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Identification in Structural Vector Autoregressions Through Graphical Modelling and Monetary Policy: A Cross-Country Analysis

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Abstract

There is an ongoing debate on how to identify monetary policy shocks in SVAR models. Graphical modelling exploits statistical properties of data for identification and offers a data based tool to shed light on the issue. We conduct a cross-country analysis, considering European Monetary Union (EMU), Japan and US. We obtain some important results. The information set of the monetary authorities, which is essential for the identification of the monetary shock seems to depend on availability of data in terms of higher frequency with respect to the policy instrument (US and Japan). Moreover, there is not yet a widespread consensus on whether or not the European Monetary Union should be considered as a closed economy. Our results indicate that EMU official interest rate depends on the US federal funds rate.

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Introduction

Advice on the best policy after the Lucas critique (1976) is generally evaluated in theoretical dynamic stochastic general equilibrium (DSGE) models. Vector auto-regression (VAR) models are instead estimated to provide empirical evidence on how macroeconomic variables respond to policy shocks in order to discriminate between alternative theoretical models. Sims (1980), in providing the new VAR framework, proposed a Cholesky decomposition on the matrix of contemporaneous relationships in order to obtain identification, obtaining a lower or upper triangular matrix. Such particular ordering is often not supported by economic criteria. Moreover, when there is correlation among contemporaneous variables, structural inference is sensitive to the specific identifying assumptions employed.

Part of the literature on monetary policy utilising VAR models, illustrated by Christiano, Eichenbaum and Evans (1999), is not exempt from such considerations. They have utilised a block lower triangular structure based on a Cholesky decomposition on the matrix of contemporaneous relationships to obtain identification. They also assume that the monetary authority's information set includes contemporaneous observations of goods market variables, that is, the policy instrument is endogenous to the contemporaneous value of such variables. While with monthly data, this implies a minimal lag restriction on the effect of monetary policy on macroeconomic variables; with quarterly data, the issue is more debatable. Moreover, it is well known that monetary authorities obtain quarterly measures on GDP and GDP deflator only with a delay.

A different perspective, for instance, is offered by Kim and Roubini (2000), amongst others. They argue that the information set of the monetary authorities depends on the availability of data in terms of higher frequency with respect to the policy instrument and adopt a structural vector autoregression (SVAR), where the matrix of the contemporaneous relationships derived to obtain identification is sparse.

Graphical Modelling (GM) is a relatively recent tool, which enables obtaining identification of SVARs, see Oxley et al. (2009). GM is a data oriented method based on the analysis of partial correlations among variables which gives rise to a conditional independence graph (CIG). In a subsequent step, all the information embodied in the relationships among the random variables in the system is utilised in a systematic way in order to obtain identification. This procedure allows reducing the number of potential SVARs originating from a unique reduced form.

The aim of the paper is to provide a data oriented perspective on identification in monetary SVARs. For our purposes, we will consider three different G-7 economies: the US, Germany till the end of 1998 and European Monetary Union (EMU) afterwards and Japan. The US undoubtedly represents a closed economy, while Japan an open economy. For EMU, we will be agnostic, potentially considering it as an open economy. For the US, our approach to identification will possibly shed light on the ongoing debate existing in the extensive literature. For Japan, it will also allow to highlight its dependence from foreign markets, since a variable is used as a proxy of its openness. Finally for EMU, which a priori has the same setting of Japan, our approach will also enable determining if it can be considered a closed or an open economy, which is still a matter of debate.

The paper is organized as follows. Section 2 make a brief overview on the strategy of identification adopted in VAR models, and in particular, in monetary VAR models. In Section 3 we discuss our econometric methodology. Section 4 describes the model. In section 5 we illustrate and discuss the empirical results. Section 6 concludes.

1. Analysing Monetary Policy in SVARs: A Brief Overview

The VAR is a simple framework which provides a systematic way to capture rich dynamics in multiple time series. It presents three varieties: reduced, recursive and structural.

The *p*th order vector autoregressive model, *m* dimensional time series $x_t = \left(x_{t,1}, x_{t,2}, ... x_{t,m}\right)'$ in reduced form can be expressed as:

$$x_t = c + A_1 x_{t-1} + A_2 x_{t-2} + ... + A_p x_{t-p} + e_t$$

where c allows for a non-zero mean of x_t, each variable is expressed as a linear function of its own past values, the past values of all other variables being considered and a serially uncorrelated error term e_t, whose covariance matrix *V* is generally not diagonal. The order p, for example, may be determined by the minimization of an order selection criterion such as the Akaike (AIC), Hannan and Quinn (HIQ) and Schwarz (SIC) information criteria.

