UNIVERSITÀ CATTOLICA del Sacro Cuore

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MONETARY POLICY AND INNOVATION IN EUROPE: AN SVAR APPROACH

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Abstract

Using quarterly data, we estimate the effects of monetary policy on innovation in the Eurozone over 2000-2021. The identification of the structural shocks relies on an SVAR framework with a set of exclusion restrictions. Although characterised by the predominance of ZLB periods, conventional monetary policy shocks affect private and public R&D spending in the medium term with some initial inertia. Unconventional monetary shocks affect innovative expenditure in the short to medium term, but their impacts vanish in the longer run.

JEL classification

O30, E31, E40, E52

Keywords

ECB, Monetary policy, Structural VAR, Innovation

1. *Introduction*

Over recent decades, several advanced economies have experienced slowdowns in aggregate growth and productivity, despite the spread of digital technologies (Ciaffi et al., 2022). Such trends are notably evident in the Euro Area post-Global Financial Crisis period. Whilst most of the Eurozone's pre-Covid era was characterised by persistently low-interest rates and unconventional monetary policy, the sudden 2021 economic rebounds and the ongoing global geopolitical tensions have led to unprecedented peaks in the inflation rate, which in turn has translated into sharp rises of European Central Bank (ECB) policy rates.

It is largely recognised that the dynamics of innovation activity represent a crucial determinant of productivity trajectories (Guérin, 2023). A recent work by Ma and Zimmermann (2023) relates monetary policy to innovation in the US, finding detrimental effects of monetary contraction on various measures of innovation. Nevertheless, opposite effects emerge in Moran and Queralto (2017), still in the US. This issue is thus open to further investigation and appears to be relevant, especially within the current global scenario characterised by, among other things, increased financial risks and uncertainties. It seems reasonable to argue that innovation activity represents a relevant channel through which monetary policy transmits its effects on the supply-side of the economy – with possible long-run implications for economic growth.

Although recent studies have estimated the real effects of monetary policy in the Eurozone (e.g. Burriel and Galesi, 2018; Pellegrino, 2018; Murgia, 2020; Badinger and Schiman, 2023), there is still a gap about the links between monetary policy and innovation. We thus contribute to the existing literature by estimating the effects of monetary policy on both private and government R&D expenditure in the Eurozone. Using quarterly data from 2000 to 2021, we propose a Structural-VAR (SVAR) framework in which identification is achieved through a parsimonious set of exclusion restrictions. We employ three different measures of monetary instruments to account for the role of expectations and unconventional monetary policy. Our limited set of prior assumptions on the distribution of the true parameters is mainly due to the persistently low-interest rates and unconventional policy that have characterised most of the period under analysis and which are likely to imply controversial or even anomalous real effects of monetary policy (Brunnermeier and Koby, 2018; Ahmed et al., 2023¸ Onofri et al., 2023).

The rest of the article is organized as follows: Section 2 builds a measure of monetary shock; Section 3 specifies the model; Section 4 discusses the identifying and overidentifying restrictions of our SVAR; Section 5 describes the nature and sources of the data employed in this study; Section 6 reports the results; Section 7 concludes the paper.

2. *Measuring the ECB's monetary shocks*

In the first stage of our analysis, we attempt to identify and separate the systematic and unexpected components of monetary policy, as proposed by Christiano et al. (1996). For this purpose, we follow Romer and Romer (2004) and split the meeting-by-meeting Main Refinancing Operations Rate (MRO) change into its predicted and unpredicted components, thus specifying the following function:

$$\Delta MRO_m = \eta + \sum_{k=1}^{2} \alpha_k \widetilde{Q_m^k} + \sum_{k=1}^{2} \beta_k \widetilde{\pi_m^k} + \sum_{k=1}^{2} \lambda_k \widetilde{u_m^k} + \sum_{k=1}^{2} \phi_k \Delta\widetilde{Q_m^k} + \sum_{k=1}^{2} \psi_k \Delta\widetilde{\pi_m^k} + \sum_{k=1}^{2} \theta_k \Delta\widetilde{u_m^k} + \rho MRO_{m-14} + \gamma \log{(A)_m} + \varepsilon_m \quad (1)$$

where $\widetilde{Q_m^k}$ is the expected k-years ahead output growth rate at the m-th ECB meeting. Analogously, the same applies to the inflation rate π and the unemployment rate u. The association of Δ with the predicted variables denotes the revisions of the forecasts with respect to the previous meeting. Compared to the original specification of Romer and Romer (2004), we augment the equation with the ECB's total assets A to control for the unconventional monetary policy – consistent with Burriel and Galesi (2018) and Murgia (2020). The OLS residual $\hat{\varepsilon}_m$ obtained through the estimation of Equation 1 is our measure of monetary policy shock. The differences between the variation in the MRO and its unpredicted component can be observed in Figure 1.

Figure 1. ECB monetary policy, 1999Q1-2023q3.

3. *Structural Var*

In order to model the structural relationship between the ECB's monetary stance and innovation activity carried out at private and government levels, as a first step, we build the following reduced-form VAR model:

$$\boldsymbol{A}(\boldsymbol{L})\boldsymbol{y}_t - \boldsymbol{B}(\boldsymbol{L})\boldsymbol{x}_t = \boldsymbol{\varepsilon}_t \tag{2}$$

where $\boldsymbol{y}$ and $\boldsymbol{x}$ are vectors of endogeneous and exogeneous variables, respectively. The sets of lagged coefficients are $\boldsymbol{A}(\boldsymbol{L}) = (\boldsymbol{I}_n - \boldsymbol{A}_1\boldsymbol{L}^1 - \ldots - \boldsymbol{A}_p\boldsymbol{L}^p)$ and $\boldsymbol{B}(\boldsymbol{L}) = (\boldsymbol{I}_n + \boldsymbol{B}_1\boldsymbol{L}^1 + \ldots + \boldsymbol{B}_q\boldsymbol{L}^q)$. The forecast errors are such that $E(\boldsymbol{\varepsilon}_t) = E(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t') = 0 \; \forall \; t \neq s$ and $E(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t') = \boldsymbol{\Sigma}$. The model specified in Equation 2 cannot unveil much about the causal relationships between the endogeneous variables, as the variance-covariance matrix $\boldsymbol{\Sigma}$ is non-diagonal. Therefore, some extensions are needed.

