Structural Factor Analysis of Interest-Rate Pass-Through in Four Euro-Area Economies

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Motivation

1. We seek to relate the movements of mortgage and business lending rates offered by banks in core and periphery countries to changes in underlying funding costs driven by implementation of monetary policy after the crisis and the greater perception of risk.

2. Since there are many different sources of risk, and many financial instruments affected by policy, we utilise a dynamic factor methodology that can summarise the influence of a large number of correlated variables.

3. Moreover, using Bernanke, Boivin and Eliasz (2005), Yamamoto (2012) and Bai and Ng (2013) we examine impulse responses to a policy rate conditioned by factors.

4. We attempt to provide economically meaningful identification of the latent factors and thereby capture the movement of key interest rate variables to shocks in the underlying policy rate (suitably identified).

5. Structural stability tests investigate the stability of the monetary transmission mechanism over the period of the crisis.
The actions of the ECB can be summarized by six types of policy that influenced short-term money market and longer term bond yields, directly or indirectly.

- First, from October 2008 banks in the euro area had access to excess liquidity because the ECB offered tender operations with fixed rate full allotments. The liquidity reached a peak of 812 billion euro (March 2012) as two 3-year Long-Term Refinancing Operations (LTROs) in December 2011 and February 2012 were made available to the banks.

- Second, from July 2013 the ECB’s Governing Council offered forward guidance on path of interest rates subject to their the outlook on inflation. This provided communication over future short rates and by implication the longer maturity rates further along the yield curve.

- Third, this was supplemented by a Outright Monetary Transactions (OMT) announcement in July 2012, which would sufficient to lower long term borrowing costs for government and banks, even though it has not been implemented to date. The flatter yield curve has lowered the cost of medium and longer term borrowing for banks.
Fourth, in June and September 2014 the ECB used balance sheet policies to offer credit easing, using four Targeted Long-Term Refinancing Operations (TLTROs) to provide long-term funding to support the real economy.

Fifth, in October and November 2014 the ECB announced and implemented an Asset Backed-Securities Purchase Programme and a Covered Bond Purchase Programme (CBPP3) to implement further easing of monetary policy.

Finally, in November 2014 the ECB began an Asset Purchase Programme (APP) to directly purchase 60 billion euro of government bonds each month till the end of September 2016. By August 2015 the ECB had purchased 414.3 billion euro under the entire APP, including 291.7 billion euro under the Public Sector Purchase Programme (PSPP), 111.5 billion euro under the Covered Bond Purchase Programme (CBPP3) and 11.1 billion euro under the Asset-Backed Securities Purchase Programme (ABSPP).
Reduced-Form Factor Model

The analysis is based on the dynamic factor model in static form:

\[ X_t = \Lambda F_t + e_t, \quad t = 1, \ldots, T; \]  

where \( X_t = (X_{1t}, \ldots, X_{Nt})' \) is an \( N \times 1 \) vector of standardized informational variables, \( F_t = (F_{1t}, \ldots, F_{rt})' \) is an \( r \times 1 \) vector of latent factors (\( r << N \)), \( \Lambda = (\lambda_1, \ldots, \lambda_N)' \) is an \( N \times r \) matrix of loadings, and \( e_t = (e_{1t}, e_{2t}, \ldots, e_{NT}) \) is an \( N \times 1 \) vector of idiosyncratic shocks. The factors are assumed to be generated by a VAR model:

\[ F_t = A_1 F_{t-1} + A_2 F_{t-2} + \ldots + A_p F_{t-p} + u_t, \] or

\[ A(L)F_t = u_t, \quad A(L) = I - A_1 L - A_2 L^2 - \ldots - A_p L^p. \]  

A stable factor VAR model admits a moving-average representation:

\[ F_t = \Phi(L)u_t, \quad \Phi(L) = I_r + \Phi_1 L + \Phi_2 L^2 + \ldots, \quad \Phi(L) = A(L)^{-1}. \]
Factor-Augmented Regression

Consider a regression

\[ y_t = \alpha + \beta' F_t + \varepsilon_t, \ t = 1, 2, \ldots, T. \]  

(4)

The variable of interest, \( y_t \), can be a (non-standardized) informational variable or it can be an additional variable, which is not included in the data set for computing latent factors.