The recursive VAR can be expressed as:

$$B_0 x_t = d + B_1 x_{t-1} + B_2 x_{t-2} + ... + B_p x_{t-p} + u_t$$

Where $B_i = B_0 A_i$ for *i* =1,…, *p*, $d = B_0 c$ and $u_t = B_0 e_t$ with covariance matrix $B_0 V B_0' = D$, which is assumed to be diagonal. Identifying assumptions typically motivated by subjective opinion on macroeconomic dynamics are expressed with reference to the contemporaneous relationships on the matrix B_0 in a recursive manner, such that B_0 results in a lower or upper triangular matrix, as pioneered by Sims (1980). Given the correlation among contemporaneous variables, the results depend on the ordering of the variables and there are *m*! recursive VARs representing all possible orderings.

The structural vector auto-regression (SVAR), pioneered by Blanchard and Watson (1986), Bernanke (1986) and Sims (1986), makes a greater use of economic theory for identification, involving the entire VAR so that all of the causal links among contemporaneous variables are specified, or just a single equation, so that only a specific causal link is identified. In this case the matrix B_0 of contemporaneous relationships derived to obtain identification is sparse.

Blanchard and Quah (1989), amongst others, have utilised a different approach to identification concerned with assumptions expressed with reference to the long run properties of the shocks.

The imposition of short run restrictions to obtain identification is complex and contentious, especially for monetary policy shocks. As documented by Christiano, Eichenbaum and Evans (1999), there is no consensus on theories of contemporaneous dependence for identifying the effects of an exogenous shock to monetary policy. They are essentially based on the perceived institutional arrangements and operational procedures implemented by the decision-makers.

The literature which has utilised the VAR framework has focused its attention on identifying schemes that allows the researcher to estimate the rule which relates policymakers' actions to the state of the economy which imply a division of the variables into three sets:

1. X_{1t}: the information set, that is, the block of variables for which the value is known when the policy is set and therefore constituted by the variables observed by the monetary authorities in setting its operating instrument
2. The policy instrument
3. X_{2t}: The block of variables whose value is known only when the policy is set

Such identification scheme represent a block recursive structure based on a Cholesky decomposition, where it is assumed that the operating instrument impacts on the first block with a lag delay, while is predetermined with respect to the contemporaneous variables whose value is known only when the policy is set and therefore has a contemporaneous effect on them. The policy instrument is often assumed to be constituted by the central bank's official interest rate, after the seminal work of Bernanke and Blinder (1992). In such block recursive VARs, it is possible to show that the impulse-response functions and variance decomposition are invariant to the order of the variables within the two blocks[1]. With these kinds of statistical identifying assumptions, Christiano et al. (2005), amongst others, assume that further than lagged values of the variables present in the model, the information set is constituted by the contemporaneous value of variables present in the goods market.

A different view has also emerged in the literature regarding the imposition of restrictions on contemporaneous relationship in SVARs, strictly based on the timing of the availability of information on the variables of interest. In this case

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[1] See Christiano, Eichenbaum and Evans (1999).

the monetary authority's information set would be constituted by only higher frequency data with respect to the policy instrument, see Kim and Roubini, (2000) and Garratt et al., (2003), amongst others.

2. Graphical Modelling and SVARs

In this section we will first illustrate the general ideas behind the GM approach for then describing its extension to the SVAR framework.

Graphical modelling is a relatively recent statistical approach aiming at uncovering statistical causation from partial correlations observed in the data. Primal contributions to the methodology are due to Dempster (1972) and Darroch, Lauritzen and Speed (1980).

The first step of the procedure is to compute the partial correlation between any two variables given all the remaining variables, which can be tested using an appropriate statistics. This will give rise to the CIG as in figure 1A, where random variables are represented by nodes and a significant partial correlation by a line called edge. In this case, for example, the edge connecting nodes A and B represents a significant partial correlation between A and B conditioned on C.