To identify the effects of monetary policy, we propose the following SVAR model:

$$\boldsymbol{A}_0\boldsymbol{A}(\boldsymbol{L})\boldsymbol{y}_t - \boldsymbol{A}_0\boldsymbol{B}(\boldsymbol{L})\boldsymbol{x}_t = \boldsymbol{A}_0\boldsymbol{\varepsilon}_t = \boldsymbol{C}\boldsymbol{v}_t \tag{3}$$

where $\boldsymbol{A}_0$ is a square matrix of dimension n (with n equal to the number of endogeneous variables) containing the contemporaneous effects among the covariates in $\boldsymbol{y}$, $\boldsymbol{C}$ is a diagonal matrix and $\boldsymbol{v}_t = \boldsymbol{A}_0\boldsymbol{C}^{-1}\boldsymbol{\varepsilon}_t$ is the structural shocks matrix. Since we aim to evaluate how the relationships among the variables in $\boldsymbol{y}$ evolve over time, we need to obtain impulse response functions (IRFs) which are economically meaningful. Thus, assuming non-singularity of $\boldsymbol{A}_0$ and $\boldsymbol{A}(\boldsymbol{L})$, we reparametrize Equation 3 into its infinite moving-average representation (Wold representation):

$$\boldsymbol{y}_t = \boldsymbol{A}(\boldsymbol{L})^{-1}\boldsymbol{B}(\boldsymbol{L})\boldsymbol{x}_t + \boldsymbol{A}_0^{-1}\boldsymbol{A}(\boldsymbol{L})^{-1}\boldsymbol{C}\boldsymbol{v}_t \tag{4}$$

where the structural IRF coefficients are given by $\boldsymbol{D}(\boldsymbol{L}) = \boldsymbol{A}_0^{-1}\boldsymbol{A}(\boldsymbol{L})^{-1}\boldsymbol{C}$. It follows that the s_{th}-ahead response of an endogeneous variable in the system following a structural shock at time t is given by $\vartheta \boldsymbol{y_{t+s}}/\vartheta \boldsymbol{v_t} = \boldsymbol{D}(\boldsymbol{s})\ \forall\ t, s \in T$ – provided that $\boldsymbol{D}(\boldsymbol{L})$ is differentiable over the entire parameter space[1].

4. *Identifying restrictions*

Given $\widehat{\boldsymbol{\Sigma}}$, we must identify $\boldsymbol{A_0}$ and $\boldsymbol{C}$ such that $E(\boldsymbol{v_t}'\boldsymbol{v_t}) = \boldsymbol{I_n}$. In other words, we need to obtain mutually orthogonal innovations in $\boldsymbol{v_t}$ to propose a causal interpretation of the shocks. Following Sims (1980) and Giannini and Amisano (2012), as well as the application to monetary policy and innovation proposed by Moran and Queralto (2017), we consider as a starting point the Cholesky decomposition of $\boldsymbol{\Sigma}$. Assuming that $\boldsymbol{\Sigma}$ satisfies the full rank conditions, we can find a unique matrix $\boldsymbol{P}$ such that $\boldsymbol{\Sigma} = \boldsymbol{PP'}$. In our case, the identification through the Cholesky decomposition implies imposing *i)* $(n^2 - n)/2$ zero-restrictions (exactly-identified model), *ii)* lower-triangularity on $\boldsymbol{A_0}$ with unit elements on the main diagonal and *iii)* diagonality on $\boldsymbol{C}$. Therefore, our Cholesky factor is given by $\boldsymbol{P}$=$\boldsymbol{A_0^{-1}C}$. We can verify the diagonality of the structural shocks matrix as follows: $E(\boldsymbol{v_t}'\boldsymbol{v_t}) = \boldsymbol{A_0C^{-1}}(\boldsymbol{A_0C^{-1}})'\boldsymbol{\Sigma}$=$\boldsymbol{\Sigma^{-1}\Sigma} = \boldsymbol{I_n}$. It is worth reporting the structure of the matrix $\boldsymbol{A_0}$ under the Cholesky identification:

$$\boldsymbol{A_0} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{pmatrix} \tag{5}$$

[1] Considering how we have defined $\boldsymbol{D}(\boldsymbol{L})$, it is interesting noting that the reduced-form parameters $\boldsymbol{A}(\boldsymbol{L})$ play a crucial role in shaping the structural IRFs. For that reason, a good structural VAR model should reflect a careful construction of its reduced-form counterpart.

where a_{ij}, for $i, j = 1, \ldots, 4$ represent the structural parameter associated with the j-th endogeneous variable in the i-th equation. In other words, the elements below the matrix's main diagonal in Equation 5 are left unconstrained in the system.

It is worth highlighting that the Cholesky factor $\boldsymbol{P}$ is not invariant to the order of the endogenous variables. Hence, deciding which structural shocks have zero contemporaneous effects in each equation is pivotal for the identification strategy. Considering both the economic and inferential features of the phenomenon, the ordering of the variables is the following: 1) GDP growth; 2) Monetary instrument; 3) Innovation; 4) Inflation rate. Such a recursive-ordering criterion is broadly in line with (Sims, 1986), at least as it concerns the non-innovation observables. More specifically, it allows for contemporaneous effects of i) interest rate in the third equation and ii) output in the second and third equations while leaving all the parameters in the inflation equation unrestricted. Placing innovation in the third place implies it takes at least one quarter to respond to inflation shocks. It is worth pointing out that our prior assumptions on the contemporaneous effects across the endogenous variables do consider the quarterly time frequency of the sample, in the sense that imposing economic or financial stickiness in the very short-run is less restrictive and more realistic compared to the case of, say, annual frequency – in which the exclusion restrictions allow for effects only after one year. Although we did not find existing works that, in the context of SVAR modelling, impose contemporaneous restrictions on innovation, it appears reasonable to assume that the firm and government innovation projects need at least one quarter to adjust to the unexpected changes in the inflation rate. While other recursive ordering combinations are possible, our approach reflects a balance in the causal ordering priorities – given the existing literature and the characteristics of our sample.

