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**Structural Factor Analysis of Interest Rate Pass Through
In Four Large Euro Area Economies**

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Structural Factor Analysis of Interest Rate Pass Through In Four Large Euro Area Economies

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Abstract: In this paper we examine the influence of unconventional monetary policy at the ECB on mortgage and business lending rates offered by banks in the major euro area countries (Germany, France, Italy and Spain). Since there are many different policy measures that have been undertaken, we utilise a dynamic factor model based on the Bernanke Boivin and Elias (2005) approach, which allows examination of impulse responses to a policy rate conditioned by structurally identified latent factors. The distinct feature of this paper is that it explores the effects of all three phases of monetary policy to emphasize the transmission channels - through short-term rates, long-term yields and perceived risk - ultimately directed towards bank lending rates. Further analysis of unconventional monetary policy is provided through rolling window impulse responses and variance decompositions of the identified financial factors on lending rates to demonstrate the changing influence of different policy measures on lending rates.

Keywords: monetary policy, dynamic factor models, interest rates, pass through

JEL Classifications: C32, C53, E43, E4

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1 Introduction

The European Central Bank (ECB) has faced ‘intense scrutiny’ over its policies in recent years. Since the global financial crisis it has implemented monetary policy in three phases - to provide ample liquidity and thereby to avoid fire sales of assets; to address funding problems and impaired markets in individual countries; and to support the weak recovery - but there is a deep inquiry whether these policies have had their intended effects (Praet, 2017a, 2017b). The ECB widened the range of acceptable collateral, undertook longer duration liquidity operations, offered forward guidance on future short term rates and took several separate decisions to make outright purchases of government bonds, covered bonds and asset backed securities (see Angelini et al. 2011, Beirne et al. 2011, Brunetti et al. 2011, Szczerbowicz 2015, ECB 2016). Perhaps the intervention that captured the imagination more than any other was the Outright Monetary Transactions (OMT) announcement in June 2012, when Mario Draghi indicated he would do ‘whatever it takes’, making outright monetary transactions if necessary. This put monetary policy in the spotlight as never before.

ECB policy has been explored by Giannone et al. (2011, 2012), ECB (2010a, 2010b, 2012, 2015a, b) and Altavilla and Giannone (2016) in money and capital markets, while the papers by ECB (2013), Hristov et al. (2014), Illes et al. (2015), Altavilla et al. (2015), Altavilla et al. (2017) and von Borstel et al. (2016) have considered the effects of particular policies on banks’ funding costs using Bayesian VARs, panel VARs and factor models. Each of these papers makes a contribution to understanding specific unconventional policy actions by the ECB. The distinct feature of our paper is that it explores the effects of all three phases of monetary policy to emphasize the transmission channels - through short-term rates, long-term yields and perceived risk - ultimately directed towards bank lending rates. Therefore while it draws on mechanisms that are documented in the recent literature, it attempts to illustrate more clearly how each set of policies operated in combination, through different transmission channels, to fundamentally affect funding costs for banks and their lending rates. Until now this broader assessment has relied on summaries of internal ECB research in speeches by policy makers (see Constâncio 2015 and Praet 2017a, b among many others) but here we show these effects in a structurally identified model.

In this paper we break new ground by using a structurally identified dynamic factor model with its foundations in Bernanke, Boivin and Elias (2005) [hereafter BBE] loading on many

correlated variables, to evaluate the effects of monetary transmission.¹ We aim to verify whether the different instruments of policy cited by Praet (2017a) had an influence over lending rates that can be identified in an econometric model. This leads us to propose the use of a structurally identified dynamic factor model to make three main contributions to the understanding of monetary transmission to lending rates in the period after the crisis. First, the application of new methodology based on Stock and Watson (2005), Yamamoto (2016) and Bai and Ng (2013) provides economically meaningful identification of the latent factors by means of suitable restrictions on the loading matrices of the factors as described in Section 4 below. This allows us to separate the impact of different instruments of policy to some degree. Of several identification schemes proposed in Stock and Watson (2005) we select the one most useful for our purposes. To our knowledge this is the first application of this methodology to the understanding of interest rate setting behaviour of banks.

Second, conditional on this identification of the latent factors we illustrate and explain the channels of transmission through the responses of key bank lending rates to structural shocks in the identified latent factors. The BBE methodology assumes that the main source of monetary policy shocks is the short term policy rate, but, clearly, in much of our sample period the policy rate was close to its effective lower bound.² Our innovation over the previous literature is to explore how the different instruments of policy, as applied in three distinct phases, may have created shocks to global risk perceptions, changes in long-term yields and short-term market rates that feed through to bank lending rates.

Third, we analyze structural changes in the monetary transmission mechanism over the period of the crisis using rolling-window estimation of factor-augmented VARs to generate surfaces of impulse responses and variance decompositions of the variation in corporate and mortgage lending rates for less vulnerable and vulnerable euro area countries. These show that while short term rates continued to influence lending rates, they do so with less impact in the post-crisis period compared to earlier years confirming the findings of other studies (c.f. ECB

¹The BBE approach allows examination of impulse responses to a policy shock conditioned by factors, but does not provide structural identification of latent factors. Examples of the BBE approach include use of large macroeconomic datasets (e.g. Boivin and Giannoni 2008), or large financial datasets (e.g. De Nicolo and Lucchetta 2012 and Eickmeier and Hofmann 2013). Buch et al. (2014) have taken this a step further using microlevel data for banks to augment a model of output, inflation, house price inflation and short-term policy rates in the United States from 1985q1 - 2005q2 using bank level data from Call Reports submitted to the Federal Reserve.

²This does not mean that there have been no policy shocks to consider; on the contrary, unconventional monetary operations have been used to make adjustments to expected future short-term rates to long-term bond yields, and global risks have provided new sources of shocks to examine.

2013, Hristov et al. 2014, and Altavilla et al. 2015, Altavilla et al. 2017). The effects of long-term yields and financial risks were longer lasting after the crisis, and all told, long-term yields and financial risks became more influential over lending rates than they had been previously. This seems consistent with the shifting emphasis of policy away from adjustment in short-term rates and towards the use of liquidity operations, forward guidance and the balance sheet, which affected banks through long-term yields and financial risk factors.³

The data used in the estimation are drawn at a monthly frequency from the harmonized monetary and financial institutions' interest rate (MIR) dataset over the sample January 2000 - June 2016 for Germany, France, Italy, and Spain. Other variables capturing the macroeconomy (as detailed in the data appendix) are obtained from EUROSTAT.

The paper is organized as follows. Section 2 contains a brief review of the literature, Section 3 offers a summary of European monetary policy actions. Next, in several sub-sections, Section 4 explains the methodology employed including identification, estimation, bootstrapping for confidence intervals and the rolling estimation procedure (to capture instabilities). Section 5 describes the data. Section 6 discusses all the results of the procedures using full-sample and rolling-window estimates. Section 7 concludes. All tables and figures are given at the end of the paper and brief appendices list the data sources used and provide an outline of the technical details of the bootstrapping algorithm used.

2 A Brief Review of the Literature

The transmission channels from ECB policies to financial markets are discussed in detail in Giannone et al. (2011, 2012), ECB (2010a, 2010b, 2012, 2015a,b), Altavilla et al. (2015) and Altavilla et al (2017). These include the effects of (a) liquidity injections on money market rates through "fixed rate/full allotment" tendering procedures of longer term refinancing operations, (b) acceptance of a wider range of eligible collateral for these operations, (b) forward guidance over future short term rates, (c) announcements of readiness to implement outright monetary transactions, (d) purchases of covered bonds and asset backed securities, and most recently (e) the asset purchase programme. Conditional forecasts from their models explain how policy might have evolved in the absence of unconventional policy. By making comparison with the actual out turn of events, they are able to determine whether the timing of unconventional

³We regard Germany and France as examples of less vulnerable countries and Italy and Spain as vulnerable countries, using the definition employed in ECB (2016).

policy measures coincides with deviations of actual data from their conditional forecasts. Their findings confirm the finding of others that liquidity operations affect the short-term interbank rates directly (ECB 2010a,b; Beirne et al. 2011) and asset purchases affect the longer term yields (ECB 2015a, b; Praet 2015). In Altavilla et al. (2017) the focus is on the impact of monetary policy after June 2014, specifically the Targeted Long-term Refinancing Operations (TLTRO) and Asset Purchase Programme (APP), and the effects of individual banks, sometimes grouped into stressed and less stressed groups. This makes a significant contribution to the understanding of bank level responses, and controls for many bank characteristics, such as sovereign exposures, capital ratios, stable funding ratios and non-performing loan levels. Our paper takes a different approach based on a BBE model with structural identification of all ECB unconventional monetary policies and concentrating on the differences in the effects on lending rates at the country level.

BBE provide a justification in the context of US monetary policy for the use of factor models summarizing a large set of data as an improvement on structural VARs proposed by Sims (1992) and Bernanke and Blinder (1992) that typically suffer from "sparse information sets". These limited datasets may lead to three problems. First, the central bank and the private sector may respond to information not included in a small-dimensional VAR, which will result in the mismeasurement of responses to policy shocks in the small-dimensional VAR because the shocks may not be identified properly. Second, there is a degree of arbitrariness in the measurement of variables essential to the problem, such as the natural rate of output and the equilibrium real rate of interest, that exacerbate the measurement problems. Third, we can only observe impulse responses for the small set of variables included in the VAR, when we may have an interest in the response to a wider range of shocks. These points are particularly relevant when we consider unconventional monetary policy that operates through many different instruments, some of which are hard to measure or unmeasurable e.g. announcements of policy intentions and that have many potential channels of transmission. The BBE approach using factor-augmented VAR (FAVAR) methodology deals with many of the problems that can emerge in modeling monetary transmission. The effective use of large data sets facilitates the measurement of complete transmission of policy shocks and allows analysis of a wider range of shocks.

Stock and Watson (2005) discuss BBE and a few alternative approaches to identification of structural shocks in FAVARs. These alternative approaches include procedures which directly identify structural shocks to unobservable common factors. Yamamoto (2016) uses three types of restrictions originally described in Stock and Watson (2005) and proposes bootstrap procedures for making inference about impulse response functions. Bai and Ng (2013) discuss

the identification of common factors, estimated by principal components, without modelling factor dynamics in a FAVAR model. Bai et al. (2016) propose a procedure to identify latent factors in a framework where some factors are observable and the joint dynamics of latent and observable factors can be described by a VAR model. However, none of these papers actually uses identified factors for the policy analysis and as far as we are aware there have been no applications to the euro area since the global financial crisis.

A very different approach has been proposed by Lombardi and Zhu (2014), which makes use of a dynamic factor model, but it does so to construct a "shadow policy rate" which is intended to represent the stance of monetary policy when nominal interest rates are at the zero lower bound. The shadow rate, originally proposed by Black (1995), has recently received significant attention as a way of resolving the issue of how to measure the stance of monetary policy in the aftermath of the global financial crisis (see, inter alia, Krippner 2014, Christensen and Rudebusch 2016). In Lombardi and Zhu (2014) the shadow rate is computed using the Expectation Maximization algorithm in a dynamic factor model where the nominal interest rates at the zero bound are substituted with missing values. The derived measure has an appealing economic interpretation and can be used in a VAR model as a policy variable. However, this measure is not a common factor; by design, it does not have to contribute much to the estimated common factor space. It is also the case that it is a proxy for the different instruments used by the ECB, and rather than identifying the effects of these instruments on short rates, long-term yield and risk perceptions, it summarizes their effects in one shadow rate.

von Borstel et al. (2016) provide a FAVAR analysis of the pre-crisis period (2003-mid 2007) and the sovereign debt crisis period (2010-2013) omitting the global financial crisis (mid 2007-2010). They estimate two separate FAVAR models for each episode, to compare the transmission of monetary policy pre- and post-crisis to bank lending rates. The model includes observable and latent factors, extracted from a large macroeconomic and financial data set. The novelty in von Borstel et al. (2016) is the use of an "effective monetary stimulus (EMS)" measure which is designed as an improvement of the shadow rate proposed by Krippner (2014). The EMS approximates monetary policy by current and expected future short rates relative to a neutral rate derived from the 2-factor Nelson-Siegel model of the yield curve even in negative territory when the zero lower bound constrains the nominal rate to be positive. They estimate the response functions to an EMS shock. Their conclusion is that the transmission of monetary policy in the second sovereign debt crisis period was weaker than in the pre-crisis period. In other words, there was a larger spread between lending rates and policy rates, which they speculate could be due to higher borrower risks, tighter supply constraints on credit, or

reduced cross-border competition between banks. The fact that their paper is directed to the explanation of interest rate pass through implies some overlap with our paper, however, our approach draws on a different technology to explain interest rate pass through.

We complement the papers by Lombardi and Zhu (2014) and von Borstel et al. (2016) that impute the effects of unconventional monetary policy on a shadow short rate by using further economic factors in the spirit of BBE. Our approach therefore provides identification of the impact of unconventional monetary policy shocks through short-term rates, long-term yields and financial risk measures. In this respect we aim to offer a structural factor interpretation and more detail about the channels of transmission which then allows us to explore the phases of monetary policy cited by Praet (2017a) and their effects.

