EUROPEAN CENTRAL BANK

WORKING PAPER SERIES
NO 632 / MAY 2006

BCE ECB EZB EKT EKP

DOES INFORMATION HELP RECOVERING STRUCTURAL SHOCKS FROM PAST OBSERVATIONS?

by Domenico Giannone
and Lucrezia Reichlin

EUROPEAN CENTRAL BANK

WORKING PAPER SERIES

NO 632 / MAY 2006

DOES INFORMATION HELP RECOVERING STRUCTURAL SHOCKS FROM PAST OBSERVATIONS? [1]

by Domenico Giannone [2]
and Lucrezia Reichlin [3]

In 2006 all ECB publications will feature a motif taken from the €5 banknote.

1 Acknowledgements: Giannone was supported by a PAI contract of the Belgian Federal Government and an ARC grant of the Communaute Francaise de Belgique. The opinions in this paper are those of the authors and do not necessarily reflect the views of the European Central Bank.

2 ECARES, Université Libre de Bruxelles - CP 114 - av. Jeanne, 44, B-1050, Brussels, Belgium; e-mail: dgiannon@ulb.ac.be

3 CEPR and European Central Bank, Kaiserstrasse 29, 60311 Frankfurt am Main, Germany; e-mail: lucrezia.reichlin@ecb.int

Address
Kaiserstrasse 29
60311 Frankfurt am Main, Germany

Postal address
Postfach 16 03 19
60066 Frankfurt am Main, Germany

Telephone
+49 69 1344 0

Internet
http://www.ecb.int

Fax
+49 69 1344 6000

Telex
411 144 ecb d

ISSN 1561-0810 (print)
ISSN 1725-2806 (online)

CONTENTS

Abstract

This paper asks two questions. First, can we detect empirically whether the shocks recovered from the estimates of a structural VAR are truly structural? Second, can the problem of non-fundamentalness be solved by considering additional information? The answer to the first question is “yes” and that to the second is “under some conditions”.

JEL Classification: C32, C33, E00, E32, O3.

Keywords: Identification, Information, Invertibility, Structural VAR.

Non Technical Abstract

Structural Vector Autoregressive Models (SVAR) are a very useful tool in applied macroeconomics since they are simple, flexible and robust to model misspecification. Moreover, under some conditions, the linearized solution of dynamic stochastic general equilibrium models (DSGE) can be approximated by a finite autoregressive model (VAR) so that SVARs can be used to match models to data.

However, if the structural model has a moving average (MA) component, the conditions under which the VAR representation is admissible may not be verified. In that case, the shocks are non-fundamental and there is no hope to recover the structural shocks from VAR estimation. This point was first made by Hansen and Sargent (1991) and Lippi and Reichlin (1993, 1994) and recently brought back in the macroeconomic debate by Chari et al. (2005), Christiano et al. (2005) and Fernandez-Villaverde et al. (2005).

This paper asks two questions. First, can we detect empirically whether the shocks recovered from the estimates of a structural VAR are truly structural? Second, can we solve the problem by considering additional information? The answer the paper provides to the first question is "yes" and that to the second is "under some conditions".

The paper illustrates these points on the basis of an empirical example where the aim is to study the effect of technology shocks on hours worked, in the spirit of Gali (1999) and Christiano et al. (2004). It concludes that the technology shock identified a' la Gali and estimated from a VAR on the growth of aggregate labor productivity and aggregate hours worked is non structural. It is also shown that the contemporaneous response of aggregated hours worked to technological shocks is not significantly different from zero when estimating the shocks from a model including sectoral hours and sectoral labor productivity, whereas it is negative if the shocks are estimated on the basis of aggregate variables alone.

1 Introduction

Structural Vector Autoregressive Models (SVAR) are a very useful tool in applied macroeconomics since they are simple, flexible and robust to model misspecification. Moreover, under some conditions, the linearized solution of dynamic stochastic general equilibrium models (DSGE) can be approximated by a finite autoregressive model (VAR) so that SVARs can be used to match models to data.

Predictions from different DSGE models can be compared empirically using the VAR tool with which a linear combination of the structural shocks are estimated as residuals of OLS regressions and then identified by imposing a set of restrictions. If such restrictions are verified by a broad class of models, different predictions of models within that class can be compared by looking at the estimated shocks and their coefficients (impulse response functions).

However, if the structural model has a moving average (MA) component, the VAR representation is admissible only under some conditions which may not be verified by the structural model. In that case, there is no hope to recover the structural shocks from VAR estimation. This point was first made by Hansen and Sargent (1991) and Lippi and Reichlin (1993, 1994) and recently brought back in the macroeconomic debate by Chari et al. (2005), Christiano et al. (2005) and Fernandez-Villaverde et al. (2005).