As a monetary instrument, we alternatively consider the main refinancing operations rate (MRO), a measure of monetary policy shocks (MPS) that we built following Christiano et al. (1996), Romer and Romer (2004) and Murgia (2020), and the ECB's total assets as a measure of the unconventional monetary stance. As concerns the vector of exogeneous covariates $\boldsymbol{x}$, we include the unemployment rate since it is a relevant explanatory factor of the variables in $\boldsymbol{y}$ – especially as it concerns monetary policy (e.g. Sims, 1986; Arias et al., 2018; Geiger and Scharler, 2021). Including the unemployment rate in the exogenous vector appears to be a good balance between the willingness to avoid misspecification and the need to maintain an acceptable ratio between the sample size and the number of free parameters[2].

As a subsequent step, we parsimoniously consider overidentifying restrictions, based on the existing theoretical and empirical literature, with due calibrations to the empirical framework proposed in this study and the behaviour of the data. In addition to the set of Cholesky restrictions described above, we assume that the monetary instrument does not respond to output changes within a quarter – in the spirit of Uhlig (2005). In other words, such an additional restriction imposes nullity on the element a_{21} in Equation 5. Although other identification schemes are possible, we prefer an agnostic approach with limited restrictions[3] for two main reasons: statistical and economic. Firstly, since T does not diverge, imposing a larger number of identifying restrictions would translate into huge costs in terms of consistency, thus

[2] In fact, a 5×5 VAR specification when $T < 90$ is unusual in the literature.
[3] Relatively to the Eurozone, the use of a limited number of identifying restrictions is proposed in the recent work of Badinger and Schiman (2023).

threatening any proper balance of the bias-variance trade-off. Secondly, a large share of the period under analysis is characterised by unconventional monetary policy and low policy rates. As emerged in recent empirical applications, the overall macroeconomic effects of monetary policy might be counterintuitive when central banks implement unconventional measures or even within conventional contexts but with policy rates persistently close to zero (Brunnermeier and Koby, 2018; Ahmed et al., 2023, Onofri et al., 2023). Except for the post-Covid period, the ECB's policy rates were persistently close to zero for most of the time. In that case, imposing further a priori restrictions based on standard economic theory might not capture the plausible "anomalies" of the true effects.

5. Data

Table 1 reports the main descriptive statistics and the sources of the actual data employed in the analysis. The sources for the forecasted variables employed in Equation 1 are the same as the actual variables (any statistic or further information on forecasts can be made available upon reasonable request).

Table 1. Summary statistics and variable sources.

Variable	Source	*T*	Mean	SD	Min.	Max.
MRO	ECB Economic Bulletin	86	1.486	1.523	0.000	4.750
Monetary policy shock	Authors' construction	86	-0.003	0.066	-0.291	0.136
ECB's total assets (logarithm, detrended)	Federal Reserve Economic Data (FRED)	86	-0.026	0.152	-0.389	0.272
GDP growth rate	ECB Survey of Professional Forecasters	86	-0.295	3.042	-15.203	13.495
Inflation rate (HICP)	ECB Survey of Professional Forecasters	86	1.662	1.006	-0.367	4.550
Unemployment rate	ECB Survey of Professional Forecasters	86	9.367	1.417	7.125	12.230
Private R&D expenditure (logarithm, detrended)	EUROSTAT- GERD by sector of performance	86	0.00074	0.023	-0.0398	0.0554
Government R&D expenditure (logarithm, detrended)	EUROSTAT- GERD by sector of performance	86	0.00033	0.022	-0.0328	0.0598

Data on private and government expenditure in research and development (R&D), gathered from the Gross Domestic Expenditure on R&D (GERD) database of Eurostat covering the period 2000-2021, represent our measure of innovation and are originally observed at the annual level[4]. To maintain a quarterly frequency of our dataset – a crucial condition for our proposed identification strategy – we transform them into quarterly data by applying a local quadratic polynomial with the sum matched to the source data.

As it concerns the innovation measure, we consider the detrended logarithm of the expenses in R&D (at private and government levels, separately)[5]. The transformation of the innovative measures into detrended logarithms, as well as of our

[4] The time series refer to the Eurozone 19 group across the whole period covered in the analysis. More specifically, the countries involved are the following: Austria, Belgium, Cyprus, Estonia, France, Finland, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Portugal, Slovakia, Slovenia, Spain.
[5] The use of the detrended logarithm of the variable follows the approach proposed by Blanchard and Quah (1989).

measure of unconventional monetary policy, is appealing because of its more desirable distributional and stationarity properties – as we can notice in Figures A1-A3 (where it is compared with its counterpart in level terms)[6].