3 Timing of Events

3.1 European Monetary Policy Actions

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. This had direct effects on very short-term interest rates, since the provision of excess liquidity through LTROs caused the euro overnight index average (EONIA) to drop from close to the main refinancing rate to the ECB deposit facility rate (the lower bound of the corridor for overnight interest rates). Only after the option was offered in 2013 for weekly repayment did banks reduce this liquidity.

Second, from July 2013 the ECB's Governing Council offered forward guidance on the 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 an OMT announcement in July 2012, which was 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 when issuing senior unsecured bonds at maturities 1-5 years, while liquidity

operations have also made cheaper short term funding available at maturities up to 3 years.

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 at relatively low rates to the banks that met certain conditions for up to 4 years, to support lending to the real economy. They also purchased assets in the two Covered Bond Purchase Programmes (CBPP1, CBPP2) and a Securities Markets Programme (SMP) set up to buy government bonds from the secondary market.

Fifth, in October and November 2014 the ECB announced and implemented an Asset Backed-Securities Purchase Programme (ABSPP) and a third 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). As a consequence, ECB Executive Board member Peter Praet in a speech dated 30 June 2015 noted “On the bank side, the APP seems to have been effective in further reducing wholesale funding costs, as portfolio rebalance effects have led to a compression of, for example, bank bond yields. Consequently, while the cost of borrowing from banks for households and firms has been declining since mid-2014, the pace of the decline has increased in recent months.”

3.2 Effects of Monetary Policy on the Composition and Cost of Funding for Banks

The composition and costs of funding for banks have been influenced by monetary policy, macroeconomic conditions, the balance-sheet strength of sovereigns and banks themselves and by regulatory policy according to ECB (2016). The differences in interest rate setting by banks across countries reflects these differences in funding costs and risks. To a large extent these differences split along the lines of less vulnerable and vulnerable countries (the latter are defined as Cyprus, Greece, Ireland, Italy, Portugal, Slovenia and Spain by ECB 2015b). And therefore, to a large degree the unconventional policies implemented by the ECB from 2012 onwards were a direct response to perceived funding problems in vulnerable countries, in order to avoid

disorderly responses in certain funding markets and to prevent forced deleveraging by banks (Praet, 2017a, b).

Since the crisis, the transmission of monetary policy has relied less on the interest channel via short-term market rates and to a larger extent on the signaling channel, expectations channel and portfolio rebalancing channel, as well as through credit channels via bank lending and balance sheet) as discussed by Constâncio (2015).

Prior to the crisis, banks in the major euro area countries raised the majority of their funds from retail deposits of households, government and non-financial firms, which were large and stable. These were supplemented by wholesale markets offering deposits of banks, and funds raised in various securities markets. Immediately after the crisis, funding from wholesale markets became more expensive and less reliable and banks in the euro area shifted their funding away from wholesale markets towards retail funding (see van Rixtel and Gasperini 2013). This was much more noticeable in the vulnerable countries than elsewhere (ECB 2016). While banks were able to continue to issue securities (with government guarantees) even after the Lehman crisis, this became more difficult for vulnerable countries as markets became more concerned about sovereign debt levels between 2010-2012. Even retail deposits in vulnerable countries began to ebb away in this period, as depositors moved accounts to countries with lower debt levels, and cross-border holdings of deposits in euro area banks by non-residents were reduced (see Forster et al. 2011). Banks at this time were forced to rely more heavily on central bank liquidity operations as described above. For the euro area as a whole, ECB (2016) shows that reliance on retail funding increased after the crisis (comparing figures for January 2005 versus September 2015) and funding from wholesale markets, securities and external liabilities fell. The effects were more substantial for vulnerable countries compared to less vulnerable countries. The introduction of the APP has further increased the levels of deposits in the banking system, although the effects differ across countries according to quarterly bank lending surveys conducted by the ECB.

The cost of bank funding has also risen since the crisis, especially in the vulnerable countries. Credit risk increased due to perceptions of risk associated with the banks themselves, but further increases in the cost of funds resulted from the perception that sovereign risk had increased in some countries, and this reached a peak in 2012. These factors contributed to higher yields on securities in vulnerable and less vulnerable countries and to elevated rates on interbank borrowing. Only with the intervention of the ECB through unconventional policies - particularly the OMT announcement in July 2012 - did these interbank rates subside, and bond

yields only completely converged at the start of the asset purchase programme as it reduced long term rates (Altavilla et al. 2015, Constâncio 2015, ECB 2016).

The cost of retail deposits also increased in the period 2008-2012 for vulnerable countries, since the reduction in monetary policy rates was not fully passed through to depositors, and banks relied more heavily in these countries on retail funding. After the OMT policy was announced in July 2012 the dispersion of deposit rates has fallen across euro area countries. ECB (2015b) shows the composite funding costs of banks declined from 2012 and that TLTRO, ABSPP and CBPP3 and APP programmes all contributed to this decline.⁴

Our concern is how these changes in composition and cost of funds impacted lending rates. Even though policy succeeded in compressing funding costs, lending rates were sticky and slow to adjust between 2011-2014. ECB (2015b) shows that banks that participated in at least one of the first four TLTRO programmes were more likely to lower their lending rates than non-participants. However, once again, whether the banks were located in vulnerable or less vulnerable countries was important, since variation in lending rates by banks in vulnerable countries did not appear to be linked to participation. Median lending rates in vulnerable countries fell from 3.89% to 2.44% from September 2011 to July 2015, while in less vulnerable countries they fell from 3.21% to 1.76%.

Our analysis is designed to evaluate the effects of different monetary policy operations through various channels, and we turn now to the methodology to explain how we identify the effects in a structural dynamic factor model.

4 Econometric Methodology

This section discusses the details of estimation, structural identification, and the computation of impulse response functions and rolling-windows. Of particular note is equation (8) which provides the identification scheme. These details are included for completeness, but the reader may proceed straight to Section 5 for the data and empirical results without much loss of continuity.

⁴Surprisingly, France had the highest composite cost of bank funding among the major euro area countries from 2008-2012, but Italy and Spain had higher costs from 2012 -2015. Germany consistently had the lowest cost of funds from 2008 - 2015.

4.1 The Reduced-form model

The analysis is based on the dynamic factor model in static form (as in Stock and Watson 2005):

$$X_t = \Lambda F_t + e_t, \quad t = 1, \dots, T; \quad (1)$$

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

$$\begin{aligned} F_t &= A_1 F_{t-1} + A_2 F_{t-2} + \dots + A_p F_{t-p} + u_t, \quad \text{or} \\ A(L)F_t &= u_t, \quad A(L) = I - A_1 L - A_2 L^2 - \dots - A_p L^p, \end{aligned} \quad (2)$$

which admits a moving-average representation:

$$F_t = \Phi(L)u_t, \quad \Phi(L) = I_r + \Phi_1 L + \Phi_2 L^2 + \dots, \quad \Phi(L) = A(L)^{-1}. \quad (3)$$

Let X_{it} be a variable of interest:

$$X_{it} = \lambda'_i F_t + e_{it}, \quad t = 1, 2, \dots, T. \quad (4)$$

This can be an informational variable or an additional variable, which is not included in the data set for computing latent factors. In our application X_{it} is a bank lending rate to households or firms.

The objective is to identify latent factors and make inference about responses of X_{it} to structural shocks in the factors, where these factors may be taken as proxies for the real and nominal sectors of the economy, exchange rates, the monetary sector, uncertainty or volatility of the stock market and long and short interest rates (as detailed in Section 5).

4.2 The Structural model

Using an $r \times r$ invertible matrix S , we let the structural factor model be defined as (see Stock and Watson 2005 or Yamamoto 2016):

$$\begin{aligned} X_t &= \Lambda^s F_t^s + e_t, \\ F_t^s &= A_1^s F_{t-1}^s + A_2^s F_{t-2}^s + \dots + A_p^s F_{t-p}^s + v_t, \end{aligned} \tag{5}$$

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

$$F_t^s = \Psi(L) v_t, \quad \Psi(L) = I_r + \Psi_1 L + \Psi_2 L^2 + \dots, \quad \Psi(L) = S^{-1} \Phi(L) S. \tag{6}$$

Invertibility of matrix S , allows us to examine the impact of the innovations (or shocks) to the factors on the interest rates that banks set for households and firms as we now explain.

4.3 Structural identification

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

$$X = F \Lambda' + e,$$

$$F = Z A + u,$$

where X is the $T \times N$ matrix of observed variables (bank lending rates), e is the $T \times N$ matrix of idiosyncratic shocks, $F = (F_1, F_2, \dots, F_T)'$ is the $T \times r$ matrix of factors, $Z = (F_{(-1)}, F_{(-2)}, \dots, F_{(-p)})$ is $T \times rp$ matrix of factor lags, $F_{(-k)} = (F_{1-k}, \dots, F_{T-k})'$, and $A = (A_1, \dots, A_p)'$ is $rp \times r$ matrix of parameters. For the structural model (5), the matrix form is

$$X = F^s \Lambda^{s'} + e,$$

$$F^s = Z^s A^s + v,$$

where $F^s = F[S^{-1}]'$, $\Lambda^s = \Lambda S$, $Z^s = Z[I_p \otimes [S^{-1}]']$, $A^s = [I_p \otimes S'] A[S^{-1}]'$, and $v = u[S^{-1}]'$. We work with these to identify the structure of the relationships between the factors and the

interest rates that banks set for households and firms in each country.

Statistical identification, implemented in the method of principals components, is achieved by imposing orthonormality of factors, $F'F/T = I_r$, which implies $(r^2 + r)/2$ restrictions, and diagonality of $\Lambda'\Lambda$, which implies $(r^2 - r)/2$ restrictions, for the total of r^2 restrictions. This is a short-run identification scheme rather than a restriction on the long-run relationships or sign restrictions on the variables. They have an intuitive explanation, and like BBE, we put structure on the factors themselves not on the shocks.

Structural restrictions, imposed in this paper, are similar to short-term restrictions in Stock and Watson (2005) and Yamamoto (2016). Firstly, the covariance matrix of structural shocks $E(v_t v_t')$ is assumed to be diagonal. This implies $(r^2 - r)/2$ restrictions. Secondly, the matrix Λ^s is assumed to be composed of two sub-matrices:

$$\Lambda^s = \begin{bmatrix} \Lambda_{1:r}^s \\ \Lambda_{r+1:N}^s \end{bmatrix}, \text{ where } \Lambda_{1:r}^s = \begin{bmatrix} 1 & 0 & \dots & 0 \\ \lambda_{21}^s & 1 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ \lambda_{r1}^s & \lambda_{r2}^s & \dots & 1 \end{bmatrix}. \quad (7)$$

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

The identification of factors depends on the choice and ordering of the first r variables in the data matrix X . For the first r informational variables

$$\begin{aligned} X_{1t} &= F_{1t}^s + e_{1t}, \\ X_{2t} &= \lambda_{21}^s F_{1t}^s + F_{2t}^s + e_{2t}, \\ &\vdots \\ X_{rt} &= \lambda_{r1}^s F_{1t}^s + \lambda_{r2}^s F_{2t}^s + \dots + F_{rt}^s + e_{rt}. \end{aligned} \quad (8)$$

The first variable instantaneously responds to a shock in the first structural factor only: a unit shock in the first factor implies a unit shock to the first variable. The second variable 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 2 is equal to one, and so on. This ordering is important in the context of the effects we intend to measure and in the identification of the role played by the various factors in influencing lending rates. A discussion of these issues is provided below in Sections 5 and 6.

4.4 Impulse response functions

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

$$X_{it} = \lambda'_i \Phi(L) u_t + e_{it},$$

the reduced-form impulse response of variable X_{it} to a shock in factor j ($j = 1, 2, \dots, r$) at horizon h ($h = 1, 2, \dots$) is

$$\phi_{ijh} = \frac{\partial X_{it+h}}{\partial u_{jt}} = \lambda'_i \Phi_h^{(j)},$$

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

$$\psi_{ijh} = \frac{\partial X_{it+h}}{\partial v_{jt}} = \lambda'_i S \Psi_h^{(j)}, \quad (9)$$

where $\Psi_h^{(j)}$ is the j th column of matrix Ψ_h . From this information we can analyse the monetary transmission channels and consider the stability of the relationships.

4.5 Estimation Procedure

Our estimation procedure follows five simple steps.

1. **Standardization and Estimation of Statistical Factors:** Model (1) is specified and estimated for standardized data: $X_{it} = (Z_{it} - \hat{\mu}_i)/\hat{\sigma}_i$ for each $i = 1, 2, \dots, N$ and $t = 1, 2, \dots, T$, where Z_{it} is the original (unstandardized) variable, $\hat{\mu}_i$ is the sample mean and $\hat{\sigma}_i^2$ is the sample variance of Z_{it} . The principal components estimator of F , denoted by $\tilde{F}$, is a $(T \times r)$ matrix composed of $\sqrt{T}$ times the eigenvectors corresponding r largest eigenvalues of the matrix XX'/NT (arranged in decreasing order), where the normalization $\tilde{F}'\tilde{F}/T = I_r$ is used. Then $\tilde{\Lambda} = X'\tilde{F}/T$ is a $(N \times r)$ matrix of estimated loadings.
2. **Estimation of factor VAR model:** The model (2) is estimated by the OLS and the moving average parameter matrices $\hat{\Phi}_j$, $j = 1, 2, \dots$, are derived recursively.