This paper asks two questions. First, can we detect empirically whether the shocks recovered from the estimates of a structural VAR are truly structural? Second, can the problem of non-fundamentalness be solved by considering additional information?

We will go through the analysis via an empirical application where we use aggregate and sectoral data for US manufacturing industries to study the effect of technology shocks on hours worked, in the spirit of Gali (1999) and Christiano et al. (2004).

2 SVAR and their critics

Suppose that the equilibrium solution of a "true" structural model links a number m of observable variables to a number q of structural shocks:

$$X_t^* = B^*(L)u_t^* \tag{2.1}$$

where X_t^* is an m-dimensional vector of observable macroeconomic variables, u_t^* is a q-dimensional vectors of shocks, white noise with unit variance, whose propagation is captured by $B^*(L) = B_0^* + B_1^*L + B_2^*L^2 + ...$, an $m \times q$ matrix of moving average filters. In general, the number of shocks, q, can be equal to or different from the number of observable variables m.

The objective of the econometrician is to make inference on the responses of the observable variables X_t^* to the shocks, i.e. the impulse response function:

$$B_h^* = \partial X_{t+h}^* / \partial u_t^*, h = 0, 1, 2, ...$$

SVAR modelling consists in two steps. First, one estimates a VAR:

$$A^*(L)X_t^* = \varepsilon_t^* \tag{2.2}$$

where $A^*(L) = A_0 + A_1^* L + ... + A_p^* L^p$ is an $m \times m$ filter of finite length p, A_0 is normalized to be lower triangular, and ε_t^* is an m-dimensional vector of orthogonal innovations.

The second step consists in inverting and rotating the VAR representation (2.2). Denoting by R a rotation matrix ($R'R = I_m$), from

$$X_t^* = [A^*(L)^{-1} R] \quad [R' \epsilon_t^*]$$

we get the impulse response to the structural shocks $R'\varepsilon_t^*$.

Condition for the procedure to recover u_t^* is the existence of a filter $N(L) = N_0 + N_1 L + N_2 L^2 + ...$ such that: $N(L)B^*(L) = I_m$. In this case we have:

$$N(L)X_t^* = N(L)B^*(L)u^*(L) = u_t^*$$

that is, the structural shocks u_t^* can be extracted from present and past observations $X_t^*, X_{t-1}^*, ...$ (u_t^* is fundamental with respect to X_t^*). In this case, the filter $A^*(L)$ and the innovations ϵ_t^*, in the finite VAR representation (2.2), are an approximation of $RN(L)$ and Ru_t^*, respectively. Notice that for such filter to exists, the number of structural shocks, q, should be less or equal to the number of observable macroeconomic variables m. Following the SVAR tradition, we will assume from now on that there are as many shocks as variables ($m = q$), but the discussion holds, with minor modifications, for $m > q$[1].

There are three possible situations in which such approximation does not work:

1. The roots of det$B^*(L)$ are on the unit circle. In this case, known as non-invertibility, the VAR representation does not work since an infinite number of lags of the observables $p = \infty$ is needed to recover the structural shocks. This situation might occur, for example, if some variables are over-differenced (see for example Christiano et al., 2004).

2. The roots of det$B^*(L)$ are inside the unit circle. In this case, the system is said to be non-fundamental, (see Hansen and Sargent, 1991; Lippi and Reichlin, 1993), and the impulse response functions cannot be recovered even with an infinite past of the observable variables ($p = \infty$).

3. The roots of det$B^*(L)$ are outside the unit circle. In this case the number of lags (p) necessary to recover the structural shock maybe very large. This might happen, for example, when some state variables are not included in the set of observable variables, (see for example Chari et al., 2005; Cooley and Dwyer, 1998).

From now on we will discuss case 2 (non-fundamentalness) which is the hardest case.

[1] If there are more shocks than variables, $m < q$, there is no hope to recover the structural shocks from a finite number of variables.

3 A well known empirical example

We consider, as an example, the empirical model introduced by Gali (1999) which is a VAR on aggregate labor productivity (y_t) and aggregate labor input, hours (h_t), whose corresponding structural MA representation is:

$$\underbrace{\begin{pmatrix} \Delta y_t \\ \Delta h_t \end{pmatrix}}_{X_t^*} = \underbrace{\begin{pmatrix} b_{11}^*(L) & b_{12}^*(L) \\ b_{21}^*(L) & b_{22}^*(L) \end{pmatrix}}_{B^*(L)} \underbrace{\begin{pmatrix} u_{1t}^* \\ u_{2t}^* \end{pmatrix}}_{u_t^*.} \tag{3.3}$$

Here u_{1t}^* is the technology shock and u_{2t}^* is the non technological shock. We are interested in the responses of hours worked to productivity shocks since this allows us to assess the empirical relevance of price stickiness in the economy. In particular, the contemporaneous response of hours to productivity shocks is expected to be negative in a sticky price economy and positive in a flexible price economy (see for example Gali, 1999; Christiano et al., 2004; Chari et al., 2005).