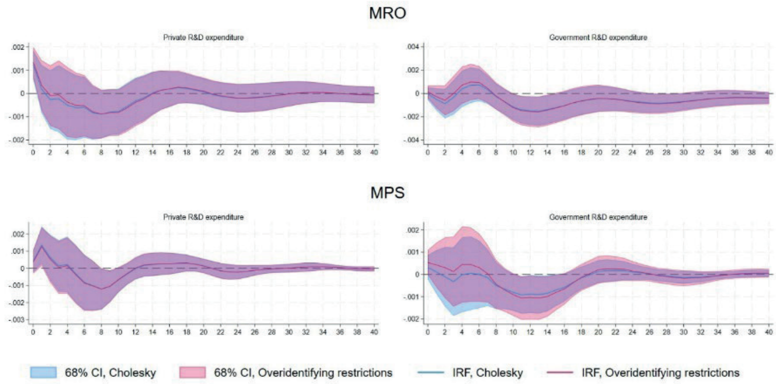
6. *Results*

We estimate separate models according to the monetary instrument employed. All the monetary variables are detrended and expressed in real terms. We report the conventional confidence intervals at the 68% level associated with each IRF. The lengths of p and q are chosen according to the values that minimize the AIC statistic. To save space, this section only shows the IRFs where monetary impulses exert their effects on innovation. The full results are reported in the online Appendix.

The IRF estimates reported in Figure 2 suggest that private and government innovation activities react differently in the wake of a monetary impulse. An MRO impulse exerts contractionary effects on private innovation from the second to the fourteenth quarters, partially aligning with Ma and Zimmermann (2023). However, once the systematic component of monetary policy is excluded, private innovation contracts only after one year and reverts faster to its long-run equilibrium. The effects exerted by our measure of monetary shocks maintain their temporary nature – consistent with their economic meaning and stationarity properties – and, at the same time, do not contrast with the previous overall findings.

[6] Formal unit root testing procedures – that we carried out by employing both the augmented Dickey-Fuller (ADF) and the Phillips–Perron (PP) tests – suggest that the series in levels are nonstationary (Table A1).

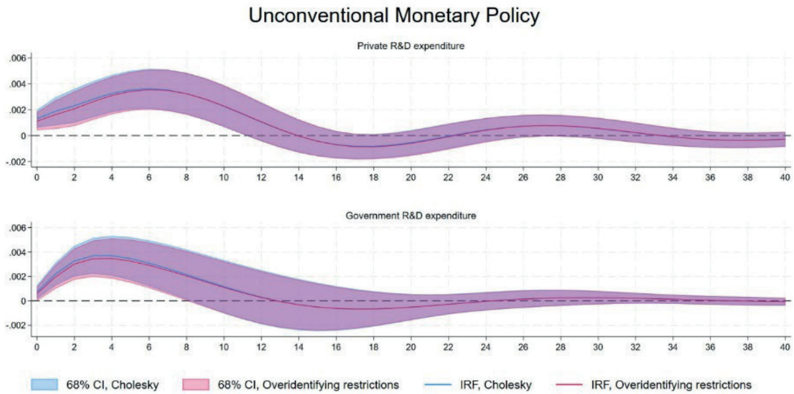
Figure 2. IRFs, monetary policy and innovation.



As for government innovations, the effects of monetary contraction in the first two years appear to be characterised by more complex nonlinearities. However, a clear decline in innovative spending emerges after two years following the monetary impulse, reaching a minimum in the twelfth quarter when both measures of monetary shocks are employed. Unlike the case of private R&D, the effects of monetary policy are persistent when government R&D is the response variable – provided that the monetary shock measure includes the systematic component. This pattern might signal that the expectations on ECB's policy rate exert different effects on private and government innovation, perhaps largely due to the role of expected returns on R&D investments, borrowing costs and fiscal constraints.

The monetary impulse in Figure 3 is given by the detrended logarithm of the ECB's total assets, whose positive shocks reflect expansionary monetary policies within the unconventional regime. Unlike the cases reported in Figure 2, we can observe a positive effect of expansionary (unconventional) monetary policy on impact, where the peak is reached faster, and the effects are offset after three years. In other words, relative to the case in which conventional monetary shocks are employed in the model, the IRFs are smoother and lean neutral in the medium- and long-run.

Figure 3. IRFs, unconventional monetary policy and innovation.



The lack of persistence in the innovation effects of unconventional monetary policy may be explained by the fact that variations in the long-run dynamics of innovative expenditure are more likely affected when the actual policy rate changes, since a mere injection of liquidity into the economy when interest rates are persistently null may not significantly alter the expected return or the borrowing costs. Such an interpretation is broadly consistent with recent empirical evidence, according to which prolonged periods of unconventional monetary policy may weaken its transmission channels (Ahmed et al., 2023) and could imply even contractionary effects of expansive monetary policy due to the phenomenon of the so-called *reversal interest rate* (Brunnermeier and Koby, 2018) – which, in the case of the present analysis, is likely to offset any long-run beneficial effect on government and private innovation activities.

7. Conclusions

The post-Covid era is so far characterised by drastic changes in the ECB's policy, as the unusual global economic scenarios and financial dynamics pose new concerns for the monetary authority. While the average productivity and growth in the Eurozone have been stagnating over the last decades, recent empirical evidence for the US suggests that innovation could be a key channel through which monetary policy transmits its effects into the real economy (Moran and Queralto, 2017; Ma and Zimmermann, 2023).

We contribute to the literature by identifying the effects of the ECB's policy on private and government innovation dynamics in the Euro Area over 2000-2021. For that purpose, we propose an SVAR framework where the identification of the structural parameters relies on a parsimonious set of exclusion restrictions –calibrated to the Eurozone's characteristics and the quarterly time-frequency of the data. The estimates support the following findings. Firstly, monetary contractions negatively affect private R&D, with a time lag between two and four quarters depending on whether the systematic monetary policy component is included (MRO vs MPS). Secondly, the negative and non-monotonic effect of monetary restrictions on government R&D tends to wear off after five years. Thirdly, unconventional monetary policy impacts public R&D faster than private spending, with a peak after four quarters; conversely, the positive effects fade away sooner (twelve quarters) compared to private R&D.

We can argue that the ECB's monetary policy transmission mechanism additionally depends, among other things, on how private and government innovation activities relate and on expected returns to R&D that ultimately depend on aggregate demand factors.