3. **Structural Identification:** The structurally restricted estimators $\hat{F}^s$ and $\hat{\Lambda}^s$, are obtained using a LDL' decomposition of $\hat{\Lambda}_{1:r}\hat{\Sigma}_u\hat{\Lambda}'_{1:r}$. The decomposition yields $\hat{\Lambda}_{1:r}\hat{\Sigma}_u\hat{\Lambda}'_{1:r} = LDL'$, where L is a unitary lower triangular matrix and D is a diagonal matrix. Then the identification matrix is

$$\hat{S} = \hat{\Lambda}_{1:r}^{-1}L \quad (10)$$

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

$$\hat{\Lambda}_{1:r}^s = \hat{\Lambda}_{1:r}\hat{S} = \hat{\Lambda}_{1:r}\hat{\Lambda}_{1:r}^{-1}L = L. \quad (11)$$

For the covariance matrix of structural shocks we have

$$\hat{\Sigma}_v = L^{-1}\hat{\Lambda}_{1:r}\hat{\Sigma}_u\hat{\Lambda}'_{1:r}(L^{-1})' = D. \quad (12)$$

The estimated structural shocks to factors, $\hat{v}_t = \hat{S}^{-1}\hat{u}_t$, are restricted to be orthogonal, though the estimated structural factors, $\hat{F}_t^s = \hat{S}^{-1}\hat{F}_t$, are not restricted to be orthogonal. The moving-average parameter matrices of the structural VAR model are $\hat{\Psi}_j = \hat{S}^{-1}\hat{\Phi}_j\hat{S}$, $j = 1, 2, \dots$.

4. **Computation of Impulse Responses:** For variable X_{it} structural impulse responses can be computed using equation (9).
5. **Computation of Confidence Intervals for Impulse Responses:** In order to evaluate uncertainty about estimated impulse responses, 90 percent bootstrap confidence intervals are computed using Procedure B from Yamamoto (2016). The procedure accounts for uncertainty in the estimators of factor VAR and loadings. The details of the procedure are reported in Appendix A.

4.6 Rolling Window Estimation

Finally, in order to evaluate changes in the pass-through, we compute rolling window estimates of the factor VAR and factor loadings. These correspond to re-computation of the impulse responses for the rolling sub-samples of data from 2007 to the end of the sample. This allows us to explore the stability of the relationships in each country to determine whether the banks

respond differently across countries to the various policy actions taken by the ECB during this period as discussed in Section 3. Full details of this analysis are given in Section 6.2.

Thus, for each $s = w, w + 1, \dots, T$, the following model is estimated:

$$\begin{aligned}\widehat{F}_t^{(T)} &= A_1 \widehat{F}_{t-1}^{(T)} + A_2 \widehat{F}_{t-2}^{(T)} + \dots + A_p \widehat{F}_{t-p}^{(T)} + u_t, \\ X_t &= \Lambda \widehat{F}_t^{(T)} + e_t, \quad t = s - w + 1, s - w - 1, \dots, s;\end{aligned}$$

where w is a window size and $\widehat{F}_t^{(T)}$ is the full-sample estimate of (statistical) factors.

The size of the window is set to 90 months: $w = 90$. The initial estimation is carried out using data from February 2000 to July 2007. The final estimation is carried out using data to June 2016. In determining the size of the window we face the usual tradeoff between the precision of each set of estimates (longer windows) and having enough (rolling) estimates to capture the variation in the data (shorter windows). A window length of 90 months is an acceptable compromise. In the limit, the analysis could be reduced to looking at the results from a rather discrete subsample analysis (say if we had only two or three windows from which estimates could be extracted if the windows were wide enough.) We are keen to avoid such a situation and thus pay a certain price in terms of precision in order to capture more variation.

For each of the rolling estimates, structural identification is carried out and impulse response functions of lending rates to shocks in structural factors as well as contributions of Factors 4-6 to the forecast error variance decompositions are computed. The factors however are estimated from the full data set and considered as data in the rolling analysis.

5 Data Description

The data set for each country comprises various macroeconomic and financial indicators including indices of industrial production, price indices, exchange rates, stock and credit market indices, and interest rates (see Appendix B). The time span of the data is from January 2000 to June 2016. Before factor estimation, the data are transformed to ensure stationarity and to remove seasonal effects and outliers.

The retail (lending) rates studied here are total (all maturities) new business rates on mortgage loans (loans for house purchases) and corporate loans (loans to non-financial corporations).

The ECB classifies the retail rate on new business by the period of initial rate fixation. The structure of loans differs across countries with respect to the period of initial rate fixation: while a large share of loans in Germany and France has a period of initial rate fixation over 1 year, a dominant share of loans in Italy and Spain has either floating rates or rates with a period of initial rate fixation of under 1 year. After the sovereign debt crisis, the share of loans with a period of initial rate fixation of over 1 year has shrunk even more in these countries resulting in erratic behaviour of retail rates with a period of initial rate fixation of over 1 year, as these rates are computed on the basis of small number of transactions. Using retail rates with a period of initial rate fixation of over 1 year would provide little information about pass-through for Italy and Spain. In order to overcome these difficulties, and retain comparability across countries, we have chosen to work with somewhat aggregate measures of these rates, although our methodology can be applied to any desired level of disaggregation.

Referring back to Section 4.3, seven common factors are estimated for each country and the structural identification scheme indicated above is implemented. The choice of the number of common factors is based on a heuristic criterion of marginal R^2 (see Forni and Reichlin 1998). Figures 1-4 show marginal R^2 values for each structural factor in regressions of individual variables onto factors. Each structural factor is strongly correlated with a set of variables which characterize the sector of the economy associated with the corresponding identifying variable. Factors 1-4 are correlated with production indices, price indices, exchange rates and monetary aggregates correspondingly. Factors 5-7 are correlated with financial market indicators, long-term and short-term rates. It is interesting to note that Figures 1 - 4 of the ‘factor loadings’ demonstrate how well particular groups are correlated with the identified factors, although these partial correlations are not used for factor identification. That is, although a lower triangular structure is employed to identify factors, (X_{1t} corresponding to IP.Manuf, X_{2t} to HICP. and so on for the seven variables in Table 1 below), there is little or no contemporaneous correlation of identified factors with other groups of variables: each factor is strongly correlated with that group of variables to which an identifying variable belongs (e.g. Factor 6 identified with the help of the 10-year swap rate is only strongly correlated with long-term rates, although no restriction is imposed on its correlation with short-term rates.)

The variables in Table 1 below therefore justify the identification of factors for two reasons: they offer the possibility of structural interpretation of common factors and provide a high correlation with the principal components.

Table 1: Selection of Identifying Variables

#	Mnemonic	Description	Transformation
1	IP.Manuf	index of industrial production, manufacturing	log-difference
2	HICP.All	index of consumer prices, all items	log-difference
3	REER42	real effective exchange rate	log-difference
4	M2	monetary aggregate M2	log-difference
5	EUROSTOXX	stock market index	log-difference
6	SWPSPR10Y	10-year swap rate	difference
7	EURIBOR6M	6-month Euribor	difference

The lower-triangular ordering adopted may be justified following BBE’s seminal contribution, subsequently adopted by much of the literature. Interest rates are ordered after indicators of production and prices. This ordering is based on the assumption that production and prices cannot respond contemporaneously (within a period) to shocks in interest rates. The ordering of real and nominal variables before financial variables and interest rates is consistent with BBE. Within the latter group however it may be possible to think of different ordering - for example ordering long rates after short rates - and we have experimented with different orderings without the main conclusions being altered. We are also guided by BBE in regarding the short rate as the most responsive to all information and also by the loading structures discussed above.

Taking the factors in reverse order, a shock to Factor 7, identified using 6-month Euribor, can be interpreted a shock to short-term (money market) rates which has no contemporaneous (within a period) effect on other sectors of the economy. A shock to Factor 6 implies a shock to long-term interest rates which has no contemporaneous effect on Factors 1-5 and a shock to Factor 5 implies a financial market shock which has no contemporaneous effect on Factors 1-4. In the next section we consider responses of bank lending rates to shocks in factors 5-7 in detail.

6 Results

6.1 Pass Through in Four Euro Area Countries

Since our main focus is on interest rate setting, we concentrate our discussion on the structurally identified effects of Factors 5-7 to understand the evolution of bank lending rates to households and firms. These are the main channels through which conventional and unconventional monetary policy has operated since the crisis.⁵

We will refer to them in reverse order. Under our chosen identification scheme, which is confirmed by the loadings reported in Figures 1-4, a positive shock to Factor 7 is associated with an unexpected permanent shift in the level of short-term interest rates, a positive shock to Factor 6 is associated with a shift in the level of long-term yields, and a shock to Factor 5 implies a shift in stock indices, volatility (VIX) and credit spreads.

Figures 5-8 show the full-sample estimates of impulse responses of total new business corporate and mortgage rates to structural shocks in Factors 5-7. There are observable responses of bank lending rates to the factors in each country. The bottom panel shows a significant positive response of bank lending rates to structural shocks in Factor 7 identified with short-term (6-month EURIBOR) wholesale rates; it has a similar impulse response in all four euro-area economies. The effects transmit a positive impulse to corporate and mortgage lending rates which then dies away quickly (within four months) as we would expect. The response to long term yields (Factor 6) and financial risks (Factor 5) also transmit a positive impulse but die away over a longer period (8-10 months). Together these impulse responses imply that shocks to these three financial factors were transmitted quite quickly to lending rates, but to evaluate the degree of pass through we need to consider the estimates of the long-run responses.

Table 2 shows the long-run responses to these factors with 90% confidence intervals. We see that the response to Factor 7 associated with short rates is significant, but while the point estimates differ from unity in some cases, the 90% confidence interval encompasses unity with only two exceptions. This implies that for most cases the results are consistent with complete pass through from short rates to corporate and mortgage lending rates in all four countries even when the point estimates are lower than one. In pre-crisis studies of interest pass through, such as Angeloni, Kashyap and Mojon (2003), the interest rate channel was the dominant influence

⁵Our model has seven factors, the first four factors capture the effects of real activity, nominal variables and real effective exchange rates. Full results of the impulse response analysis of Factors 1-4 are available from the authors on request.

of monetary policy. As a result many studies have focused exclusively on the pass through of short-rates, ECB (2013), Hristov et al. (2014), Altavilla et al. (2015) and Altavilla et al. (2017) suggests pass through has diminished since 2007, while von Borstel et al. (2016) argue it has not changed. In this study we emphasize that we are concerned about pass through of all three phases of ECB monetary policy, which focuses attention on the impact of long-term yields and risk factors as well as short rates. The interest rate channel operating through short rates may still retain its significance but other channels have become relatively more important since the crisis as subsequent analysis will show.

Some of the exceptions to full short-term interest rate pass through in Table 2 are interesting in their own right. One of these exceptional cases occurs for German mortgage rates, which demonstrate a low level of estimated pass through for short rates (Factor 7), but a high estimated pass through (close to unity) on long-term yields (Factor 6). This seems to match the fact that many German banks have consistently issued covered bonds to finance their mortgage lending activity (van Rixtel and Gasperini 2013). The evidence for France, reveals pass through of long-term yields (Factor 6) is also close to unity for corporate loans, but only 0.45 for mortgages, for Italy pass through for corporate loans is close to 0.65 but it is much weaker for mortgage lending rates than in Germany. Although covered bond issuance grew in France, Italy and Spain through the sovereign debt crisis, which may have raised the sensitivity of lending rates to long term yields over this period, for much of our sample covered bond issuance was not particularly high. Our pass through estimates for the full sample period may reflect this.

All four countries show relatively low pass through of risk measures (Factor 5) to lending rates but exploration of the evolution of the pass-through using 90-month rolling-window estimations and variance decompositions over the critical period 2008-2013 sheds more light on this matter.

6.2 Exploring Changes in Monetary Transmission Through the Crisis

An important question we need to address is whether there was any variation in the relative importance of our three factors over the sample period, and particularly during the period starting with the global financial crisis and encompassing the sovereign debt crisis. This period runs from 2008 - 2012, but we estimate the effects to the end of the sample.

We know that the ECB relied less on the use of main refinancing operations as the financial

crisis unfolded, and subsequently developed the use of liquidity operations, forward guidance and its balance sheet to influence the path of long-term yields (ECB 2015a, Praet 2017a, b). Euro area bank lending surveys and ECB (2015b) show that lending was influenced through the yields on securities issued by banks as the ECB used TLTRO and APP programmes to lower long-term yields (see Praet 2017a). In Germany and France the reported effects from event studies suggest 10 year bond yields fell by 12-17 basis points, and in Italy and Spain by larger amounts (15-18 basis points in Spain and 26-56 basis points in Italy). The effects of asset purchase programmes is likely to have stimulated portfolio rebalancing, as assets purchased by the ECB were initially purchased with more liquid but lower yielding assets, but gradually were replaced by other assets such as sovereign bonds with higher yields (see Constâncio 2015). This would have further lowered longer term interest rates making funding costs cheaper, allowing banks to lower retail rates.

