer price index,[23] except for the United Kingdom, for which we use real non-oil GDP and the GDP deflator.[24] All series are seasonally adjusted. The selection of the short-term interest rate varies between countries. For Canada, the United Kingdom and the United States we use the yield on three-month Treasury bills.[25] For France, Germany, and Japan we use three-month money market rates.[26] The quarterly data points are averages of the monthly observations.

In order to use long-run identifying restrictions, shocks to the endogenous variables must have long-run effects, i.e. the relevant variables need to be non-stationary. As a preliminary step it is therefore useful to investigate the long-run properties of the data using unit root tests. Table A contains the results from Augmented (with 4 lags) Dickey-Fuller tests on the data, together with critical values from MacKinnon (1991). The power of the tests is likely to be affected adversely by the inclusion of the lagged differences, since some lags are likely to be insignificant.

Note that in many cases we can reject the hypothesis that the *level* of prices is non-stationary when no time trend is included in the tests. When the time trend is included, however, the test statistics typically fall drastically. We interpret this result as being due to the fact that in the early part of the sample the rate of inflation was typically quite high, and then fell gradually to very low levels in the early 1990s. In the absence of a time trend, the secular fall in the inflation rate is interpreted as the price level converging to a constant level; in the presence of the time trend, the fall in inflation is properly interpreted as being secular in nature, and not as evidence that the price level is stationary.[27] Given the low power of ADF tests, we interpret the results as indicating that the rates of inflation and real output growth are stationary around a linear time trend.

Turning to the short-term interest rates, the results indicate that at the 10% level we can reject the unit root hypothesis in France, Germany, Italy and the United Kingdom using at least one of the two tests. Given the low power of the tests, we again conclude that the short-term interest rates are likely to be stationary.

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22 The code in the BIS database is RHGB.

23 The code is VEBA..01, except for Italy, where VEBAIT02 was used.

24 The codes are RUGBGB04 and RNBBGB01.

25 The codes were as follows: Canada, HEPACA01; Italy, HEPAIT02; the United Kingdom, HEPAGB01; the United States: HEPAUS02.

26 The codes were as follows: France, HEEAFR02; Germany, HEEADE02; Japan, HEEAJP02.

27 It is interesting to note that in the case of variables that are likely to be stationary, such as the rate of inflation or real income growth, there is typically little difference between the test statistics with and without a time trend.

Table A

ADF tests for unit roots
1973:1-1993:4

Countries	Variables	Without trend[1]	With trend[2]
Canada	p_t	- 3.16 **	- 0.80
	Δp_t	- 1.46	- 3.23 *
	y_t	- 1.68	- 1.70
	Δy_t	- 3.75 ***	- 4.02 **
	r_t	- 2.21	- 1.87
	Δr_t	- 3.58 ***	- 3.91 **
France	p_t	- 2.61 *	- 0.37
	Δp_t	- 1.06	- 2.68
	y_t	- 1.53	- 2.23
	Δy_t	- 3.46 **	- 3.69 **
	r_t	- 2.75 *	- 2.72
	Δr_t	- 5.15 ***	- 5.25 ***
Germany	p_t	- 1.34	- 2.19
	Δp_t	- 1.88	- 1.81
	y_t	- 0.35	- 3.03
	Δy_t	- 3.52 ***	- 3.51 **
	r_t	- 3.51 ***	- 3.48 **
	Δr_t	- 4.05 ***	- 4.03 **
Italy	p_t	- 3.26 **	0.02
	Δp_t	- 1.69	- 3.63 **
	y_t	- 1.85	- 2.22
	Δy_t	- 4.89 ***	- 5.29 ***
	r_t	- 2.62 *	- 2.42
	Δr_t	- 5.66 ***	- 6.03 ***
Japan	p_t	- 5.35 ***	- 5.15 ***
	Δp_t	- 2.27	- 3.76 **
	y_t	- 0.71	- 3.04
	Δy_t	- 3.60 ***	- 3.64
	r_t	- 1.57	- 2.52
	Δr_t	- 3.44 **	- 3.64 **
United Kingdom	p_t	- 3.26 **	0.01
	Δp_t	- 1.69	- 3.62 *
	y_t	- 0.39	- 2.33
	Δy_t	- 2.21	- 2.20
	r_t	- 2.93 **	- 2.74
	Δr_t	- 4.38 ***	- 4.57 ***
United States	p_t	- 2.88 *	- 1.71
	Δp_t	- 2.20	- 3.40 *
	y_t	- 0.13	- 3.16
	Δy_t	- 3.78 ***	- 3.72 **
	r_t	- 1.70	- 1.88
	Δr_t	- 2.98 **	- 3.10

Note: */**/*** indicates significance at 10/5/1% level.

[1] Critical values: -2.58; -2.90; -3.51. [2] Critical values: -3.25; -3.46; -4.07.