However, our findings should be interpreted parsimoniously, as they reflect the links between a common monetary policy and the aggregate innovation activity in the Euro Area. Indeed, we cannot rule out that the responses of private and government innovation within each Eurozone member are heterogeneous. As a result, the estimated dynamic effects can be seen as average country-specific responses whose weight is given by the individual innovation efforts. Accounting for the cross-country heterogeneity within the Eurozone, as well as how innovation shocks within a Eurozone country propagate across the borders, appear to be relevant issues to address in future research.

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Appendix

Figure A1. Private R&D expenditure, 2000Q1-2021-Q4.

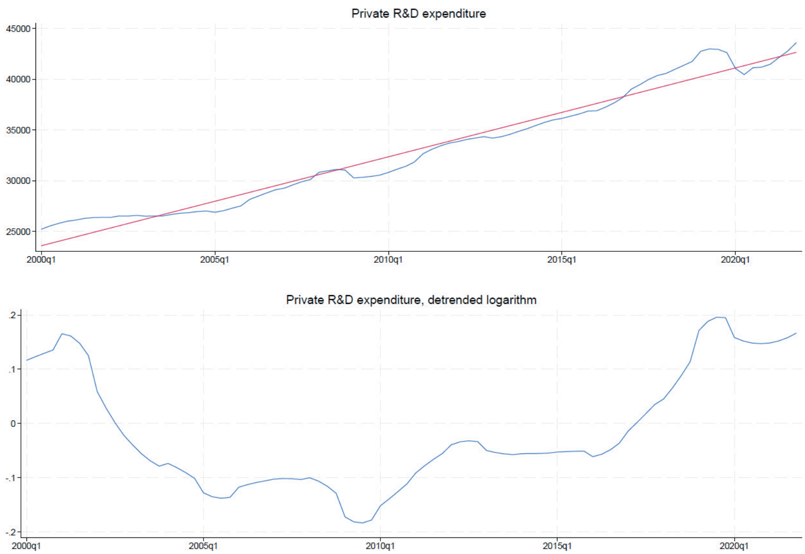


Figure A2. Government R&D expenditure, 2000Q1-2021-Q4.

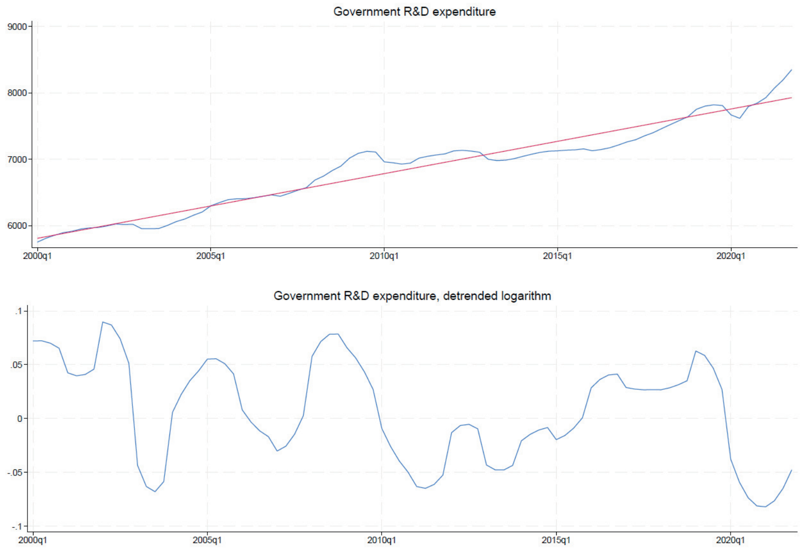


Figure A3. ECB's total assets, 2000Q1-2021-Q4.

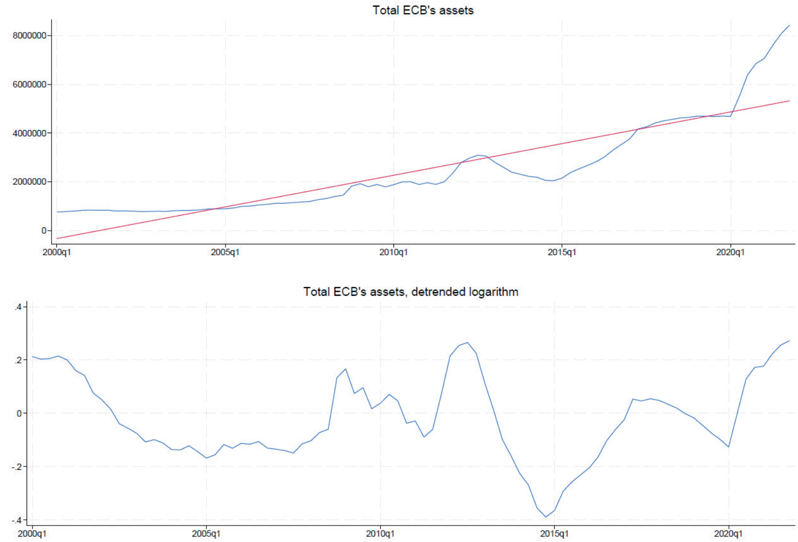


Table A1. Unit root tests, *p*-values.

	ADF	PP
Priv. R&D Exp., Lag(1)	0.1659	0.5713
Priv. R&D Exp., Lag(2)	0.1622	0.4915
Priv. R&D Exp., Lag(3)	0.0870	0.4425
Priv. R&D Exp., Lag(4)	0.3758	0.4400
Gov. R&D Exp., Lag(1)	0.7446	0.9538
Gov. R&D Exp., Lag(2)	0.6873	0.9032
Gov. R&D Exp., Lag(3)	0.6804	0.8572
Gov. R&D Exp., Lag(4)	0.8940	0.8404
ECB Assets., Lag(1)	0.9939	1.0000
ECB Assets., Lag(2)	0.9968	1.0000
ECB Assets., Lag(3)	0.9949	1.0000
ECB Assets., Lag(4)	0.9964	1.0000

Notes. We approximate the *p*-values following the approach of MacKinnon (1996). The autoregressive equations include a time-trend.