The objective is to identify latent factors and make inference about responses of \( y_t \) to structural shocks in the factors.

In our application, \( y_t \) is a retail rate.
Using an $r \times r$ invertible matrix $S$, let the structural factor model be defined as (see Yamamoto 2012):

\[ X_t = \Lambda^s F_t^s + e_t, \]

\[ F_t^s = A_1^s F_{t-1}^s + A_2^s F_{t-2}^s + \ldots + A_p^s F_{t-p}^s + \nu_t, \]

where $\Lambda^s = \Lambda S$, $F_t^s = S^{-1}F_t$, $A_k^s = S^{-1}A_k S$, and $\nu_t = S^{-1}u_t$ is a structural innovation. The moving-average representation of structural factor VAR is

\[ F_t^s = \Psi(L)\nu_t, \quad \Psi(L) = I_r + \psi_1 L + \psi_2 L^2 + \ldots, \quad \Psi(L) = S^{-1}\Phi(L)S. \]
Impulse Response Functions

For the moving-average form of equation (4),

\[ y_t = \alpha + \beta' \Phi(L) u_t + \varepsilon_t, \]

the reduced-form impulse response of variable \( y_t \) to a shock in factor \( j \) \((j = 1, 2, \ldots, r)\) at horizon \( h \) \((h = 1, 2, \ldots)\) is

\[ \frac{\partial y_{t+h}}{\partial u_{jt}} = \beta' \Phi_h^{(j)}, \]

where \( \Phi_h^{(j)} \) is the \( j \)th column of matrix \( \Phi_h \). The impulse response of variable \( y_t \) to a shock in structural factor \( j \) at horizon \( h \) is

\[ \frac{\partial y_{t+h}}{\partial v_{jt}} = \beta' S \Psi_h^{(j)}, \]

where \( \Psi_h^{(j)} \) is the \( j \)th column of matrix \( \Psi_h \).
Matrix Representation

Consider a matrix form of model (1)-(2)

\[ X = F \Lambda' + e, \]
\[ F = ZA + u, \]  

(7)

where \( X \) is the \( T \times N \) matrix of observed variables, \( e \) is the \( T \times N \) matrix of idiosyncratic shocks, \( F = (F_1, F_2, \ldots, F_T)' \) is the \( T \times r \) matrix of factors, \( Z = (F_{-1}, F_{-2}, \ldots, F_{-p}) \) is \( T \times rp \) matrix of factor lags, \( F_{-k} = (F_{1-k}, \ldots, F_{T-k})' \), and \( A = (A_1, \ldots, A_p)' \) is \( rp \times r \) matrix of parameters.

For structural model (5), the matrix form is

\[ X = F^s \Lambda^s' + e, \]
\[ F^s = Z^s A^s + v, \]  

(8)

where \( F^s = F[S^{-1}]' \), \( \Lambda^s = \Lambda S \), \( Z^s = Z \left[ I_p \otimes [S^{-1}]' \right] \), and \( A^s = \left[ I_p \otimes S' \right] A[S^{-1}]' \), and \( v = u[S^{-1}]' \).
Statistical identification, implemented in the method of principals components, is achieved by choosing that normalisations $F'F/T = I_r$ and $\Lambda'\Lambda$ is diagonal.