The results of our analysis are interpreted in the context of a counterfactual exercise, simulating changes in the perceived responsiveness of bank lending rates to shocks in the identified factors. The perceived responsiveness is based on the 90-month rolling-window estimation of a small-scale FAVAR model, which is carried out in the aftermath of the financial crisis.⁶

Figures 9-12 show the three dimensional response surfaces of lending rates (expressed in percentage points on the vertical axis) to unit shocks in Factors 5, 6 and 7 over time running from July 2007 to June 2016, with impulse responses given for a horizon of 12 months.

Considering first the impulse responses of mortgage and corporate loan rates to Factor 7 we can explore how the perceived responsiveness of retail rates to short-term interbank rates changed as the crisis progressed. For all four countries the responses of retail rates shows a sharp initial response that tails off quickly. For most countries the estimated initial response is much higher than the corresponding impulse response for the full sample reported for each country/lending rate in Figures 5-8. We conclude from this that the response to short-term interest rates initially rose during the crisis but subsequently fell below the average level for the full sample. We can see some variation over time, which results from individual country effects e.g. mortgage and corporate lending rates in Germany became much less responsive after 2010 to 6-month Euribor, and this shows that during the sovereign debt crisis German banks were net lenders on the interbank market not borrowers. A similar response is seen for French banks.

⁶The responses, based on the rolling-window estimates, should be interpreted as measures of hypothetical responses assuming the model is correct. The analysis helps to understand the relationship between the development of the crisis, policy responses to the crisis and perceived changes in the pass-through implied by the model.

As the crisis progressed and the unconventional policy measures were implemented policy impacted on banks' funding costs through long-term market yields. The OMT announcement in July 2012 and subsequent TLTRO and asset purchase programmes from 2014 lowered the yields on sovereign bonds and covered bonds. The variation in responsiveness to shocks in Factor 6 in 2009-2012 can be observed in all considered countries. In the early years 2008-09 banks passed through the long rates quite quickly (within a few months), but after 2010 the effects lingered for some time as can be seen by the shallower slope of the impulse response functions for each country/lending rate. It is possible to observe a fall in the initial impact of long-term yields on corporate lending rates in France, Italy and Spain. While the initial impact of the shock was smaller than the effects reported in Figures 5-8, the shocks did not die out as quickly, which implies the pass through occurred more gradually after 2010 over a period of many months. This may reflect a change in the funding environment as banks relied on longer term funding (liquidity and securities issues) that had a more persistent effect on lending rates and suggests that the signaling, expectations and portfolio rebalancing channels discussed in Constâncio (2015) began to play a greater role.

A similar observation can be made about financial risks recorded in the responses to Factor 5, which also showed a lower but more persistent response to shocks that extended the pass through over time. In all countries at the end of 2008 and the beginning of 2009 the magnitude of the initial impact increased significantly, but it deteriorated very quickly over the 12 month horizon. After 2010 however, the effects were longer lasting, and mounted noticeably in the sovereign debt crisis for France, Italy and Spain. They were lower thereafter in response to the Outright Monetary Transactions (OMT) announcement in July 2012 and subsequent TLTRO and asset purchase programmes from 2014 as we might expect from the discussion of the effects of risks on the banking system (via the bank lending channel) in Constâncio (2015).

Our results offer a general picture, which is consistent with the research based on data from the credit register in Italy by Gambacorta and Mistrulli (2014). They show that the spread between loan rates and short term borrowing costs widened due to the overall rise in credit risk although bank-firm relationships shielded certain borrowers from the full effects of the crisis.

Figures 13-16 show the contributions of Factors 4-6 to the forecast error variance decomposition for bank lending rates, based on the rolling-window estimates. The decomposition is computed for horizons of 1, 6, and 12 months over period from 2008 to 2016. The total contribution of Factors 5-7 to the variance decomposition decreased over time; however, the contribution of individual factors followed heterogeneous dynamics across countries and bank

lending rates and that is where we focus our attention.

Among financial factors, Factor 7, associated with short-term rates, made the greatest contribution to forecast error variance, although there is observable difference between countries, products and different horizons. In Germany Factor 6 (long term yields) was more important in the immediate aftermath of the crisis, but Factor 7 become progressively more important, especially for corporate lending. In France, Italy and Spain, Factor 7 made the greatest contribution to the forecast error variance for corporate lending and mortgages. The initially negligible contribution of the financial risk factor (Factor 5) increased in 2009 in all four countries as would be expected in the aftermath of a crisis. There were noticeable reductions in the financial risk factor in 2012 and 2014 when OMT announcements and other unconventional monetary policy operations (LTROs, TLTROs and asset purchase programmes such as CBPP3 and ABSPP) were implemented.

The conclusions we draw are that the effects of shocks to long-term yields and financial risks in particular had longer lasting effects on corporate and mortgage lending rates, while shocks to short rates died out relatively quickly and were smaller in magnitude than observed for the full sample. We support the general view (Hristov et al. 2014, ECB 2013, and von Borstel et al. 2016) that pass through diminished during the crisis, but we offer more detail on the impact of unconventional policy through structural factors associated with long-term yields and financial risks, and its variation over time. There are notable increases in the influence of long term yields and financial risk factors after the crisis which were reduced by the use of various unconventional policies by the ECB consistent with the descriptions offered by Constâncio (2015) and Praet (2017a).

7 Conclusions

Monetary policy is under scrutiny as never before, and particularly in terms of its ability to influence bank retail rates. This is because so much credit for real activity in the euro area is intermediated through the banking system. In this paper we make use of a new structurally identified dynamic factor model to explain the impact of monetary policy on lending rates. This is a step forward from the Bernanke et al. (2005) FAVAR model used prior to the financial crisis to improve structural VARs, and extended by others to explore episodes when short policy rates were at the zero lower bound. With our new methodology based on Stock and Watson (2005) and Yamamoto (2016) applied to this issue for the first time, we are not restricted to

explore the impact of short-term policy shocks or a single summary measure of monetary policy that becomes increasingly difficult to reconcile with the many unconventional monetary policy actions of the European Central Bank. Unconventional monetary policy actions of the ECB have had an impact on the level of short-term interest rates, long-term bond yields, and on risk perceptions (see Giannone et al. 2011 and Altavilla et al. 2015). Movement in these three factors have been shown to influence the cost of funds for banks via signaling, expectations and portfolio rebalancing channels and therefore to reduce bank lending rates.

Based on our analysis, a picture emerges of lower point estimates of pass through of short-term interest rates during and after the global financial crisis compared to the full sample estimates, but long-term yields played a greater part than before. We show that the impact of policy was nevertheless swift for factors picking up short-term interest rates and slightly slower and more persistent for factors picking up the effects of long-term yields and financial risks. Our results captured by the impulse responses using rolling window algorithms illustrate the differential impact of monetary policy between countries and over different episodes of the financial and sovereign debt crises. A particular advantage of using structurally identified factors corresponding to rates and risk factors is that we can observe the effect of new monetary policy instruments used by the ECB verifying that the monetary transmission channels cited by Praet (2017a) did influence interest rate pass through.

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Appendix A: Outline of Bootstrap Procedure

For each bootstrap iteration $k = 1, 2, \dots, K$

- (1) Resample the (centered) residuals $\{\hat{e}_t\}$ and $\{\hat{u}_t\}$ with replacement and label them $\{e_t^{(k)}\}$ and $\{u_t^{(k)}\}$; generate bootstrap samples $\{F_t^{(k)}\}$ and $\{X_t^{(k)}\}$ from

$$\begin{aligned} F_t^{(k)} &= \tilde{A}_1 F_{t-1}^{(k)} + \tilde{A}_2 F_{t-2}^{(k)} + \dots + \tilde{A}_p F_{t-p}^{(k)} + u_t^{(k)}, \\ X_t^{(k)} &= \hat{\Lambda} F_t^{(k)} + e_t^{(k)} \end{aligned}$$

- (2) Get estimates $\hat{\Lambda}^{(k)}$ by the OLS
- (3) Use the bootstrap factors $F_t^{(k)}$ to get (bias-corrected)* estimates of parameters of the bootstrap factor VAR model, $\hat{A}_1^{(k)}, \hat{A}_2^{(k)}, \dots, \hat{A}_p^{(k)}$ and $\hat{\Sigma}_u^{(k)}$
- (4) Compute the bootstrap matrix of structural restrictions $\tilde{S}^{(k)}$; compute and store the bootstrap impulse responses $\hat{\psi}_{ijh}^{(k)}$.

Sort the bootstrap impulse responses $\{\hat{\psi}_{ijh}^{(k)}\}_{k=1}^K$ and for given $\alpha \in (0, 1)$ select $100\%\alpha$ and $100\%(1 - \alpha)$ percentiles $(\hat{\psi}^\alpha, \hat{\psi}^{1-\alpha})$. The resulting $100(1 - 2\alpha)$ confidence interval for ψ_{ijh} is $(\hat{\psi}_{ijh} - \hat{\psi}^{1-\alpha}, \hat{\psi}_{ijh} - \hat{\psi}^\alpha)$

Bias correction is carried using Kilian (1998) procedure as implemented in Yamamoto (2016).

Appendix B: Data Description

Table: Data Description

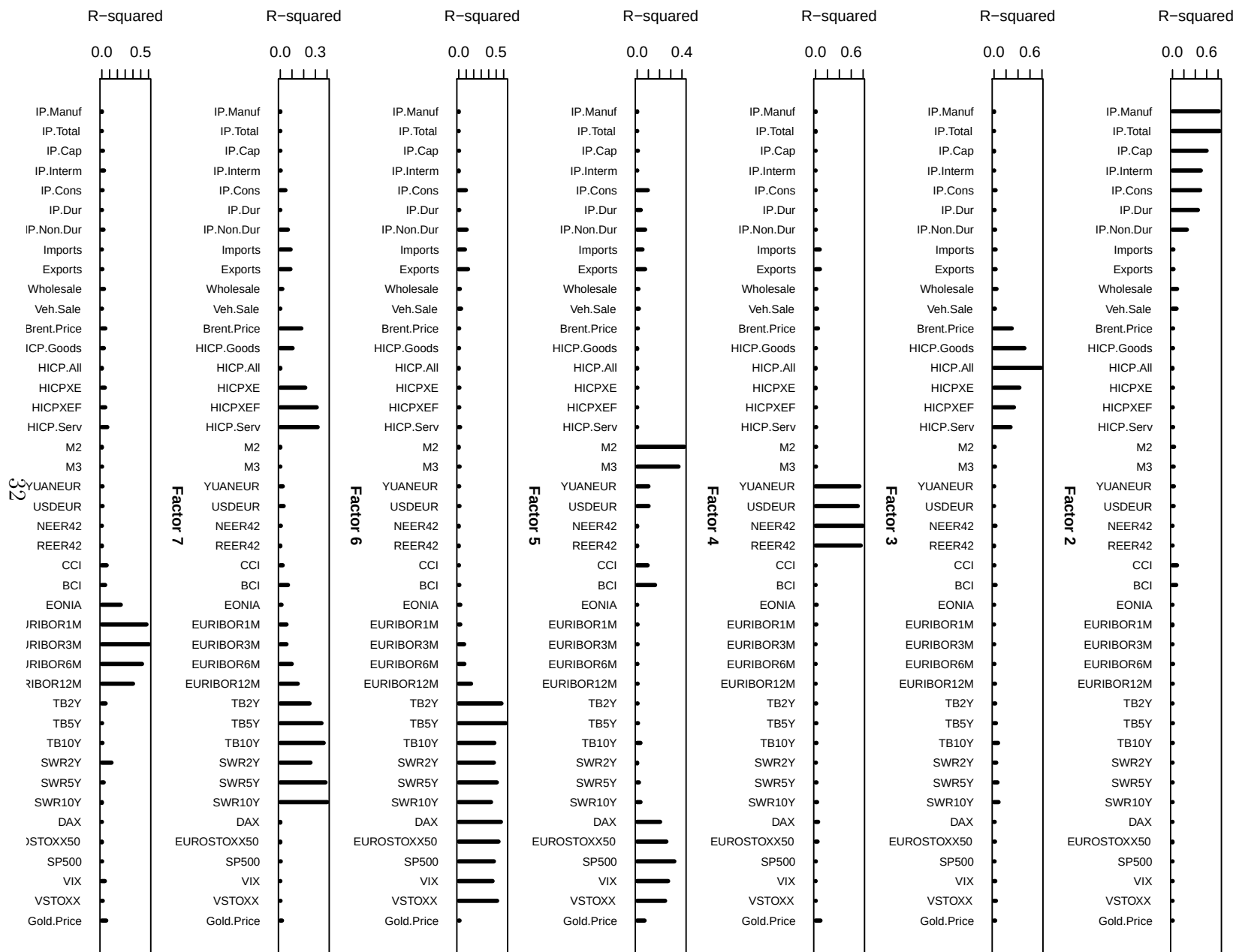
Mnemonic	Description	Data Source	SA*	TC**
IP.Manuf	Manufacturing, volume index of production	Eurostat	Yes	2
IP.Total	Industry, volume index of production	Eurostat	Yes	2
IP.Constr	Construction, volume index of production	Eurostat	Yes	2
IP.Non.Dur	Non-durable consumption goods, volume index of production	Eurostat	Yes	2
IP.Dur	Durable consumption goods, volume index of production	Eurostat	Yes	2
IP.Interm	Intermediate goods, volume index of production	Eurostat	Yes	2
IP.Cap	Capital goods, volume index of production	Eurostat	Yes	2
Exports	Total exports, current prices, EUR mln	Eurostat	Yes	2
Imports	Total imports, current prices, EUR mln	Eurostat	Yes	2
HICP.Goods	Harmonized index of consumer prices, goods	Eurostat	Yes	2
HICP.ALL	HICP, all items	Eurostat	Yes	2
HICP.XE	HICP, all items, excluding energy	Eurostat	Yes	2
HICP.XEF	HICP, all, excluding energy and food	Eurostat	Yes	2
HICP.Serv	HICP, services	Eurostat	Yes	2
CCI	Consumer confidence indicator	OECD	Yes	2
BCI	Business confidence indicator	OECD	Yes	2
YUANEUR	Exchange rate, YUAN	ECB	No	2
USDEUR	Exchange rate, USD	ECB	No	2
NEER42	Nominal effective exchange rate - 42 trading partners	Eurostat	Yes	2
REER42	Real effective exchange rate - 42 trading partners	Eurostat	Yes	2
M1	M1 Stock	National CB	Yes	2
M2	M2 Stock	National CB	Yes	2
M3	M3 Stock	National CB	Yes	2
EONIA	EONIA, overnight rate	No	1	
EURIBOR3M	EURIBOR, 3 Months	ECB	No	1
EURIBOR6M	EURIBOR, 6 Months	ECB	No	1
EURIBOR12M	EURIBOR, 12 Months	ECB	No	1
SWR2Y	Swap rate, 2 years	Bloomberg	No	1
SWR5Y	Swap rate, 5 years	Bloomberg	No	1
SWR10Y	Swap rate, 10 years	Bloomberg	No	1
TBSPR2Y	Treasury bond yield, 2 years	Bloomberg	No	1
TBSPR5Y	Treasury bond yield, 5 years	Bloomberg	No	1
TBSPR10Y	Treasury bond yield, 10 years	Bloomberg	No	1
CDS.GVT	CDS spread, 5 years, Government	Bloomberg	No	1
DAX/CAC/FTSE/IGBM	Country-specific stock exchange index	Yahoo!Finance	No	2
EUROSTOXX	EUROSTOXX 50 index	ECB	No	2
SP500	US stock exchange index	Yahoo!Finance	No	2
VSTOXX	EUROSTOXX volatility index	STOXX	No	1
VIX	CBOE volatility index	Yahoo!Finance	No	1
Gold.Price	London Gold Price, USD/roy ounce	BoE	No	2