Table A2. Reduced-form variance-covariance matrix $\widehat{\boldsymbol{\Sigma}}$, MRO and private innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	3.78090040	.	.	.
(2) MRO	0.04023599	0.04153005	.	.
(3) Private innovation	0.00415228	0.00046698	0.00004627	.
(4) Inflation	0.11017114	0.01472999	-0.00053374	0.16957124

Table A3. $\widehat{\boldsymbol{A_0}}$, MRO and private innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) MRO	-0.00741475	1	0	0
(3) Private innovation	-0.00151863	-0.00799896	1	0
(4) Inflation	-0.05209786	-0.44518913	-13.89308	1
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) MRO	0	1	0	0
(3) Private innovation	-0.00151863	-0.00799889	1	0
(4) Inflation	-0.05209634	-0.44518281	-13.893081	1

Table A4. $\hat{C}$, MRO and private innovation.

	(1)	(2)	(3)	(4)
Cholesky				
(1) GDP growth	1.2041386	0	0	0
(2) MRO	0	0.15653241	0	0
(3) Private innovation	0	0	0.00556571	0
(4) Inflation	0	0	0	0.27848321
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.2041386	0	0	0
(2) MRO	0	0.15678684	0	0
(3) Private innovation	0	0	0.00556571	0
(4) Inflation	0	0	0	0.27848319

Table A5. Cholesky factor ***P***, MRO and private innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	1.20413860	0	0	0
(2) MRO	0.00892838	0.15653241	0	0
(3) Private innovation	0.00190006	0.00125210	0.00556571	0
(4) Inflation	0.09310557	0.08708202	0.07732491	0.27848321

Figure A4. IRFs, MRO and private innovation.

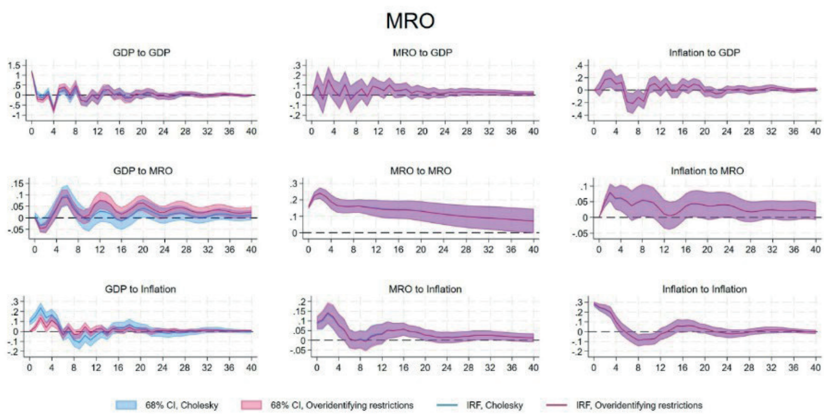


Table A6. Reduced-form variance-covariance matrix $\widehat{\boldsymbol{\Sigma}}$, monetary shock and private innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	3.47920060	.	.	.
(2) Monetary shock	0.00216797	0.00329745	.	.
(3) Private innovation	-0.00358818	0.00002630	0.00004422	.
(4) Inflation	0.14333358	0.00233572	-0.00057227	0.17272336

Table A7. $\widehat{\boldsymbol{A_0}}$, monetary shock and private innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) Monetary shock	0.00138228	1	0	0
(3) Private innovation	-0.00144592	-0.00777049	1	0
(4) Inflation	-0.07696021	-0.48829008	-14.40617	1
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) Monetary shock	0	1	0	0
(3) Private innovation	-0.0144592	-0.07770430	1	0
(4) Inflation	-0.0769601	-0.48829603	-14.40617	1

Table A8. $\widehat{C}$, monetary shock and private innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.2132425	0	0	0
(2) Monetary shock	0	0.05282746	0	0
(3) Private innovation	0	0	0.00586383	0
(4) Inflation	0	0	0	0.28613033
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.2132425	0	0	0
(2) Monetary shock	0	0.05285407	0	0
(3) Private innovation	0	0	0.00586383	0
(4) Inflation	0	0	0	0.28613031

Table A9. Cholesky factor $\boldsymbol{P}$, monetary shock and private innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	1.21324250	0	0	0
(2) Monetary shock	-0.00167705	0.05282746	0	0
(3) Private innovation	0.00174122	0.00041050	0.00586383	0
(4) Inflation	0.11763680	0.03170879	0.08447528	0.28613033

Figure A5. IRFs, monetary shock and private innovation.

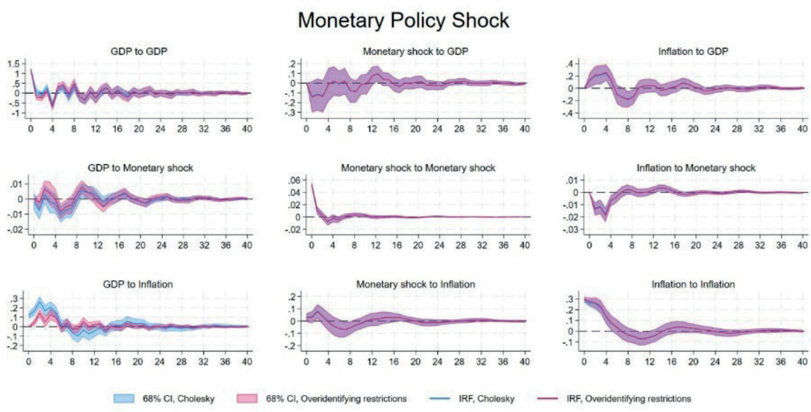


Table A10. Reduced-form variance-covariance matrix $\widehat{\boldsymbol{\Sigma}}$, MRO and government innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	4.54547650	.	.	.
(2) MRO	0.06039441	0.04238307	.	.
(3) Government innovation	0.00249698	-0.00011075	0.00003203	.
(4) Inflation	0.20618729	0.01837624	0.00032831	0.17288376