For structural identification, we impose restrictions, which are similar to short-term restrictions in Yamamoto (2012):

- Firstly, the covariance matrix of structural shocks $E(\nu_t\nu_t')$ is assumed to be diagonal. This implies $(r^2 - r)/2$ restrictions.
- Secondly, the matrix $\Lambda^s$ is assumed to be composed of two sub-matrices:

$$
\Lambda^s = \begin{bmatrix}
\Lambda^s_{1:r} \\
\Lambda^s_{r+1:N}
\end{bmatrix}, \text{ where } \Lambda^s_{1:r} = \begin{bmatrix}
1 & 0 & \ldots & 0 \\
\lambda^s_{21} & 1 & \ldots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
\lambda^s_{r1} & \lambda^s_{r2} & \ldots & 1
\end{bmatrix}.
$$

(9)

This implies $(r^2 + r)/2$ restrictions on the matrix $\Lambda$. 


Interpretation of Structural Restrictions

The identification of factors depends on the choice and ordering of the first \( r \) variables in the data matrix \( X \).

Under this framework, the first variable, \( X_{1t} \) instantaneously responds to a shock in the first structural factor only: a unit shock in the first structural factor implies a unit shock to \( X_{1t} \).

The second variable, \( X_{2t} \), instantaneously responds to shocks in structural factors 1 and 2. The response of the second variable to a unit shock in the second structural factor is equal to one.

The third variable, \( X_{3t} \), responds to shocks in structural factors 1-3. The response of the third variable to a unit shock in the third structural factor is equal to one.

And so on (for the first \( r \) variables).
Data Description

Time span: January 2003 - December 2013

Structure of data sets:

- Indices of industrial production, retail trade, exports-imports
- Price indices: producer and consumer prices, energy prices
- Real and nominal exchange rates
- Stock market indices and risk measures
- Money aggregates
- Interest rates: short-term and long-term

Retail lending rates:

- loans to non-financial corporations, total, new business
- lending for house purchases, households, total, new business
## Selection of Identifying Variables

<table>
<thead>
<tr>
<th>#</th>
<th>Mnemonic</th>
<th>Description</th>
<th>Transformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IP.Manuf</td>
<td>index of industrial production, manufacturing</td>
<td>log-difference</td>
</tr>
<tr>
<td>2</td>
<td>PPI.Manuf</td>
<td>index of producer prices, manufacturing</td>
<td>log-difference</td>
</tr>
<tr>
<td>3</td>
<td>REER42</td>
<td>real effective exchange rate</td>
<td>log-difference</td>
</tr>
<tr>
<td>4</td>
<td>DAX/CAC40/FTSEMI/IGBM</td>
<td>stock market index</td>
<td>log-difference</td>
</tr>
<tr>
<td>5</td>
<td>SWPSPR5Y</td>
<td>5-year swap rate</td>
<td>difference</td>
</tr>
<tr>
<td>6</td>
<td>EURIBOR6M</td>
<td>6-month Euribor</td>
<td>difference</td>
</tr>
</tbody>
</table>
Estimation Steps

- Estimate statistical factors using the method of principal components
- Estimate a reduced-form VAR model for statistical factors
- Compute identification matrix $\hat{S}$, using $LDL'$ factorization of estimated matrix $\hat{\Lambda}_{1:r} \hat{\Sigma}_u \hat{\Lambda}_{1:r}'$
- Estimate parameters of the factor-augmented regression (4) for $y_t$
- Compute responses of $y_t$ to shocks in structural factors
- Compute confidence intervals for impulse responses (uncompleted)
Methodological Issues

Identification depends on

- choice of the number of factors
- choice and ordering of identifying variables
- model selection for factor VAR

Weighing uncertainty of factor estimates in the inference about impulse responses
Estimation of Structural Model: Details

In order to compute the identification matrix $\hat{S}$, $LDL'$ factorization is implemented:

$$\hat{\Lambda}_{1:r}\hat{\Sigma}_u\hat{\Lambda}'_{1:r} = LDL',$$  \hfill (10)

where $L$ is a unitary lower triangular matrix and $D$ is a diagonal matrix. Then the identification matrix is

$$\hat{S} = \left[\hat{\Lambda}_{1:r}\right]^{-1}L$$  \hfill (11)

and the submatrix $\hat{\Lambda}^s_{1:r}$ of the loadings matrix of structural factors is

$$\hat{\Lambda}^s_{1:r} = \hat{\Lambda}_{1:r}\hat{S} = \hat{\Lambda}_{1:r}\left[\hat{\Lambda}_{1:r}\right]^{-1}L = L.$$  \hfill (12)