The system is identified by assuming that only technological shocks can affect the long run level of productivity

$$b_{12}^*(1) = \lim_{s \to \infty} \partial y_{t+s} / \partial u_{2t}^* = 0.$$

4 Is non-fundamentalness detectable?

Let us consider a system in which the set of variables of interest X_t^* is augmented with blocks of additional variables, $X_{1t}, ..., X_{kt}$. The general representation is:

$$\begin{pmatrix} X_t^* \\ X_{1t} \\ ... \\ X_{kt} \end{pmatrix} = \begin{pmatrix} B^*(L) & \Psi^*(L) \\ B_1(L) & \Psi_1(L) \\ ... & ... \\ B_k(L) & \Psi_k(L) \end{pmatrix} \begin{pmatrix} u_t^* \\ v_t \end{pmatrix} \tag{4.4}$$

where v_t are additional structural shocks, orthogonal to the shocks of interest u_t^*. The model (2.1) implies the restriction $\Psi^*(L) = 0$, i.e. that the additional shocks v_t are specific to the added variables. In a compact form the system (4.4) can be rewritten as:

$$\begin{pmatrix} X_t^* \\ X_t \end{pmatrix} = \begin{pmatrix} B^*(L) & 0 \\ B(L) & \Psi(L) \end{pmatrix} \begin{pmatrix} u_t^* \\ v_t \end{pmatrix}$$

where $X_t = (X_{1t}', ..., X_{kt}')'$ is a vector of additional variables of dimension n, $B(L) = (B_1(L), ..., B_k(L))'$ and $\Psi(L) = (\Psi_1(L), ..., \Psi_k(L))'$.

Non-fundamentalness can be easily detected by looking at this larger system. Precisely, if u_t^* is fundamental with respect to X_t^*, then the structural shocks can be recovered from the past of the observables, $u_t^* = N(L)X_t^*$. This implies:

$$X_{it} = B_i(L)N(L)X_t^* + \Psi_i(L)v_t.$$

Since v_t is orthogonal to X_t^*, then X_{it} depends only on the past of X_t^* . It hence follows that X_{it} does not Granger cause X_t^* (Sims, 1972). This proves the following[2]:

Proposition If any of $X_{it}, i = 1, ..., k$, Granger causes X_t^*, then u_t^* is non-fundamental with respect to X_t^*.

Non-fundamentalness can hence be detected empirically by checking wether the block of interest X_t^* is (weakly) exogenous with respect to potentially relevant additional blocks of variables that are likely to be driven by sources that are common with the variables of interest. This is a quite stringent condition; we will further discuss it later.

We can check the condition above for Gali (1999)'s model (3.3) on aggregate hours and productivity by looking at sectoral information. Precisely, we test for block exogeneity of the aggregate manufacturing X_t^* variables with respect to sectoral variables $X_{it} = (\Delta y_{it}, \Delta h_{it})'$ which represents the bivariate vector of the growth rate of labor input and labor productivity for the two-digit manufacturing sectors, $i = 1, ..., 18$. Our data are annual and consist of measures hours of all persons and output per hour (source: Bureau of Labor Statistics). The sample is 1949-2000. Results are reported in Table 1.

Table 1: Granger Causality Test

	F-test	p-value		F-test	p-value
Non Durable Sectors			**Durable Sectors**		
Food & Kindred Prod.	1.58	0.81	Lumber & Wood Prod.**	13.85	0.01
Textile Mills Prod.**	14.18	0.01	Furniture & Fixtures	6.87	0.14
Apparel &Related Prod.	6.83	0.15	Stone, Clay & Glass **	15.23	0.00
Paper & Allied Prod.	2.18	0.70	Primary Metal Ind.	6.19	0.19
Printing & Publishing	6.52	0.16	Fabricated Metal Prod.	5.18	0.27
Chem. & Allied Prod.	3.73	0.44	Ind. Machinery,Comp.Eq.	6.51	0.16
Petroleum Refining**	11.34	0.02	Electric & Electr. Eq.	0.63	0.96
Rubber & Plastic Prod.	5.62	0.23	Transportation Equip.	3.59	0.46
			Instruments**	20.42	0.00
Misc. Manufacturing	1.71	0.79			