TECHNICAL APPENDIX

This appendix presents the precise form of our estimated equations and reviews how the identifying restrictions are imposed. The estimation strategy follows Shapiro and Watson (1988).

The model consists of three equations: an income equation, a price equation and an interest rate equation. We first estimate the income equation, which is given by (disregarding the constant and trend term):

$$\Delta y_t = \sum_{k=1}^{n} \alpha_k \Delta y_{t-k} + \sum_{k=0}^{n-1} \beta_k \Delta^2 p_{t-k} + \sum_{k=0}^{n-1} \delta_k \Delta r_{t-k} + \varepsilon_t^y \tag{A1}$$

where n denotes the order of the VAR. The results reported in the paper are based on n=5. Since the *change* in the inflation rate and interest rates enters in the equations, the *level* of the inflation rate and interest rates have no permanent effects on the level of income. Thus, the residual is proportional to the aggregate supply shock, ε_t^y. Note also that since contemporaneous prices and interest rates enter, the equation is estimated with instrumental variables, using Δy_{t-j}, Δp_{t-j}, and r_{t-j} $(j = 1,...,n)$ as instruments.

We also estimate, by OLS, the inflation and interest equations, which are given by:

$$\Delta p_t = \sum_{k=1}^{n} \phi_k \Delta y_{t-k} + \sum_{k=1}^{n} \gamma_k \Delta p_{t-k} + \sum_{k=1}^{n} \eta_k r_{t-k} + v_t^p \tag{A2}$$

$$r_t = \sum_{k=1}^{n} \kappa_k \Delta y_{t-k} + \sum_{k=1}^{n} \lambda_k \Delta p_{t-k} + \sum_{k=1}^{n} \mu_k r_{t-k} + v_t^r \tag{A3}$$

These are reduced form equations, in the sense that the errors are correlated with the aggregate supply shock in (A1), and are linear combinations of the structural aggregate demand and monetary policy shocks. Next we disentangle these contemporaneous correlations in the data.

The estimated reduced form errors in v_t are functions of the underlying, unobserved, structural disturbances in ε_t. More precisely, we have that:

$$\begin{bmatrix} v_t^y \\ v_t^p \\ v_t^r \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \times \begin{bmatrix} \varepsilon_t^y \\ \varepsilon_t^d \\ \varepsilon_t^m \end{bmatrix} \tag{A4}$$

We calculate the a_{ij}'s and the structural shocks using a two-step procedure. We first decompose the regression errors into three orthogonal shocks, which we then normalise to have unit variance.

Since the residual in the first equation, v_t^y, is proportional to the supply shock, ε_t^y, we set $a_{11} = 1$. Since the structural shocks are orthogonal, we can obtain preliminary estimates of a_{21} and a_{31} by running the following regressions:

$$v_t^p = a_{21}\varepsilon_t^y + \xi_t^p \tag{A5}$$

$$v_t^r = a_{31}\varepsilon_t^y + \xi_t^r \tag{A6}$$

ξ_t^p and ξ_t^r are correlated, but, by construction, orthogonal to ε_t^y. To proceed, note that

$$\xi_t^p = a_{22}\varepsilon_t^d + a_{23}\varepsilon_t^m \tag{A7}$$

$$\xi_t^r = a_{32}\varepsilon_t^d + a_{33}\varepsilon_t^m \tag{A8}$$

Our task is to obtain estimates of the variables on the right-hand side of (A7 - A8). Since monetary policy shocks have no contemporaneous effect on the level of income, its effect on the income level through the interest rate $(a_{33}\delta_0)$ and on the income level through the price level $(a_{23}\beta_0)$ must sum to zero, so that $a_{23} = -a_{33}\delta_0 / \beta_0$. This in turn implies that $\varepsilon_t^d = \frac{(\xi_t^d + \delta_0 / \beta_0 \xi_t^r)}{(a_{22} + \delta_0 / \beta_0 a_{32})}$. We therefore set the (non-normalised) demand shock equal to $\xi_t^d + \delta_0 / \beta_0 \xi_t^r$. We can then obtain a preliminary estimate of a_{22} and a_{32} by estimating (A7) and (A8). The residual in (A8) is proportional to the monetary policy shock, so we set $a_{33} = 1$, which in turn gives us an estimate of a_{23}.

The obtained estimates of the a_{ij}'s and the structural shocks are preliminary in the sense that the structural shocks do not have unit variance. The last step of the identification procedure involves normalising the shocks and parameters. Note from (A4) that we have:

$$v_t v_t^T = \Omega = A\varepsilon_t \varepsilon_t^T A^T \tag{A9}$$

whereas in the main text we noted:

$$\Omega = A(0)A(0)^T \tag{6}$$

Thus, we set $A(0) = A\sqrt{\varepsilon_t \varepsilon_t^T}$, which completes the identification.

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