Table A11. $\widehat{\boldsymbol{A_0}}$, MRO and government innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) MRO	-0.01503926	1	0	0
(3) Government innovation	-0.00090301	0.00012075	1	0
(4) Inflation	-0.06123004	-0.45100454	-4.0446022	1
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) MRO	0	1	0	0
(3) Government innovation	-0.00090285	0.00012209	1	0
(4) Inflation	-0.06123737	-0.45106972	-4.0445846	1

Table A12. $\widehat{\boldsymbol{C}}$, MRO and government innovation.

	(1)	(2)	(3)	(4)
Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.3925683	0	0	0
(2) MRO	0	0.16248073	0	0
(3) Government innovation	0	0	0.00497546	0
(4) Inflation	0	0	0	0.29673578
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.3925683	0	0	0
(2) MRO	0	0.16382492	0	0
(3) Government innovation	0	0	0.00497546	0
(4) Inflation	0	0	0	0.2967358

Table A13. Cholesky factor $\boldsymbol{P}$, MRO and government innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	1.39256830	0	0	0
(2) MRO	0.02094319	0.16248073	0	0
(3) Government innovation	0.00125497	-0.00001962	0.00497546	0
(4) Inflation	0.09978837	0.07320020	0.02012376	0.29673578

Figure A6. IRFs, MRO and government innovation.

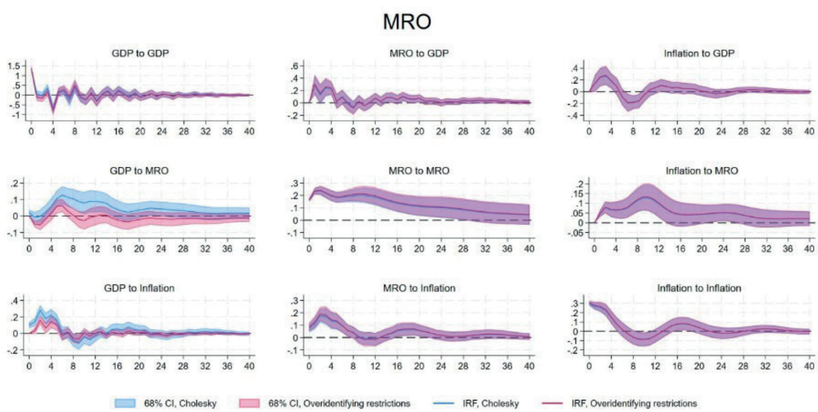


Table A14. Reduced-form variance-covariance matrix $\hat{\boldsymbol{\Sigma}}$, monetary shock and government innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	4.58863750	.	.	.
(2) Monetary shock	0.01266831	0.00307873	.	.
(3) Government innovation	0.00243603	8.738e-06	0.00003114	.
(4) Inflation	0.23529526	0.0020591	0.00029216	0.17549019

Table A15. $\widehat{\boldsymbol{A_0}}$, monetary shock and government innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) Monetary shock	-0.00626086	1	0	0
(3) Government innovation	-0.00080222	-0.00640066	1	0
(4) Inflation	-0.07318589	-0.69659237	-1.9997943	1
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) Monetary shock	0	1	0	0
(3) Government innovation	-0.00080225	-0.00640018	1	0
(4) Inflation	-0.07318053	-0.69651028	-1.9997915	1

Table A16. $\widehat{\boldsymbol{C}}$, monetary shock and government innovation.

Cholesky

	(1)	(2)	(3)	(4)
(1) GDP growth	1.4467668	0	0	0
(2) Monetary shock	0	0.04965214	0	0
(3) Government innovation	0	0	0.00503149	0
(4) Inflation	0	0	0	0.30257025

Overidentifying restrictions

	(1)	(2)	(3)	(4)
(1) GDP growth	1.4467668	0	0	0
(2) Monetary shock	0	0.0504716	0	0
(3) Government innovation	0	0	0.00503149	0
(4) Inflation	0	0	0	0.30257025

Table A17. Cholesky factor ***P***, monetary shock and government innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	1.4467668	0	0	0
(2) Monetary shock	0.0090580	0.04965214	0	0
(3) Government innovation	0.0012186	0.00031781	0.00503149	0
(4) Inflation	0.1146296	0.03522285	0.01006195	0.30257025

Figure A7. IRFs, monetary shock and government innovation.

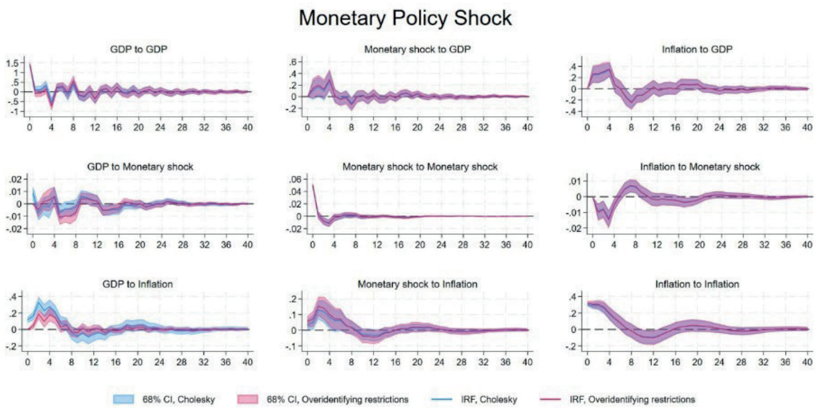


Table A18. Reduced-form variance-covariance matrix $\hat{\boldsymbol{\Sigma}}$, unconventional monetary policy and private innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	3.68618300	.	.	.
(2) ECB assets	-0.01191767	0.00170967	.	.
(3) Private innovation	0.00355609	0.00003234	0.00004437	.
(4) Inflation	0.08099991	0.00125697	0.00029321	0.14440222