For the covariance matrix of structural shocks we have

$$\hat{\Sigma}_v = L^{-1}\hat{\Lambda}_{1:r}\hat{\Sigma}_u\hat{\Lambda}'_{1:r} (L^{-1})' = D.$$  \hfill (13)
Factors are estimated using standardized variables: \( X = C_T Z D_N \), where \( Z \) is a matrix of original (non-standardized) informational variables \( C_T = [I_T - \frac{1}{T} \mathcal{I} t \mathcal{I} t'] \) is \((T \times T)\) centering matrix, \( \mathcal{I} T = (1, 1, \ldots, 1)' \) is \((T \times 1)\) unit vector, \( D_N = \left[ \text{diag}(\hat{\Sigma}) \right]^{-1/2} \) is \((N \times N)\) diagonal standardization matrix, and \( \hat{\Sigma} = \frac{1}{T} X C_T X' \) is the sample covariance matrix. Hence, factors do not have units of measurement.

In structural analysis we are interested in responses of an economic variable (e.g., interest rate) to structural shocks which have economic interpretation. Hence, impulse responses are rescaled:

\[
\frac{\partial \hat{y}_{t+h}}{\partial v_{jt}} = \hat{\sigma}_j \hat{\beta}' \hat{S} \hat{\Psi}^{(j)}_h,
\]

where \( \hat{\sigma}_j \) is the standard deviation of variable \( j \) \((j = 1, 2, \ldots, r)\).
In order to evaluate changes in the pass-through, the rolling window estimation of factor VAR and factor-augmented regressions is implemented.

For each $s = w, w + 1, \ldots, T$, the following model is estimated:

$$
\hat{F}_t^{(T)} = A_1 \hat{F}_{t-1}^{(T)} + A_2 \hat{F}_{t-2}^{(T)} + \ldots + A_p \hat{F}_{t-p}^{(T)} + u_t, t = s - w + 1, s - w - 1, \ldots, s;
$$

(14)

$$
y_t = \alpha + \beta' \hat{F}_{t-1}^{(T)} + \varepsilon_t, t = s - w + 1, s - w - 1, \ldots, s
$$

(15)

where $w$ is a window size and $\hat{F}_t^{(T)}$ is the full-sample estimate of (statistical) factors.
The size of the window is set to 60 months: $w = 60$.

The initial estimation is carried out using data from February 2003 to January 2008.

The final estimation is carried out using data from January 2009 to December 2013.

For each of the rolling estimates, structural identification is carried out and impulse response functions of lending rates to shocks in structural factors are computed. The surfaces of these impulse response functions are shown in Figures.
Marginal $R^2$s of Structural Factors 1-3: Germany
Marginal $R^2$s of Structural Factors 4-6: Germany
Full-Sample Estimates of Cumulative Impulse Responses: Germany

Figure: Response of mortgage rate to a shock in Factor 4

![Graph of mortgage rate response to Factor 4 shock]

Figure: Response of mortgage rate to a shock in Factor 5

![Graph of mortgage rate response to Factor 5 shock]

Figure: Response of mortgage rate to a shock in Factor 6

![Graph of mortgage rate response to Factor 6 shock]

Figure: Response of corporate rate to a shock in Factor 4

![Graph of corporate rate response to Factor 4 shock]

Figure: Response of corporate rate to a shock in Factor 5

![Graph of corporate rate response to Factor 5 shock]

Figure: Responses of corporate rate to a shock in Factor 6

![Graphs of corporate rate responses to Factor 6 shock]
Surfaces of Rolling Estimates of Cumulative Impulse Responses: Germany