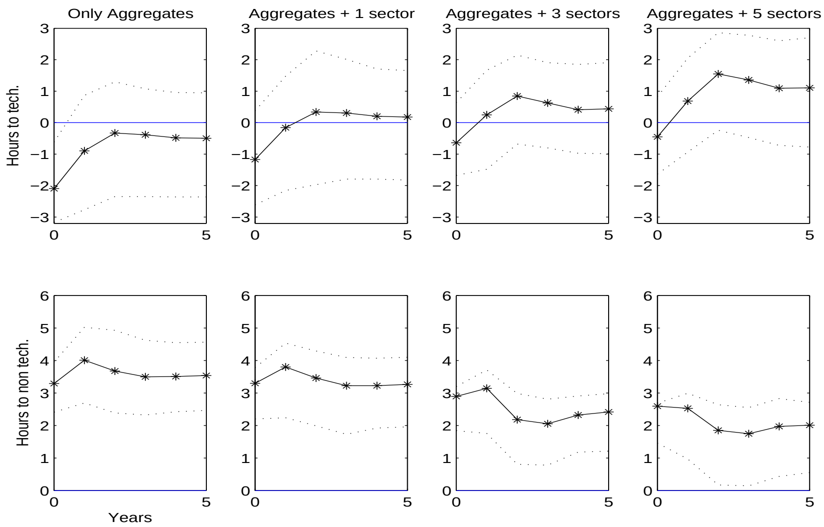
The test is for the null hypothesis: X_{it} does not Granger-cause X_t^* for $i = 1, ..., k$.
** indicates that the null hypothesis is rejected at 1% level.

For five sectors (25% of the total) the hypothesis of weak erogeneity is rejected, hence non-fundamentalness of the system (3.3) is detected. The Granger-causing sectors, ordered according to their F-stat associated to the Granger causality test, (starting from the sectors with respect to which the aggregate manufacturing are less likely to be weakly exogenous) are: Instruments, Stone, Clay & Glass, Textile Mills Products, Lumber & Wood Products and Petroleum Refining.

[2]This result was first introduced by Forni and Reichlin (1996) in the case in which data follow a factor structure.

If we augment the aggregate VAR model with the k sectors most likely to Granger-cause the aggregate manufacturing system, the shape of the estimated response of output to the technology shock changes. Figure 1 reports the estimated responses of hours worked to technology (upper panel) and non-technology (lower panel), for four different system and for $k = 0, 1, 3, 5$. We start from a system with only aggregate measures of hours and productivity ($k = 0$, first column) and then we add the Instruments sector ($k = 1$ second column), the Instruments, Stone, Clay & Glass, Textile Mills Product sectors ($k = 3$, third column), and finally all the Granger causing sectors at 5% level ($k = 5$, fourth column)[3].

Figure 1: **Impulse response functions of hours to structural shocks**



Dotted lines are 5% confidence bands.

The impulse response functions computed by estimating the VAR only with aggregate manufacturing sectors show a contemporaneous ($k = 0$) decline of hours worked in response to a technology shock. This result is in line with the finding of Gali (1999) and has been considered as evidence of substantial price stickiness in the US economy. However, when we add additional sectors, the response of hours worked to technology shocks are shifted upward while the response to non technology shocks are shifted downward. Clearly, as we add the Instruments sector, the contemporaneous impulse response becomes insignificant. Point estimates increase monotonically, approaching zero when we add all five Granger-causing sectors.

[3]We identify the system by imposing that sectoral shocks have no contemporaneous effects on the aggregate and by requiring, as usual, that only technological shocks can affect the long run level of aggregate labor productivity.

5 Does large information help?

In the previous Section we have seen that sectoral information can help detecting non-fundamentalness of the structural shocks with respect to the aggregate variables. Here we ask the question of whether, in general, by enlarging the econometrician information set, we can solve the non-fundamentalness problem. In general, larger information does not necessarily solve the problem of non-fundamentalness since in general the structural shocks are not fundamental with respect to the whole set of variables if they are not with respect to the small sub-set. This is easily seen by computing the roots of the moving average of system (4.4):

$$\det \begin{pmatrix} B^*(z) & 0 \\ B(z) & \Psi(z) \end{pmatrix} = [\det B^*(z)][\det \Psi(z)]$$

where $B(L) = (B_1(L), ..., B_k(L))$. If some roots of $B^*(z)$ are inside the unit circle then the larger system will have roots outside the unit circle as well, unless some roots of $\det B^*(z)$ cancel with those of $\det \Psi(z)$.

However, information helps under some conditions. Let us illustrate them in the case of a finite moving average to the shocks of interest. The discussion holds for the more general case, but requires a heavier notation.