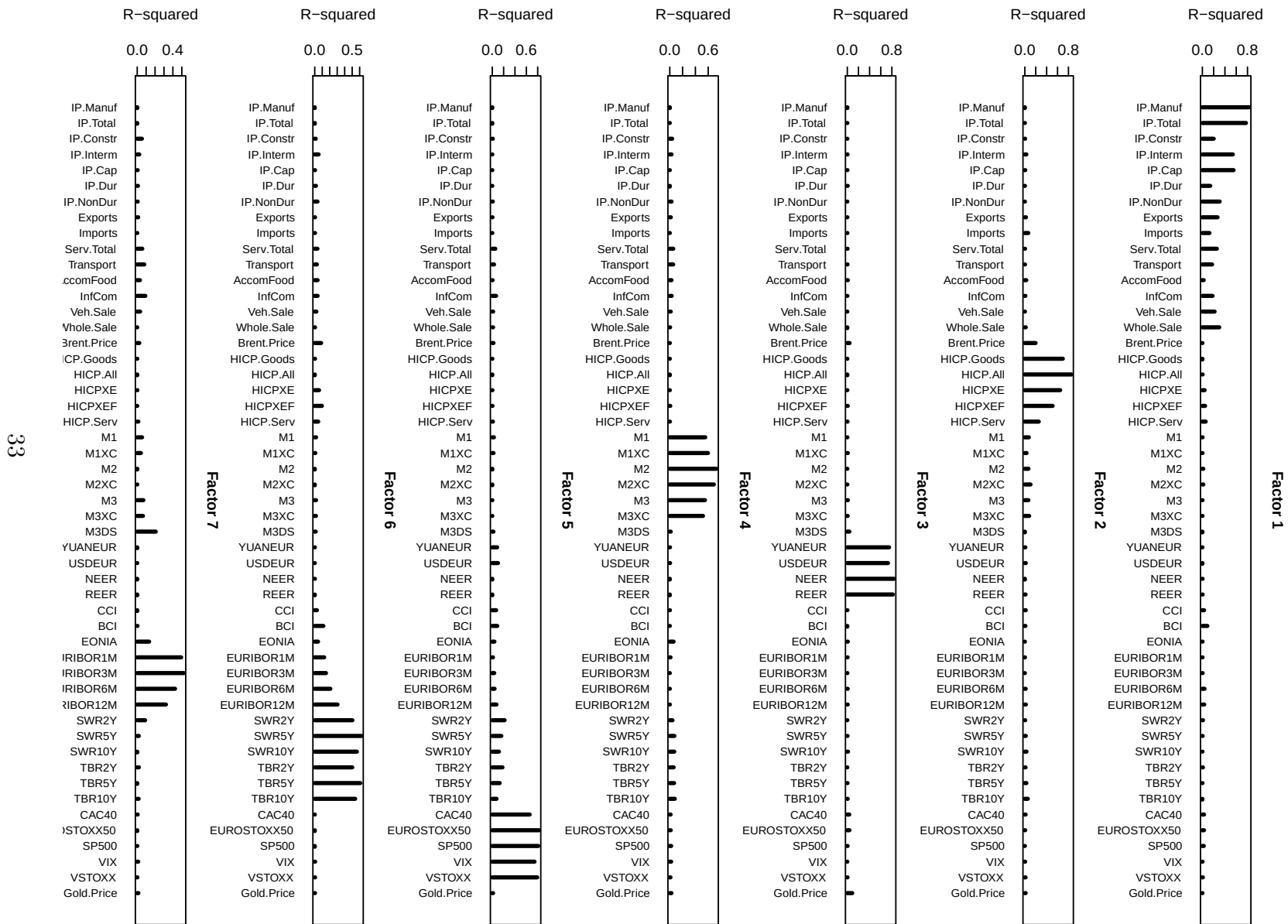
*Seasonal adjustment: Yes - series was adjusted, No - series was not adjusted

**Transformation code: 1- difference, 2 - log-difference

Table 1: Estimates of Long-Run Responses, 90-percent Bootstrap Confidence Intervals

		Germany	France	Italy	Spain
Corporate Rate	Factor 5	0.5711	0.6148	0.3917	0.4494
		[0.1119,1.0369]	[0.2241,1.0587]	[0.1241,0.7001]	[0.1476,0.7673]
	Factor 6	1.2896	0.9655	0.6464	0.2777
		[0.4833,2.3232]	[0.4256,1.6022]	[0.1906,1.1977]	[0.1026,0.4651]
	Factor 7	1.0198	0.8522	1.5724	0.8496
		[0.6583,1.3609]	[0.6041,1.1108]	[1.0582,2.2481]	[0.5125,1.2080]
Mortgage Rate	Factor 5	0.3143	0.2365	0.1669	0.4913
		[0.1031,0.5377]	[0.0694,0.4480]	[0.0349,0.3234]	[0.1326,0.8949]
	Factor 6	1.0441	0.4509	0.2747	0.3712
		[0.4038,1.8508]	[0.1454,0.8063]	[0.0502,0.5720]	[0.1302,0.6445]
	Factor 7	0.5097	0.8043	1.0824	1.0189
		[0.2534,0.7570]	[0.5025,1.1631]	[0.6395,1.6515]	[0.6648,1.3865]