Figure: Responses of mortgage rate to shocks in Factor 4

Figure: Responses of mortgage rate to shocks in Factor 5

Figure: Responses of mortgage rate to shocks in Factor 6

Figure: Responses of corporate rate to shocks in Factor 4

Figure: Responses of corporate rate to shocks in Factor 5

Figure: Responses of corporate rate to shocks in Factor 6
Marginal $R^2$s of Structural Factors 1-3: France
Marginal $R^2$s of Structural Factors 4-6: France
Full-Sample Estimates of Cumulative Impulse Responses: France

**Figure:** Response of mortgage rate to a shock in Factor 4

**Figure:** Response of mortgage rate to a shock in Factor 5

**Figure:** Response of mortgage rate to a shock in Factor 6

**Figure:** Response of corporate rate to a shock in Factor 4

**Figure:** Response of corporate rate to a shock in Factor 5

**Figure:** Responses of corporate rate to a shock in Factor 6
Surfaces of Rolling Estimates of Cumulative Impulse Responses: France

Figure: Responses of mortgage rate to shocks in Factor 4

Figure: Responses of mortgage rate to shocks in Factor 5

Figure: Responses of mortgage rate to shocks in Factor 6

Figure: Responses of corporate rate to shocks in Factor 4

Figure: Responses of corporate rate to shocks in Factor 5

Figure: Responses of corporate rate to shocks in Factor 6
Marginal $R^2$s of Structural Factors 1-3: Italy
Marginal $R^2$s of Structural Factors 4-6: Italy
Full-Sample Estimates of Cumulative Impulse Responses: Italy

Figure: Response of mortgage rate to a shock in Factor 4
Figure: Response of mortgage rate to a shock in Factor 5
Figure: Response of mortgage rate to a shock in Factor 6

Figure: Response of corporate rate to a shock in Factor 4
Figure: Response of corporate rate to a shock in Factor 5
Figure: Responses of corporate rate to a shock in Factor 6
Marginal $R^2$s of Structural Factors 1-3: Spain
Marginal $R^2$s of Structural Factors 4-6: Spain
Full-Sample Estimates of Cumulative Impulse Responses: Spain

Figure: Response of mortgage rate to a shock in Factor 4

Figure: Response of mortgage rate to a shock in Factor 5

Figure: Response of mortgage rate to a shock in Factor 6

Figure: Response of corporate rate to a shock in Factor 4

Figure: Response of corporate rate to a shock in Factor 5

Figure: Responses of corporate rate to a shock in Factor 6
Surfaces of Rolling Estimates of Cumulative Impulse Responses: Spain

Figure: Responses of mortgage rate to shocks in Factor 4

Figure: Responses of mortgage rate to shocks in Factor 5

Figure: Responses of mortgage rate to shocks in Factor 6

Figure: Responses of corporate rate to shocks in Factor 4

Figure: Responses of corporate rate to shocks in Factor 5

Figure: Responses of corporate rate to shocks in Factor 6
Some Observations

- For Germany, France, and Italy the responsiveness of mortgage rates to factors identified using interest rates (factors 5 and 6) is weaker than the responsiveness of corporate rates.

- The response to a shock in factor 6, identified using 6-month Euribor, had a large structural shift in the end of 2008 - beginning of 2009 in all countries (after a sharp decrease in the ECB policy rates). Then the pass-through from the short-term rates was flattened till the end 2012 - beginning 2013 when a mild increase of the pass-through following the non-standard policy measures of the ECB.

- The responsiveness of retail rates in Germany and France to factor 5, identified using 5-year swap rate, decreased in 2012-2013. On the contrary, the responsiveness of retail rates in Italy and Spain to the same factor increased in 2012-2013.
Conclusions

- Broadly speaking, a picture emerges of less than full pass through, with substantial instabilities.

- We do not directly attack the question of policy making at the zero lower bound, the instabilities inherent in the pass through coefficients, captured by the rolling algorithms, hint at the differential impact of monetary policy in times of crisis.

- The use of identified factors - to our knowledge the only such use in the literature - to investigate pass through gives concrete meaning to the impact of the different categories of variables (real, nominal and financial) which have impact on pass through.