Suppose that (4.4) satisfies the following restriction: $B(L) = B_0 + B_1 L + ... + B_s L^s$; that is, the effect of all shocks in zero after s periods. The system can hence be rewritten as:

$$X_t = \mathbf{B}\mathbf{U}_t^* + \Psi(L) v_t$$

where $\mathbf{B} = (B_0, B_1, ..., B_s)$ is a $km \times q(s+1)$ matrix and $\mathbf{U}_t^* = (u_t^{*\prime}, ..., u_{t-s}^{*\prime})'$ is of dimension $q(s+1)$.

Let us start from the assumption that $v_t = 0$, i.e. that the system is driven by q shocks only. In this case, if $\mathbf{B}'\mathbf{B}$ is of full rank, we have:

$$\text{Proj}[\mathbf{U}_\text{t}^*|\text{X}_\text{t}] = \left(\mathbf{B}'\mathbf{B}\right)^{-1}\mathbf{B}' X_t = \left(\mathbf{B}'\mathbf{B}\right)^{-1}\mathbf{B}'\mathbf{B}\mathbf{U}_t^* = \mathbf{U}_t^*$$

and we can recover U_t^*, and hence u_t^*, from the present of X_t. This is to say that u_t^* is fundamental with respect to X_t^*.

As Forni et al. (2005) have shown, fundamentalness with respect to $(X_t^{*\prime}, X_t')'$ is a less stringent condition if the system size is larger than the number q of the relevant shocks. In this case, to extract u_t^* from the present and past of all variables of the observables, we just need the full-rank condition above. The latter ensures that the dynamic of the panel is sufficiently rich so that, by exploiting the cross-sectional dynamic, it is possible to recover the lags of the common shocks.

Let us now consider the more realistic case in which $e_t = \Psi(L) v_t \neq 0$. In this case, sufficient conditions for recovering the U^* can be established by studying the properties of the system as we increase the number of auxiliary variables we consider. This analysis is provided in details by Forni et al. (2005).

Let us here reformulate the problem for our case. We have:

$$\text{Proj}[\mathbf{U}_t^*|\text{X}_t] = \left(\mathbf{B}'\Sigma_e^{-1}\mathbf{B} + I_{q(s+1)}\right)^{-1}\mathbf{B}'\Sigma_e^{-1/2}\mathbf{B}\mathbf{U}_t^* + \left(\mathbf{B}'\Sigma_e^{-1}\mathbf{B} + I_{q(s+1)}\right)^{-1}\mathbf{B}'\Sigma_e^{-1/2}e_t$$

where $\Sigma_e = \text{Cov}(e_t)$. To recover U_t^* we need two conditions. Precisely[4]:

A1) $\mathbf{B}'\mathbf{B}/n \to Q$ as $n \to \infty$ where Q is of full rank;

A2) $\|\Sigma_e/n\| \to 0$ as $n \to \infty$;

where $n = mk$.

Assumption A1 ensures that the shocks of interest are pervasive throughout the cross-section and that they generate heterogenous dynamics. Assumption A2 ensures that the remaining shocks do not propagate "too much" and can therefore be considered as idiosyncratic, sectoral shocks or as measurement error.

Under A1 and A2, as the cross-sectional dimension n goes to infinity, we have:

$$\left(\mathbf{B}'\Sigma_e^{-1}\mathbf{B} + I_{q(s+1)}\right)^{-1}\mathbf{B}'\Sigma_e^{-1/2}e_t \to 0$$

and hence

$$\text{Proj}[\mathbf{U}_t^*|\text{X}_t] \to \mathbf{U}_t^*$$

.

These conditions imply that asymptotically, for n large, we can eventually recover the structural shocks.

How realistic are condition A1 and A2? For the empirical example we are considering here, with aggregate and sectoral variables, the conditions are satisfied provided that sectoral variables Granger-cause the aggregate.

Assumption A2 is satisfied since, by construction, sectoral shocks v_t's do not affect aggregate manufacturing measures, i.e. $\Psi^*(L) = 0$. For assumption A1 to be satisfied, the macro shocks, which are our shocks of interest, must affect all sectors and this implies that the sectoral variables Granger-cause the aggregates. Evidence on the latter is given by results on Granger causality described in Section 4.

Therefore, the reliable result is the one produced by the system augmented by the Granger-causing sectors and this indicates that there is no evidence of hours worked going down in response to technological shocks.

In a more general case, conditions A1 and A2 are satisfied if data can be represented by an approximate factor model (Forni et al., 2005). A large literature has brought evidence that these models are a good empirical representation of large panels of macro data and of sectoral or regional data (Giannone et al. (2004), Stock and Watson (2005), Bernanke et al. (2005), Forni et al. (2005)). The estimation and identification theory for shocks and impulse responses is developed by Forni et al. (2005) so that these models can be easily used for structural analysis and they are a valid alternative to SVAR analysis when information may help solving the problem of non-fundamentalness.