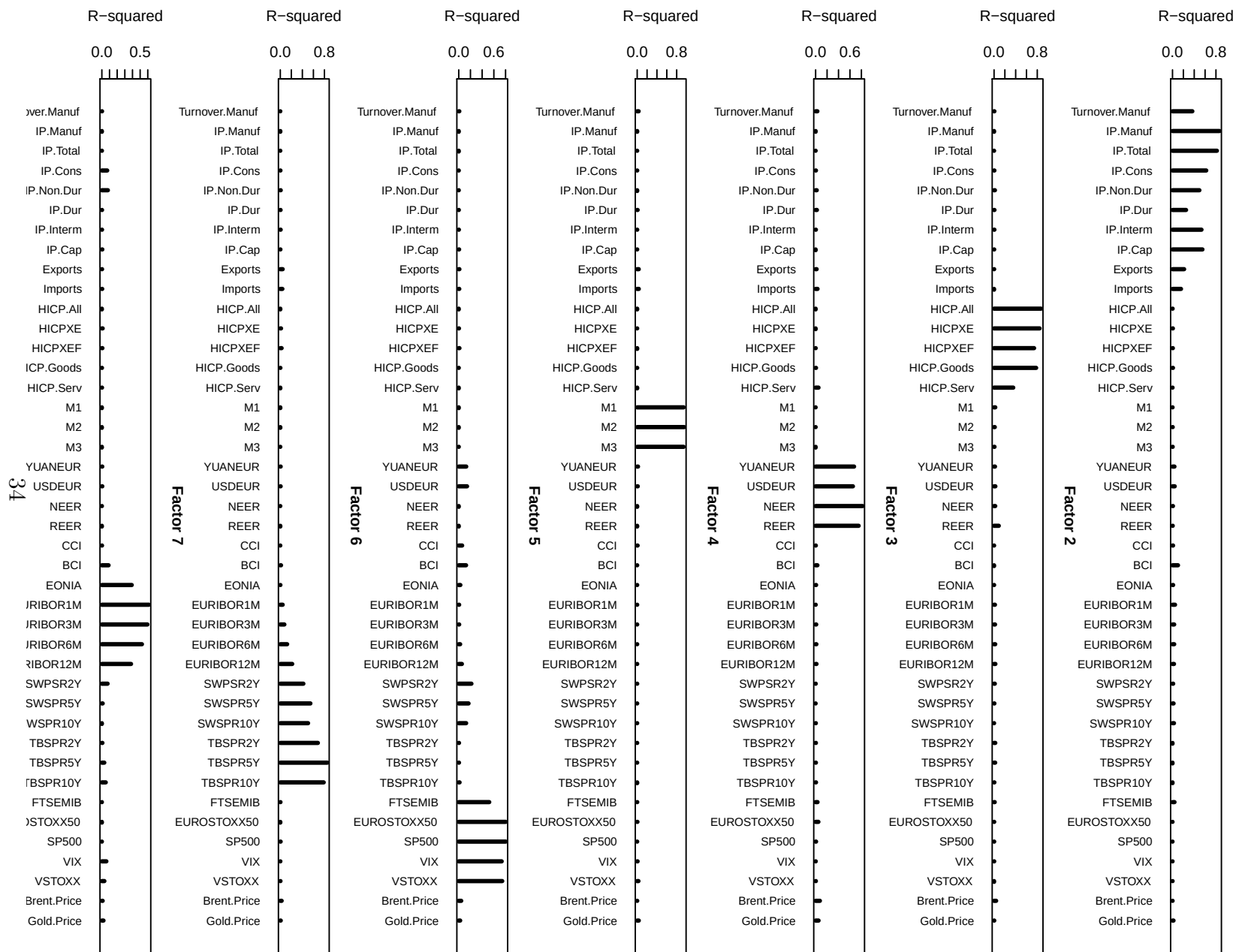


Figure 3: Factor Loadings, Italy

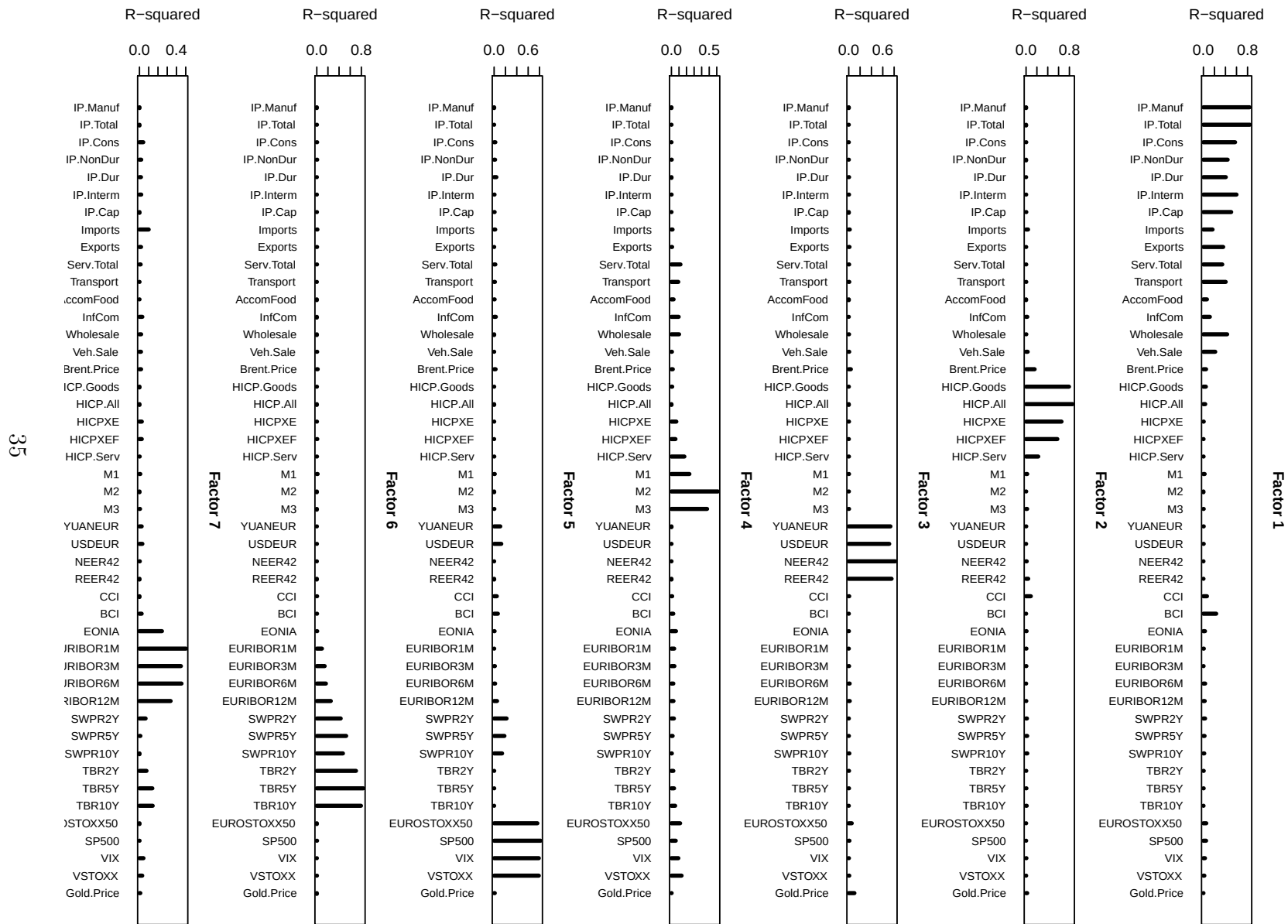


Figure 4: Factor Loadings, Spain

Figure 5: Impulse responses of lending rates to shocks in Factors 4-6, Germany

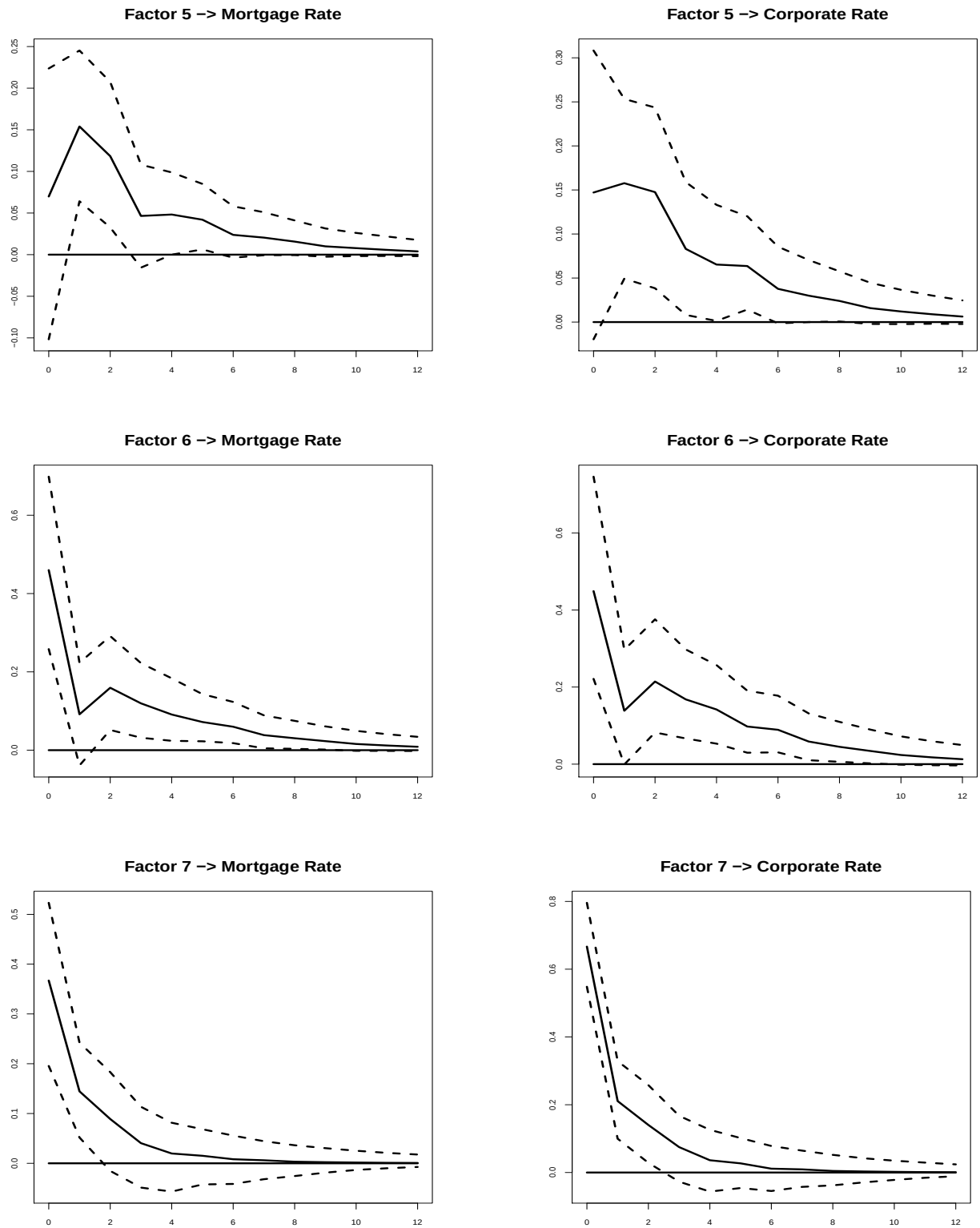


Figure 6: Impulse responses of lending rates to shocks in Factors 5-7, France

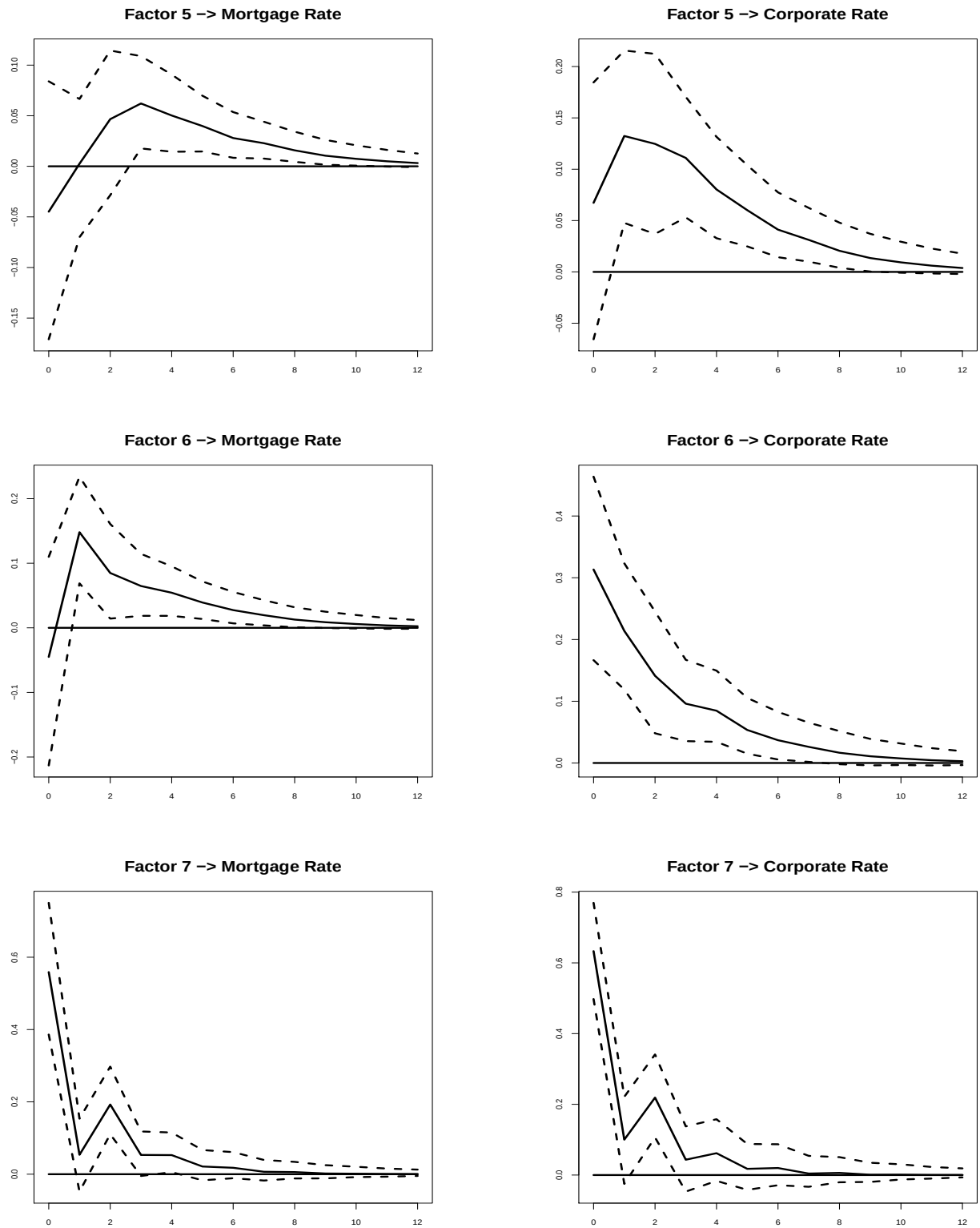


Figure 7: Impulse responses of lending rates to shocks in Factor 5-7, Italy

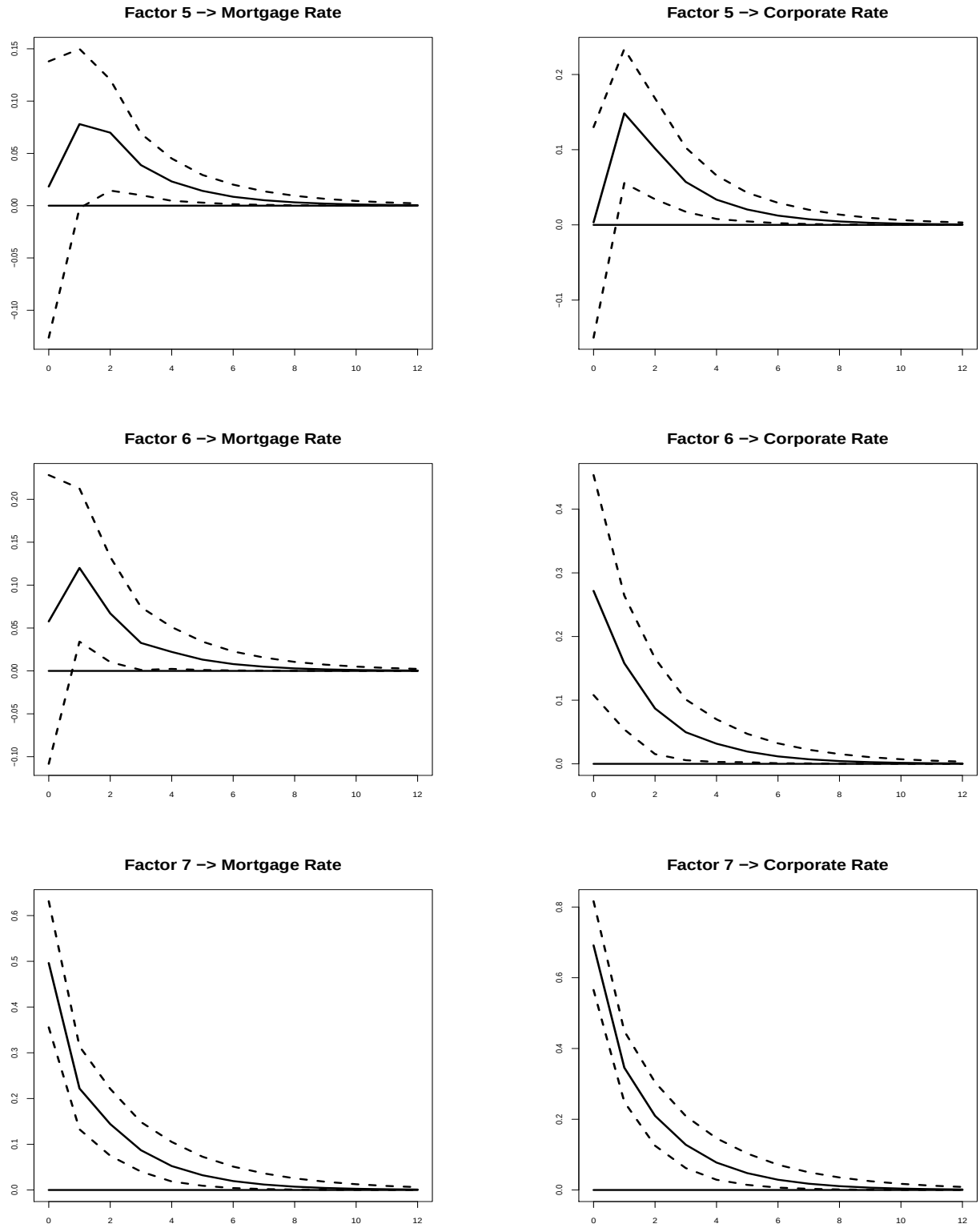