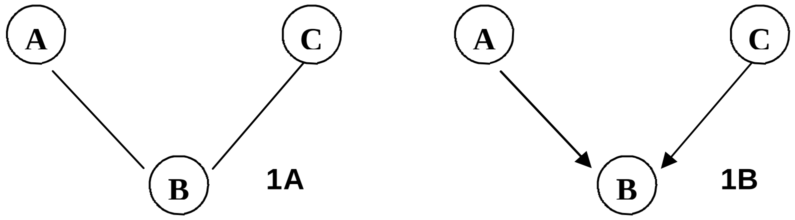

Figure 1: CIG and one of the potential corresponding DAGs

A significant partial correlation implies conditional dependence if the variables are jointly distributed as a multivariate Gaussian distribution. This is why the undirected graph is called conditional independence graph.

In the linear least square context, the variables included in a CIG can be characterized by relationships in terms of linear predictability, obtaining a Directed Acyclic Graph (DAG), which is therefore more informative. In the DAG in figure 1B, for example, A has predictive power on B. What we can observe is the CIG, where every edge can assume two possible directions, therefore there are 2^n possible DAGs, where n is the number of edges. There are two statistically based general rules, which allow to reduce the number of potential DAGs. First, the moralization rule that considering for example the CIG in figure 1A, allows to exclude the DAG in Figure 1B, in which A and C have predictive power on B, since, statistically, a significant partial correlation between A and C should be observed in the CIG in figure 1A. An example should provide a more intuitive insight into the moralization rule: we have a friend that we have not seen for a long time, who is nowadays a football

player. To be a good football player (P), he must have good skills (S) and/or must work hard (W). Therefore S and W have predictive power on P. We know that he didn't have good skills. The only think we can deduce is that he worked hard. This example shows that S and W are correlated given P.
Second, any DAG has to satisfy the principle of acyclicality, since this allows completely determining the distribution of a set of variables. Figure 2 shows a CIG with a corresponding DAG which can be excluded given its cyclicality.

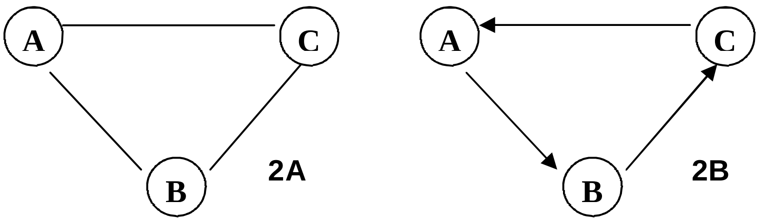

Figure 2: CIG with a corresponding cyclical DAG.

The acyclicality in a DAG implies a recursive ordering of the variables. However such lower or upper triangular matrix, in most cases will be sparse, where each element in turn depends on none, one or more elements.
Given the moralization rule, there is always a unique CIG deriving from a given DAG, obtained by transforming arrows into undirected edges and linking unlinked parents of a common child with a *moral edge.* In the DAG shown in Figure 1.A, A and C are the *parents* of B. In order to obtain the corresponding unique CIG we must transform arrows into edges and add a moral edge between parents A and C as in figure 2A.
The SVAR, as shown by Oxley et al. (2009), amongst others, can be represented by a DAG, where current and lagged variables are represented by nodes and dependence by arrows. The first step in constructing the SVAR is the determination of the lag order through the minimization of an order selection criterion.
Once determined the lag order, in order to construct the CIG among contemporaneous variables conditioned on all the remaining contemporaneous and lagged variables, we need to derive the sample partial correlation between the contemporaneous variables, calculated from the inverse $\hat{W}$ of the sample covariance matrix $\hat{V}$ of the whole set of variables as:

$$\hat{\rho}\left(x_{i,t,}x_{j,t} \middle| \{x_{k,t-w}\}\right) = -\hat{W}_{rs} / \sqrt{(\hat{W}_{rr}\hat{W}_{ss})}$$

where $\{x_{k,t-w}\}$ is the whole set of variables excluding the two variables considered and where *r* and *s* index the variables $x_{i,t}$ and $x_{j,t}$ in the matrices $\hat{V}$ and $\hat{W}$.
The critical value utilised to test for the significance of the sample partial correlations is calculated utilising the relationship between a regression t-

value and the sample partial correlation, as shown by Greene (1993), and considering the asymptotic normal distribution of the t value for time series regression coefficients. It is given by:

$$\frac{z}{\sqrt{(z^2+v)}}$$

where v are the residual degrees of freedom obtained as a regression of one variable on all the remaining variables and z represents a critical value at a chosen significance level of the standard normal distribution. Whenever a sample partial correlation is greater than the calculated critical value, a link in the CIG is retained. The next step is to consider all the admissible DAGs for an evaluation from a likelihood perspective.