[4]We define by $\|\cdot\|$ the L_2 matrix norm which correspond to the largest eigenvalue for positive definite matrices.

6 Dealing with the curse of dimensionality problem

The discussion of the previous Section implies that we may have to consider many auxiliary variables and this leads to the possibility of running out of degrees of freedom. In our empirical illustration, for example, modelling all sectors together implies considering a system of 38 equations (= 2 × 18 sectors + 2 aggregates) with only 51 observations in time.

A solution to this problem is provided by the dynamic factor literature. In fact, under the assumptions A1 and A2 defined in the previous Section, the system has an approximate factor structure (see Forni et al., 2005) whereby the variables are driven by few pervasive shocks and n idiosyncratic ones. In this case all the relevant information can be captured by few common factors (see Forni et al., 2000; Stock and Watson, 2002).

Precisely, under A1 and A2 the following representation holds:

$$\begin{pmatrix} X_t^* \\ X_t \end{pmatrix} = \begin{pmatrix} \Lambda^* \\ \Lambda \end{pmatrix} F_t + \Psi(L)v_t$$

where $F_t = DF_{t-1} + Cu_t^*$. F_t is $r \times 1$ and u_t is $(q \times 1)$, $D(L)$ is $(r \times r)$ finite stable filter and C is $r \times q$ matrix. Hence $B^*(L) = \Lambda^* D(L)^{-1}C$ and $\Psi(L)v_t$ is an idiosyncratic component, poorly cross-sectionally correlated[5].

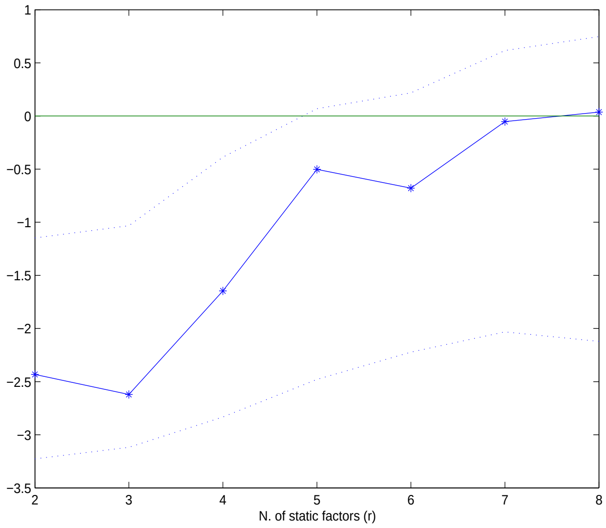
The common factors F_t can be estimated by the first r principal components of $(X_t^{*'}, X_t')'$. The parameters Λ, Λ^*, D, C can hence be estimated by ordinary least squares considering the estimated factors as if they were know (see Forni et al., 2005, for details). Once parameters are estimated we can impose the identification restriction $b_{21}^*(1) = 0$ as in the traditional SVAR literature, see Forni et al. (2005) for details.

Figure 2 plots the contemporaneous response of hours to technology shocks for different values of r, the number of common factors. For $r = 2$, results are very similar to those obtained only with aggregate manufacturing labor input and labor productivity. This is due to the fact that the span of the first two principal components is very close to the span of the aggregate manufacturing measure, since principal components are a weighted average of sectoral variables. Notice that, as we add more common factors (r increases), we capture more sectoral information and the contemporaneous response of hours to productivity increases monotonically.

This confirms the result that the negative contemporaneous response of hours to technology is an artifact due to non-fundamentalness of the structural shocks with respect to aggregate variables, i.e. we cannot extract the structural shocks on the basis of the growth rate of aggregate labor productivity and labor input alone. Enlarging the information set of the econometrician, we have a larger chance of capturing the structural shocks and indeed the contemporaneous response of hours becomes not significantly different from zero.

[5] The difference between the number of common factors r and the number of common shocks q captures dynamic heterogeneity across sections. In the finite MA example of the previous section we have $r = q(s + 1)$. For details see Forni et al. (2005).

Figure 2: **Contemporaneous response of hours to technology shock: factor model estimation for different number of static factors (r)**



Dotted lines are 5% confidence bands.

7 Lessons for applied work

The discussion above suggests some lessons for applied work. Even when the object of interest is a small system, one should check for the possibility of non-fundamentalness by augmenting it with auxiliary variables. Variables which have forecasting power (Granger-cause) for the variables of that system or factors capturing the information from a large data set should be included in the estimation. The auxiliary variables, beside being Granger-causing the key variables, must have strong commonality with them and small idiosyncratic dynamics, weakly cross-sectionally correlated.

The shocks of interest will be recoverable as long as they are "pervasive". This implies that, in general, it is easier to recover "large" shocks which affect all variables (key and auxiliary ones as well) than small ones.