Figure 8: Impulse responses of lending rates to shocks in Factor 5-7, Spain

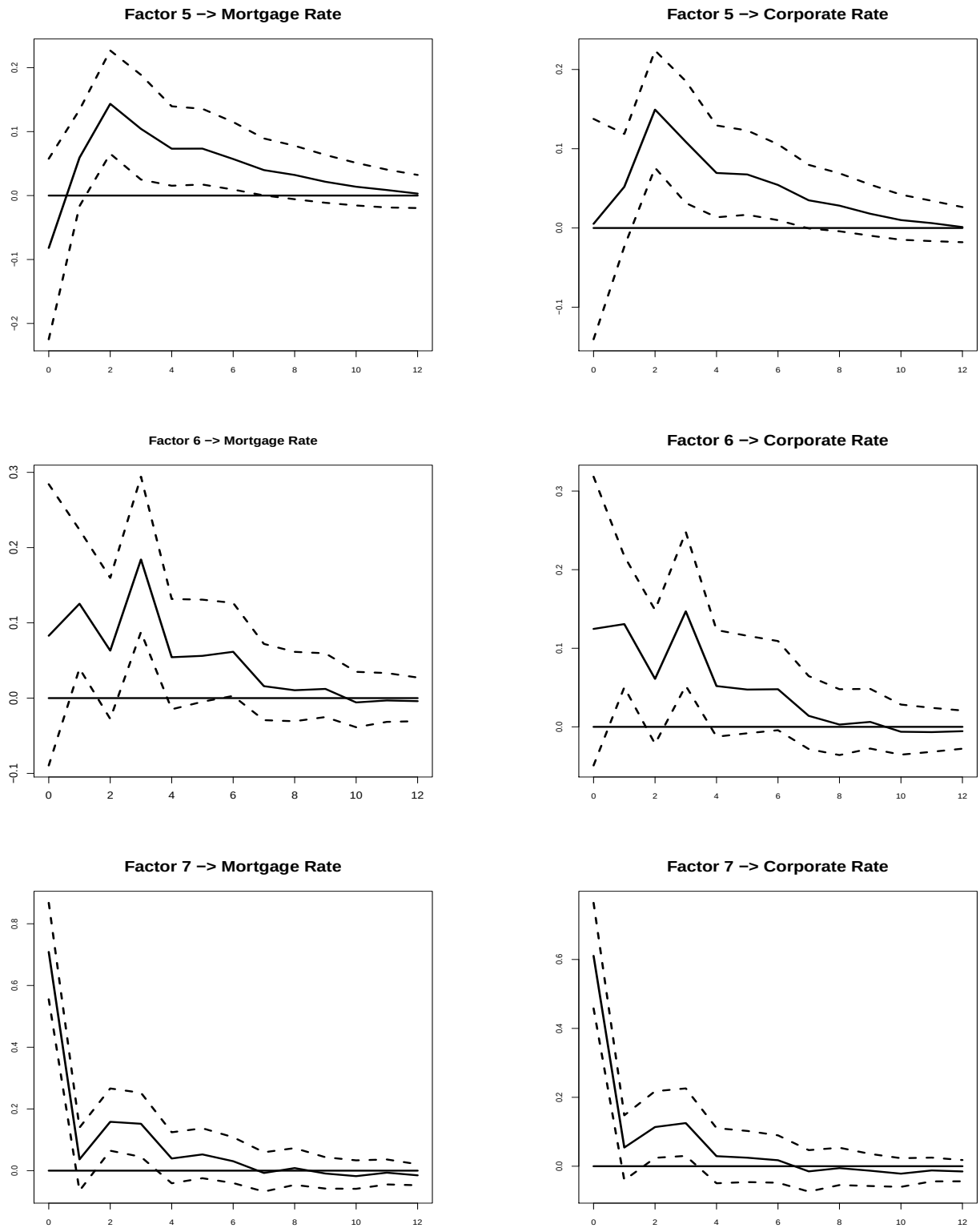


Figure 9: Surfaces of impulse responses of lending rates to shocks in Factors 4-6, Germany

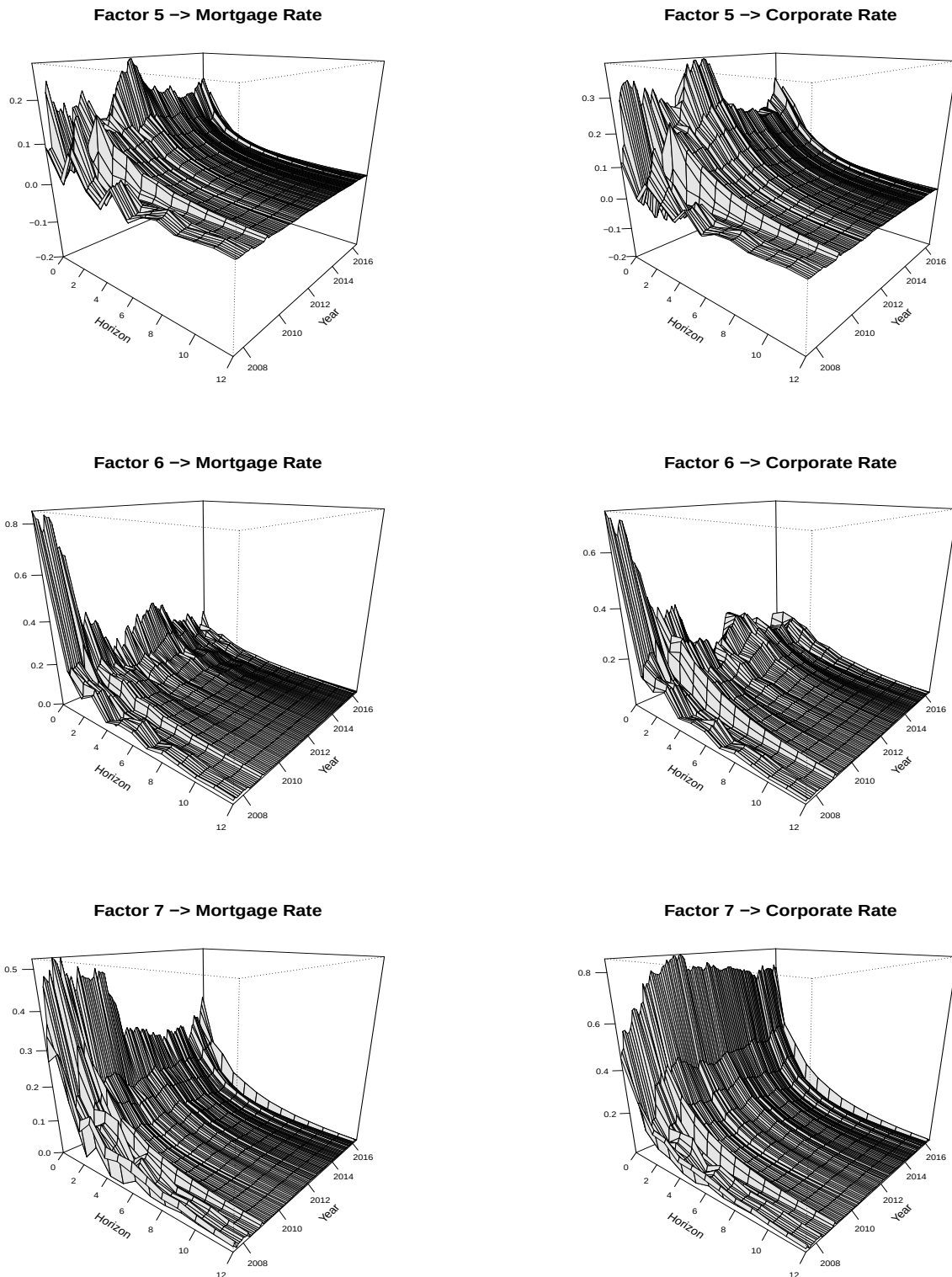


Figure 10: Surfaces of impulse responses of lending rates to shocks in Factors 5-7, France

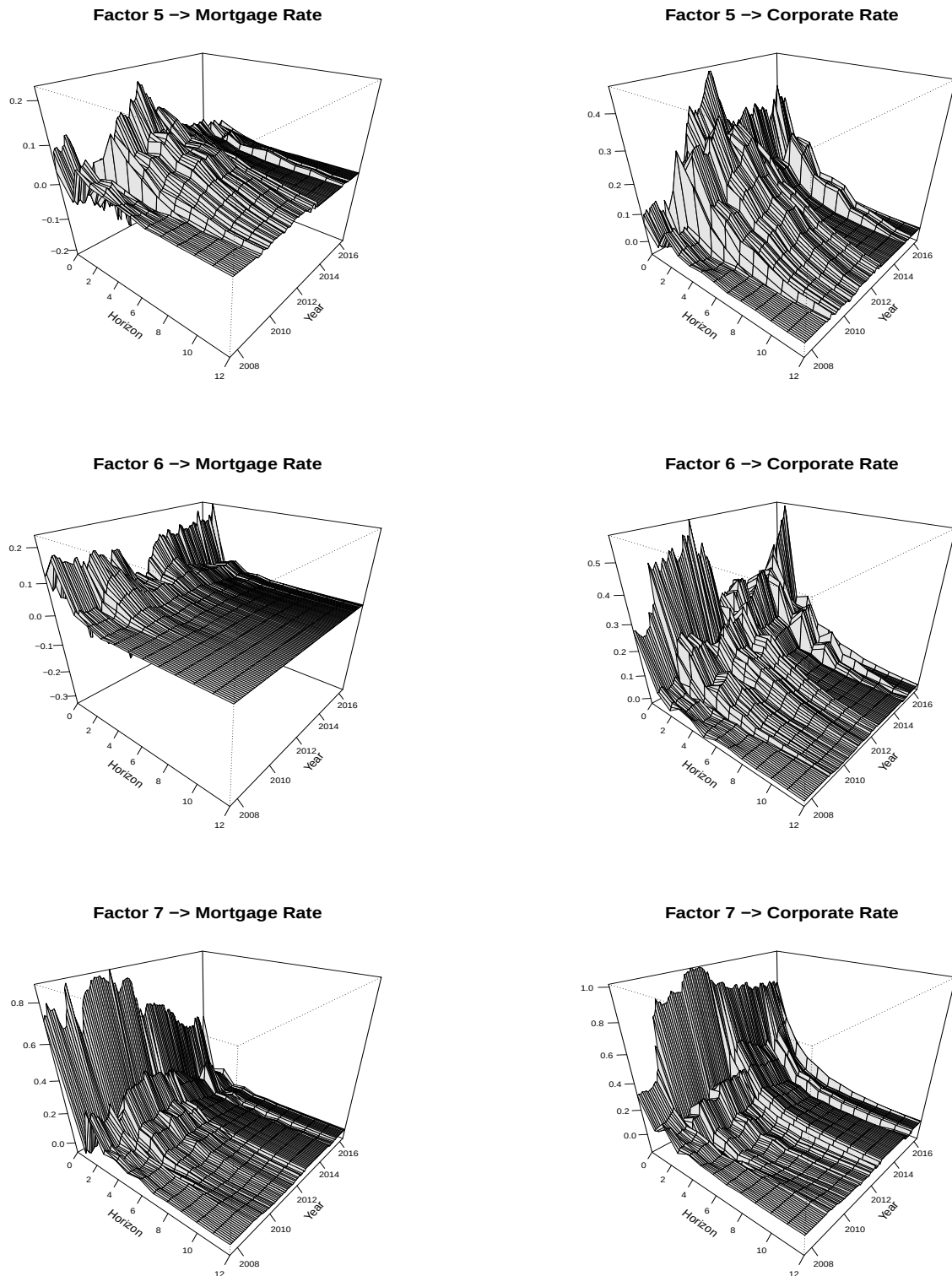


Figure 11: Surfaces of impulse responses of lending rates to shocks in Factors 4-6, Italy