Table A19. $\widehat{\boldsymbol{A_0}}$, unconventional monetary policy and private innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) ECB assets	0.00241056	1	0	0
(3) Private innovation	-0.00093329	-0.03316331	1	0
(4) Inflation	-0.01528051	-0.17292795	-5.5096182	1
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) ECB assets	0	1	0	0
(3) Private innovation	-0.00093327	-0.03316453	1	0
(4) Inflation	-0.01527929	-0.17300712	-5.5096206	1

Table A20. $\widehat{C}$, unconventional monetary policy and private innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.8582433	0	0	0
(2) ECB assets	0	0.03930434	0	0
(3) Private innovation	0	0	0.0062047	0
(4) Inflation	0	0	0	0.3573934
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.8582433	0	0	0
(2) ECB assets	0	0.03955877	0	0
(3) Private innovation	0	0	0.0062047	0
(4) Inflation	0	0	0	0.3573934

Table A21. Cholesky factor ***P***, unconventional monetary policy and private innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	1.8582433	0	0	0
(2) ECB assets	-0.0044794	0.03930434	0	0
(3) Private innovation	0.0015857	0.00130346	0.0062047	0
(4) Inflation	0.0363571	0.01397840	0.0341855	0.3573935

Figure A8. IRFs, unconventional monetary policy and private innovation.

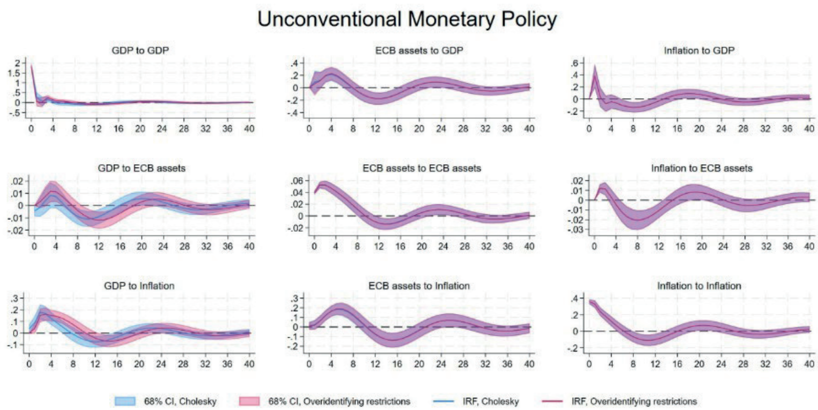


Table A22. Reduced-form variance-covariance matrix $\widehat{\boldsymbol{\Sigma}}$, unconventional monetary policy and government innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	4.51970840	.	.	.
(2) ECB assets	-0.01791064	0.00174919	.	.
(3) Government innovation	0.00277320	0.00002989	0.00002976	.
(4) Inflation	0.20154028	0.00011772	0.00026828	0.16551848

Table A23. $\widehat{A_0}$, unconventional monetary policy and government innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) ECB assets	0.00197112	1	0	0
(3) Government innovation	-0.00080777	-0.01834538	1	0
(4) Inflation	-0.04201155	-0.36882877	-3.893975	1
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1	0	0	0
(2) ECB assets	0	1	0	0
(3) Government innovation	-0.00080768	-0.01834994	1	0
(4) Inflation	-0.04201600	-0.36861883	-3.8939617	1

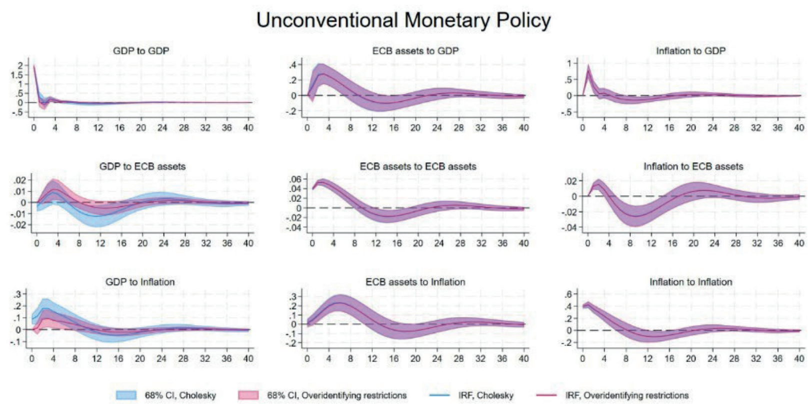
Table A24. $\widehat{\boldsymbol{C}}$, unconventional monetary policy and government innovation.

Cholesky				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.9727221	0	0	0
(2) ECB assets	0	0.03933217	0	0
(3) Government innovation	0	0	0.00509929	0
(4) Inflation	0	0	0	0.3892093
Overidentifying restrictions				
	(1)	(2)	(3)	(4)
(1) GDP growth	1.9727221	0	0	0
(2) ECB assets	0	0.03952392	0	0
(3) Government innovation	0	0	0.00509929	0
(4) Inflation	0	0	0	0.38920932

Table A25. Cholesky factor $\boldsymbol{P}$, unconventional monetary policy and government innovation.

	(1)	(2)	(3)	(4)
(1) GDP growth	1.97272210	0	0	0
(2) ECB assets	-0.00388847	0.03933217	0	0
(3) Government innovation	0.00152217	-0.00072156	0.00509929	0
(4) Inflation	0.08737020	0.01731659	0.01985651	0.3892093

Figure A9. IRFs, unconventional monetary policy and government innovation.



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