References

Ben Bernanke, Jean Boivin, and Piotr Eliasz. Measuring monetary policy: A factor augmented autoregressive (favar) approach. *Quarterly Journal of Economics*, 120:387–422, 2005.

V. V. Chari, Patrick J. Kehoe, and Ellen R. McGrattan. A critique of structural vars using business cycle theory. Federal Reserve Bank of Minneapolis Working Paper 631, 2005.

Lawrence Christiano, J. Martin Eichenbaum, and Robert Vigfusson. What happens after a technology shock? NBER Working Paper 9819, 2004.

Lawrence Christiano, J. Martin Eichenbaum, and Robert Vigfusson. Assessing structural vars? Manuscript, Northwestern University, 2005.

Thomas F. Cooley and Mark Dwyer. Business cycle analysis without much theory: A look at structural vars. *Journal of Econometrics*, 83:57–88, 1998.

Jesus Fernandez-Villaverde, Juan Rubio-Ramirez, and Thomas J. Sargent. A, b, c's (and d)'s for understanding vars. NBER Technical Working Paper 0308, 2005.

Mario Forni, Domenico Giannone, Marco Lippi, and Lucrezia Reichlin. Opening the black box: Structural factor models with large cross-sections. Manuscript, ECARES, Université Libre de Bruxelles, 2005.

Mario Forni, Marc Hallin, Marco Lippi, and Lucrezia Reichlin. The generalized dynamic factor model: identification and estimation. *Review of Economics and Statistics*, 82:540–554, 2000.

Mario Forni and Lucrezia Reichlin. Dynamic common factors in large cross-sections. *Empirical Economics*, 21:27–42, 1996.

Jordi Gali. Technology, employment, and the business cycle: Do technology shocks explain aggregate fluctuations? *American Economic Review*, 89:249–271, 1999.

Domenico Giannone, Lucrezia Reichlin, and Luca Sala. Monetary policy in real time. In Mark Gertler and Kenneth Rogoff, editors, *NBER Macroeconomics Annual*, pages 161–200. MIT Press, 2004.

Lars P. Hansen and Thomas J. Sargent. Two difficulties in interpreting vector autoregressions. In Lars P. Hansen and Thomas J. Sargent, editors, *Rational expectations econometrics*. Underground Classics in Economics Boulder and Oxford: Westview Press, 1991.

Marco Lippi and Lucrezia Reichlin. The dynamic effects of aggregate demand and supply disturbances: comment. *American Economic Review*, 83:244–252, 1993.

Marco Lippi and Lucrezia Reichlin. Var analysis, nonfundamental representations, blaschke matrices. *Journal of Econometrics*, 63(1):307–325, 1994.

Christopher A Sims. Money, income, and causality. *American Economic Review*, 62:540–52, 1972.

James. H. Stock and Mark. W. Watson. Macroeconomic forecasting using diffusion indexes. *Journal of Business and Economics Statistics*, 20:147–162, 2002.

James H. Stock and Mark W. Watson. Implications of dynamic factor models for var analysis. Manuscript, Princeton University, 2005.

European Central Bank Working Paper Series

For a complete list of Working Papers published by the ECB, please visit the ECB's website (http://www.ecb.int)

585 "Are specific skills an obstacle to labor market adjustment? Theory and an application to the EU enlargement" by A. Lamo, J. Messina and E. Wasmer, February 2006.

586 "A method to generate structural impulse-responses for measuring the effects of shocks in structural macro models" by A. Beyer and R. E. A. Farmer, February 2006.

587 "Determinants of business cycle synchronisation across euro area countries" by U. Böwer and C. Guillemineau, February 2006.

588 "Rational inattention, inflation developments and perceptions after the euro cash changeover" by M. Ehrmann, February 2006.

589 "Forecasting economic aggregates by disaggregates" by D. F. Hendry and K. Hubrich, February 2006.

590 "The pecking order of cross-border investment" by C. Daude and M. Fratzscher, February 2006.

591 "Cointegration in panel data with breaks and cross-section dependence" by A. Banerjee and J. L. Carrion-i-Silvestre, February 2006.

592 "Non-linear dynamics in the euro area demand for M1" by A. Calza and A. Zaghini, February 2006.

593 "Robustifying learnability" by R. J. Tetlow and P. von zur Muehlen, February 2006.

594 "The euro's trade effects" by R. Baldwin, comments by J. A. Frankel and J. Melitz, March 2006

595 "Trends and cycles in the euro area: how much heterogeneity and should we worry about it?" by D. Giannone and L. Reichlin, comments by B. E. Sørensen and M. McCarthy, March 2006.

596 "The effects of EMU on structural reforms in labour and product markets" by R. Duval and J. Elmeskov, comments by S. Nickell and J. F. Jimeno, March 2006.