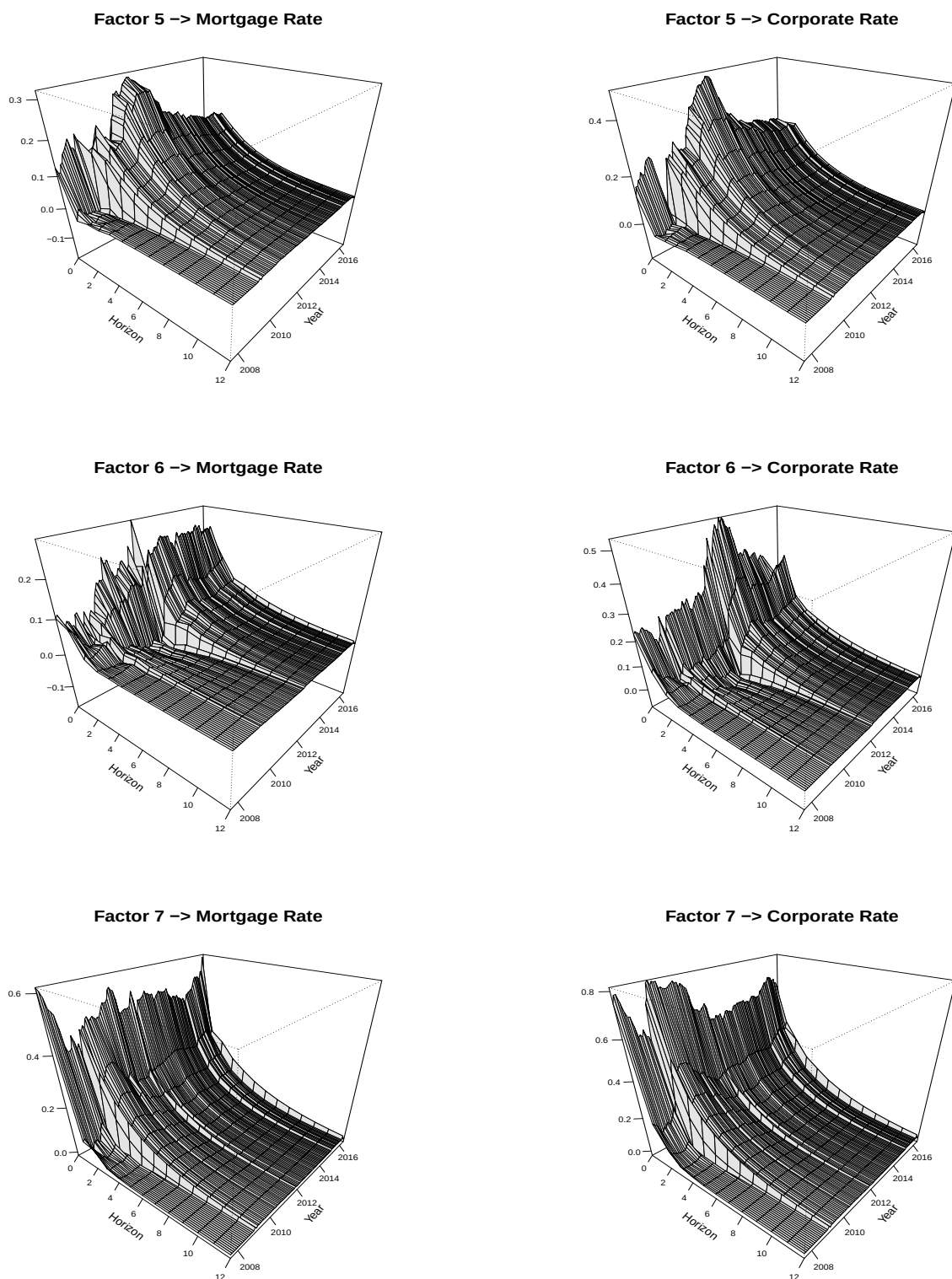


Figure 12: Surfaces of impulse responses of lending rates to shocks in Factors 5-7, Spain

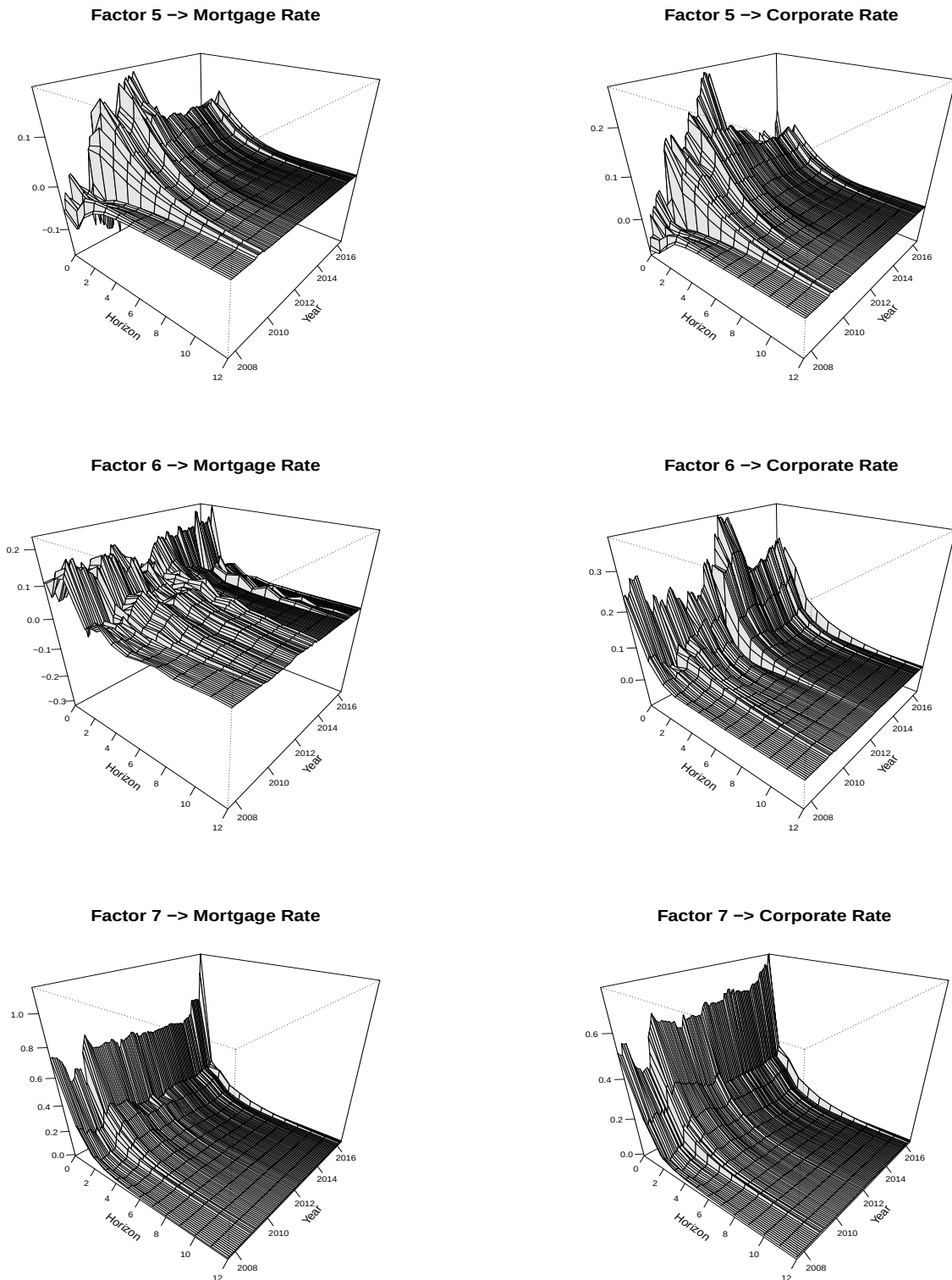


Figure 13: Contribution of Factors 5-7 to variance decomposition, Germany

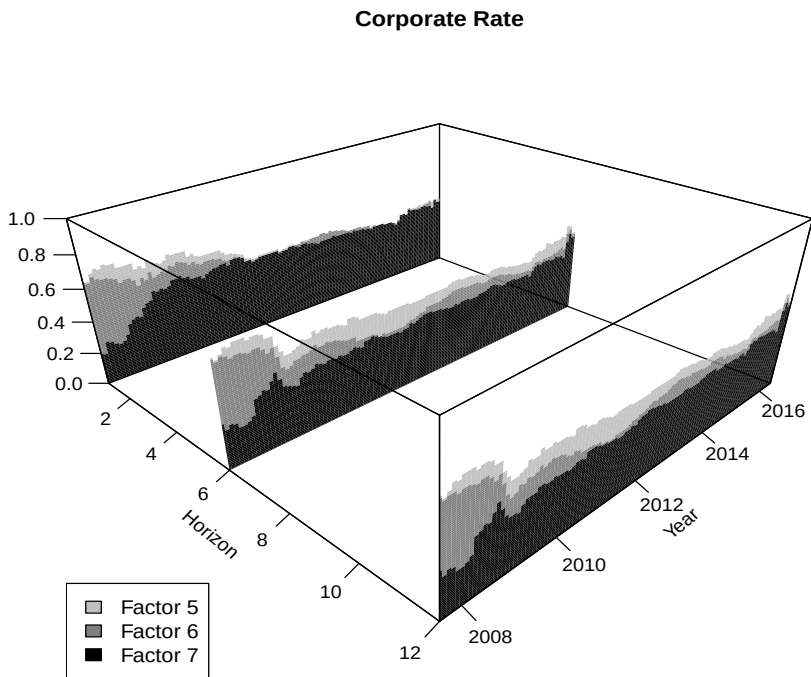


Figure 14: Contribution of Factors 5-7 to variance decomposition, France

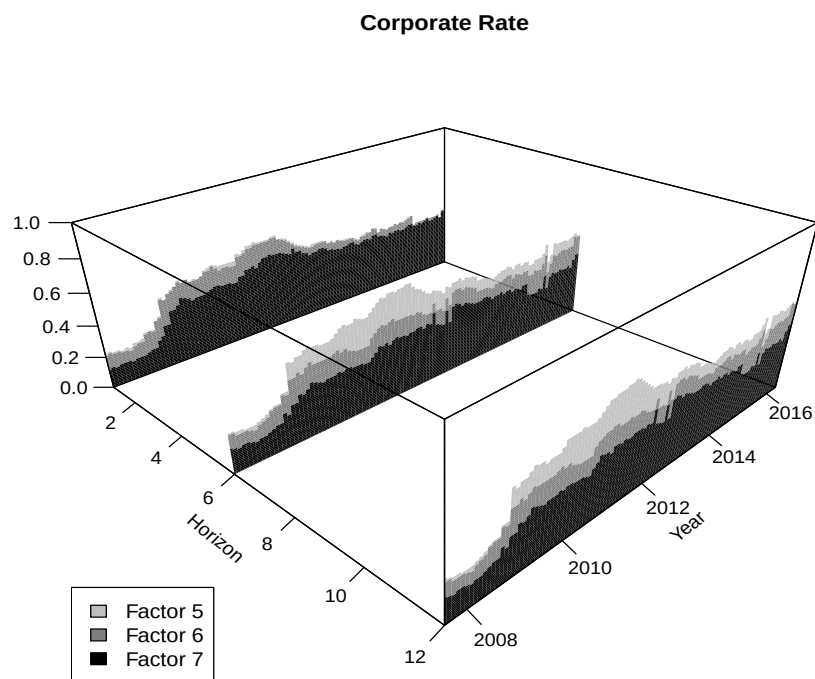


Figure 15: Contribution of Factors 5-7 to variance decomposition, Italy

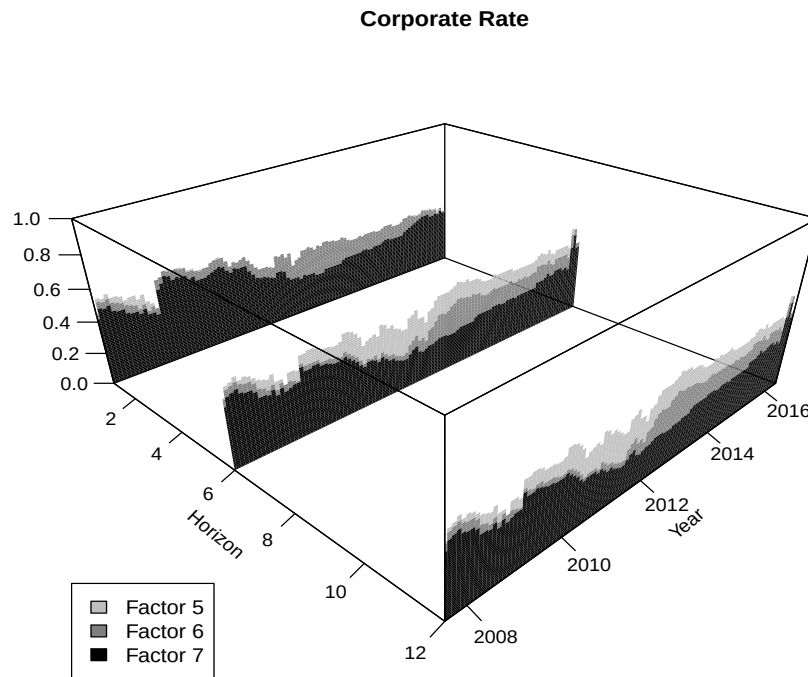


Figure 16: Contribution of Factors 5-7 to variance decomposition, Spain