Often, different competing SVARs have distributional properties for the variables which are likelihood equivalent, i.e. they may yield the same information criterion. Hence, in order to determine the contemporaneous relationships needed to obtain identification, the partial correlation between contemporaneous and lagged variables are also computed, for then considering only the lagged values where a significant partial correlation appears. In these circumstances it is possible to obtain an evaluation of the contemporaneous relationships based on information criterion.

We will subsequently consider and conduct our diagnostic checks on the model in which all lags are included, since this is the kind of hypothesis assumed in the literature. For example, in order to obtain identification of the structural shocks, we assume that the correlation matrix of the residuals, in the SVAR chosen, is diagonal. A first diagnostic check is thus inspecting the significance of such correlations. Moreover, as this procedure typically imposes over-identifying restrictions, a χ^2 likelihood-ratio test can also be conducted.

Granger and Swanson (1997) have applied a similar strategy to sort out an order among contemporaneous variables, based on the partial correlations of the innovations derived from the reduced form, applying a general residual orthogonalization to the innovations. GM offers a systematic way to the residual ortogonalization, which is needed to obtain identification in SVAR models.

3. Model Specification and Data

The solution of a DSGE model can be approximated by a restricted VAR. It seems natural to utilise in an unrestricted VAR the same variables generally utilised in a DSGE model. This is why we will consider for all countries a measure of the GDP, price level and interest rate. A commodity price index is also added to solve the price puzzle. This setting for the US, which is a closed economy, according to the literature can represent a good approximation to the true data generating process in a SVAR framework. Although, as we will see below, we will conduct a different strategy to our methodology for Japan and EMU[2], we need to introduce at least one variable indicating their openness. The US federal funds rate, according to Favero and Giavazzi (2008), can be a good proxy of the openness of a country and is therefore considered for Canada and EMU.

For all countries we utilise the log of real GDP, the producer price index and the GDP deflator. As policy instrument we consider the federal funds rate for US. For EMU and Japan we utilise the discount rate[3]. The federal funds rate is also considered for EMU and Japan, for the reason explained above.

For US, we use quarterly data over the period 1959:1-2006:4. For the other two countries, we need to take into account the Bretton Woods fixed exchange rate regime, that would possibly reveal a connection to the US interest rate in which we are not interested. Moreover, although Germany has operated in a fixed but flexible exchange rate regime with other European central banks, it has acted as a leader, as shown by Giavazzi and Giovannini (1988), which also strengthens our hypothesis for the EMU setting. Therefore, we consider as representative of EMU, quarterly German data over the period 1976:1-1998-4[4], for then considering EMU series referring to the same variables till 2006:4, see Favero and Giavazzi (2008), for a similar strategy. For Japan we consider quarterly data over the period 1972:1-2006:4.

All data except the interest rates are seasonally adjusted. The data are extracted from the IMF database in its International Financial Statistics, with the exception for Germany and EMU of the GDP deflators which are taken from the OECD database[5] and the producer price indexes for Germany and EMU which are taken respectively from the Eurostat[6] and OECD databases.

4. Empirical Results

We consider the variables in levels as in Christiano et al. (2005). The comparison between different countries, although the possible differences in the institutional setting may highlight some common characteristics of the different central banks

For US, AIC indicates a lag order of 4, while SIC and HIC suggest 2 lags. We prefer to use 4 lags, since the consequences of overestimation of the order are less serious than underestimation, see Kilian (2001). In order to construct the CIG, we compute the partial correlations between variables at 10% significance level giving rise to the CIG in figure 3:

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[2] We give for certain that Japan is an open economy, while for EMU we do not exclude it on a priori ground.

[3] For Germany the discount rate has been considered as well.

[4] It starts from 1976, since we have not found all series available from the 1972.

[5] In the IMF GDP deflator there is a clear jump due to Germany reunification, while this jump has been smoothed out in the OECD data.

[6] This is, to our knowledge, the longer series available.