597 "Price setting and inflation persistence: did EMU matter?" by I. Angeloni, L. Aucremanne, M. Ciccarelli, comments by W. T. Dickens and T. Yates, March 2006.

598 "The impact of the euro on financial markets" by L. Cappiello, P. Hördahl, A. Kadareja and S. Manganelli, comments by X. Vives and B. Gerard, March 2006.

599 "What effects is EMU having on the euro area and its Member Countries? An overview" by F. P. Mongelli and J. L. Vega, March 2006.

600 "A speed limit monetary policy rule for the euro area" by L. Stracca, April 2006.

601 "Excess burden and the cost of inefficiency in public services provision" by A. Afonso and V. Gaspar, April 2006.

602 "Job flow dynamics and firing restrictions: evidence from Europe" by J. Messina and G. Vallanti, April 2006.

603 "Estimating multi-country VAR models" by F. Canova and M. Ciccarelli, April 2006.

604 "A dynamic model of settlement" by T. Koeppl, C. Monnet and T. Temzelides, April 2006.

605 "(Un)Predictability and macroeconomic stability" by A. D'Agostino, D. Giannone and P. Surico, April 2006.

606 "Measuring the importance of the uniform nonsynchronization hypothesis" by D. A. Dias, C. Robalo Marques and J. M. C. Santos Silva, April 2006.

607 "Price setting behaviour in the Netherlands: results of a survey" by M. Hoeberichts and A. Stokman, April 2006.

608 "How does information affect the comovement between interest rates and exchange rates?" by M. Sánchez, April 2006.

609 "The elusive welfare economics of price stability as a monetary policy objective: why New Keynesian central bankers should validate core inflation" by W. H. Buiter, April 2006.

610 "Real-time model uncertainty in the United States: the Fed from 1996-2003" by R. J. Tetlow and B. Ironside, April 2006.

611 "Monetary policy, determinacy, and learnability in the open economy" by J. Bullard and E. Schaling, April 2006.

612 "Optimal fiscal and monetary policy in a medium-scale macroeconomic model" by S. Schmitt-Grohé and M. Uribe, April 2006.

613 "Welfare-based monetary policy rules in an estimated DSGE model of the US economy" by M. Juillard, P. Karam, D. Laxton and P. Pesenti, April 2006.

614 "Expenditure switching vs. real exchange rate stabilization: competing objectives for exchange rate policy" by M. B. Devereux and C. Engel, April 2006.

615 "Quantitative goals for monetary policy" by A. Fatás, I. Mihov and A. K. Rose, April 2006.

616 "Global financial transmission of monetary policy shocks" by M. Ehrmann and M. Fratzscher, April 2006.

617 "New survey evidence on the pricing behaviour of Luxembourg firms" by P. Lünnemann and T. Y. Mathä, May 2006.

618 "The patterns and determinants of price setting in the Belgian industry" by D. Cornille and M. Dossche, May 2006.

619 "Cyclical inflation divergence and different labor market institutions in the EMU" by A. Campolmi and E. Faia, May 2006.

620 "Does fiscal policy matter for the trade account? A panel cointegration study" by K. Funke and C. Nickel, May 2006.

621 "Assessing predetermined expectations in the standard sticky-price model: a Bayesian approach" by P. Welz, May 2006.

622 “Short-term forecasts of euro area real GDP growth: an assessment of real-time performance based on vintage data” by M. Diron, May 2006.

623 “Human capital, the structure of production, and growth” by A. Ciccone and E. Papaioannou, May 2006.

624 “Foreign reserves management subject to a policy objective” by J. Coche, M. Koivu, K. Nyholm and V. Poikonen, May 2006.

625 “Sectoral explanations of employment in Europe: the role of services” by A. D’Agostino, R. Serafini and M. Ward-Warmedinger, May 2006.

626 “Financial integration, international portfolio choice and the European Monetary Union” by R. A. De Santis and B. Gérard, May 2006.

627 “Euro area banking sector integration: using hierarchical cluster analysis techniques” by C. Kok Sørensen, J. M. Puigvert Gutiérrez, May 2006.

628 “Long-run money demand in the new EU Member States with exchange rate effects” by C. Dreger, H.-E. Reimers and B. Roffia, May 2006.

629 “A market microstructure analysis of foreign exchange intervention” by P. Vitale, May 2006.

630 “Implications of monetary union for catching-up member states” by M. Sánchez, May 2006.

631 “Which news moves the euro area bond market?” by M. Andersson, L. J. Hansen and S. Sebestyén, May 2006.

632 “Does information help recovering structural shocks from past observations?” by D. Giannone and L. Reichlin, May 2006.

ISSN 1561081-0