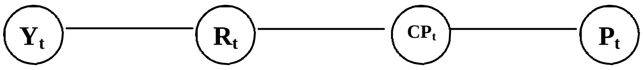

Figure 3: CIG derived for US

The interest rate (R_t) is connected to output (Y_t) and commodity price (CP_t), and there is a further connection between CP_t and the price level (P_t). We need to establish to which contemporaneous variable the interest rate is endogenous, if any, and the direction in the relationship between CP_t and P_t. We have 2^3 possible SVAR. They are shown in figure 4.

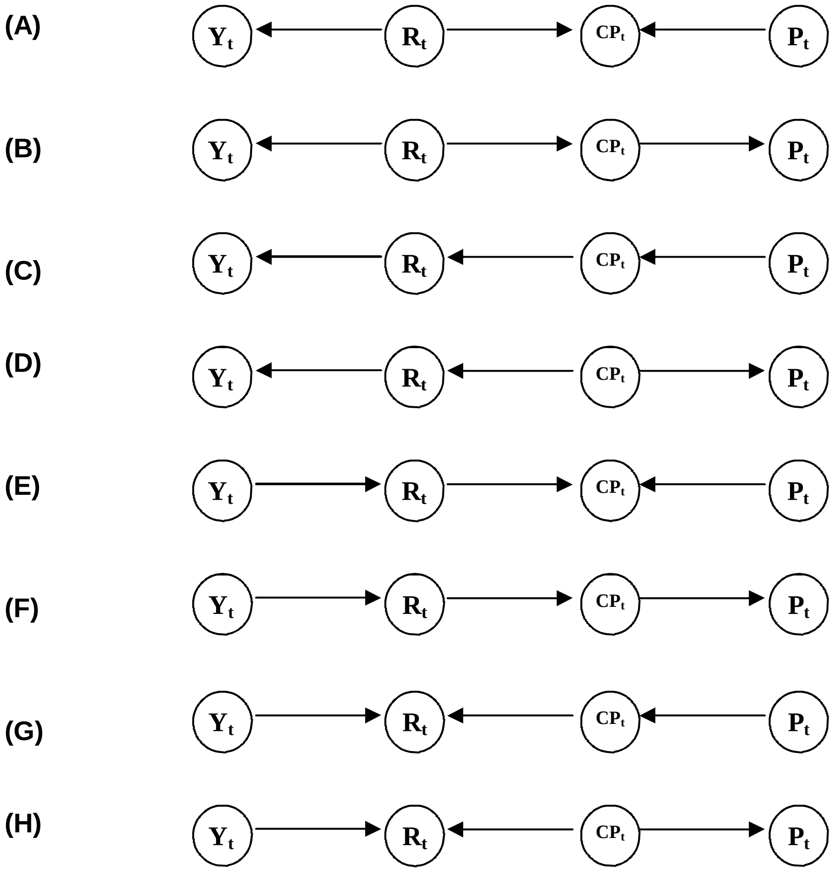

Figure 4: DAGS deriving from the CIG in figure 3

DAGS (A), (E), (G), and (H) can be excluded following the moralization rule. We need to evaluate the four remaining potential SVARs. Table 1 shows AIC, HIC and SIC of the four remaining SVARs.

MODEL	AIC	HIC	SIC
B	646.47	675.32	717.67
C	623.78	652.63	694.98
D	628.76	657.61	699.96
F	640.15	669.00	711.36

Potential SVARs for US

Table 1: Information Criteria of the possible SVAR for US

The contemporaneous relationship indicated in the DAG (C) is the best performing from a likelihood perspective.

R_t is solely endogenous to CP_t. and has a contemporaneous effect on Y_t, which is economically plausible at quarterly frequency and a common assumption in DSGE models. P_t drives CP_t and is economically plausible, if we think that P_t can be a proxy of the unit costs which impact on CP_t.

Table 2 shows the correlation of the structural errors for model (C), with a critical value at 5% equal approximately to 0.146. They are all statistically not different from zero.

	u^Y	u^R	u^{CP}	u^P
u^Y	1.000	*	*	*
u^R	0.015	1.000	*	*
u^{CP}	-0.035	-0.027	1.000	*
u^P	-0.099	0.047	0.000	1.000

Table 2: Correlation between structural errors of the US model.

We also fail, as expected, to reject the likelihood-ratio test for the three over-identifying restrictions with a p-value equal to 0.39.

For Japan the AIC indicates a lag order of 4. Computing the partial correlations, we obtain for the contemporaneous relationships, the CIG in figure 5:

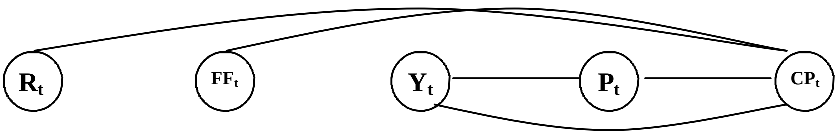

Figure 5: CIG derived for Japan

Japan's interest rate (R_t) and the US federal funds rate (FF_t), are connected to the only commodity price (CP_t), while output (Y_t), the price level (P_t) and

CP_t are all connected to each other. Theoretically we have 2^5 possible SVARs. But we take for given that is FF_t to have predictive power on CP_t. This allows reducing sensibly the number of potential SVARs. Because of the moralization rule, it is CP_t to have predictive power on R_t, since in the opposite case, there should be a significant partial correlation (edge) between R_t and FF_t. For the same reasons, CP_t has predictive power on Y_t and P_t. The only direction we need to establish is the one between Y_t and P_t, giving rise to the DAGs shown in figure 6:

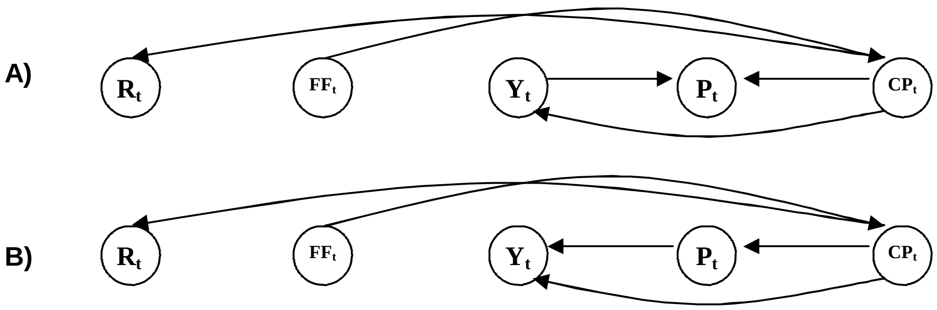

Figure 6: DAGS deriving from the CIG in figure 5

Table 3 shows AIC, HIC and SIC of the two potential SVARs.

MODEL	AIC	HIC	SIC
A	-372.44	-325.82	-257.71
B	-371.10	-324.48	-256.38

Potential SVARs for Japan

Table 3: Information Criteria of the possible SVARs for Japan

The information criteria suggest that is Y_t to have predictive power on P_t, which is economically plausible. In this case the contemporaneous CP has predictive power on all the other variables, with the exception of FF_t, which is economically plausible and of which it is important to highlight that also in this case the policy instrument depend only on the contemporaneous value of CP_t. Table 4 show the correlations between the structural errors, with a critical value at 5% equal approximately to 0.169. Also in this case, they are all statistically not different from zero. The likelihood-ratio test for the five over-identifying restrictions has a p-value equal to 0.31.

	u^R	u^{FF}	u^Y	u^P	u^{CP}
u^R	1	*	*	*	*
u^{FF}	0.069	1	*	*	*
u^Y	0.089	0.084	1	*	*
u^P	-0.087	0.130	-0.000	1	*
u^{CP}	-0.012	0.000	-0.016	-0.023	1

Table 4: Correlation between structural errors of Japan model.

Finally, we need to consider the EMU. The AIC suggests two lags. Figure 7 shows the resulting CIG:

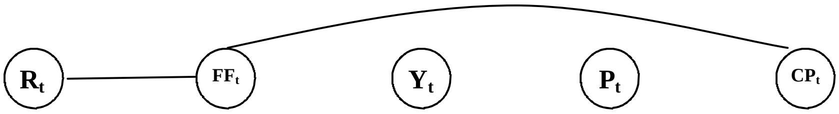

Figure 7: CIG derived for EMU

Y_t and P_t result exogenous to the contemporaneous value of the other variables present in the model. There is a connection between FF_t and CP_t, but more interestingly there is a contemporaneous relationship between EMU's policy instrument R_t and the US federal funds rate. Many would argue that on a priori ground we can give a direction to the two relationships, that is, FF_t has predictive power on both the other variables, but we want to be agnostic, relying on the information criteria in the choice of the best SVAR. We have 2^2 possible SVARs indicated in figure 8:

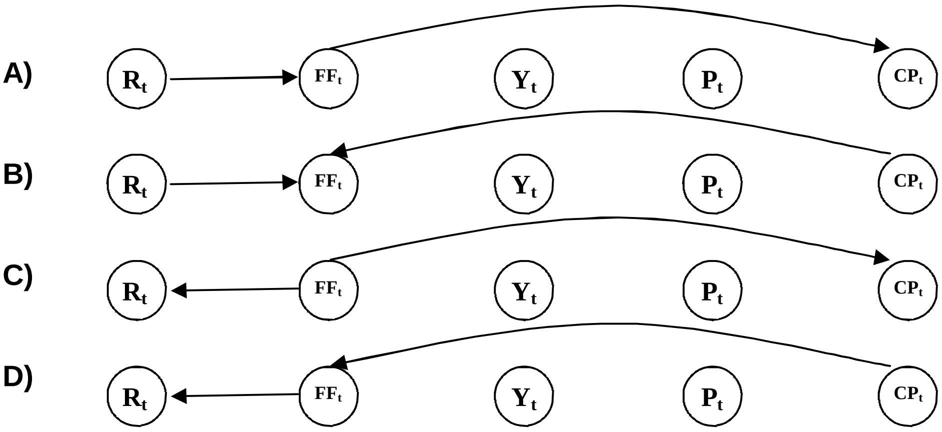

Figure 8: DAGS deriving from the CIG in figure 7

Model B can be excluded because of the moralization rule. Table 5 shows AIC, HIC and SIC of the three remaining potential SVARs:

MODEL	**AIC**	**HIC**	**SIC**
A	-746.84	-728.51	-701.72
C	-759.78	-741.45	-714.6546
D	-752.15	-733.82	-707.03

Potential SVARs for EMU

Table 5: Information Criteria of the possible SVARs for EMU

All the information criterion incontrovertibly show (model C) that is the federal funds rate to have predictive power on the EMU interest rate and the commodity price (model C) as we would have expected, showing the consistency of GM in determining the contemporaneous relationships for identification.

Table 6 shows the correlation between the structural errors, with a critical value at 5% equal approximately to 0.179. Also in this case, they are all statistically not different from zero. The likelihood-ratio test for the eight over-identifying restrictions has a p-value equal to 0.82.

	u^R	u^{FF}	u^Y	u^P	u^{CP}
u^R	1	*	*	*	*
u^{FF}	0.000	1	*	*	*
u^Y	0.041	0.042	1	*	*
u^P	0.051	-0.154	-0.077	1	*
u^{CP}	0.014	0.000	-0.051	0.145	1

Table 6: Correlation between structural errors of EMU model.

There are some important results to highlight. First, these results indicate that the monetary authority's decision may not depend on contemporaneous output and GDP deflator. For US and Japan, it is determined by the contemporaneous value of commodity price. The information set of the monetary authority seems to be conditioned by the availability of data in terms of frequency, given that the producer price index is available at monthly frequency, while GDP and GDP deflator are available at quarterly frequency with a delay. Results also indicate that a Cholesky decomposition, where every variable is connected to all the other variables, may not be appropriate for identification. Finally, although in the literature some researchers have modelled EMU as a closed economy, see Smets and Wouters (2004), amongst others, our results confirm the findings of Favero and Giavazzi (2008): EMU can probably not be considered a closed economy, given that in our setting for EMU, contemporaneous US federal funds rate has predictive power on the European contemporaneous discount rate.

5. Conclusions

On the base of the models employed, our results appear to be more in line with Kim and Roubini (2000), who argue that we need to consider the contemporaneous interest rate endogenous to the contemporaneous value of variables available at higher frequency. Moreover, they consider a structural vector autoregressions rather that a Cholesky decomposition in order to identify their model, as in our case. As a robustness check, it would be interesting to apply GM for obtaining identification with the Factor Augmented Vector Autoregression (FAVAR), where a greater number of time series can be used, since monetary authorities make use of many economic time series to extract information on expected inflation. It will be, however, object of future research. It is our hope that this paper also shows that GM, when integrated with economic priors, can represent a valid identifying scheme.

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