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Comovements and heterogeneity in the euro area analyzed in a non-stationary dynamic factor model

Sandra Eickmeier

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Deutsche Bundesbank, Wilhelm-Epstein-Strasse 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-1
Telex within Germany 41227, telex from abroad 414431, fax +49 69 5601071

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

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Abstract:

This paper seeks to assess comovements and heterogeneity in the euro area by fitting a non-stationary dynamic factor model (Bai and Ng, 2004), augmented with a structural factor setup (Forni and Reichlin, 1998), to a large set of euro-area macroeconomic variables observed between 1982 and 2003. This framework allows us to estimate stationary and non-stationary common factors and idiosyncratic components, to identify the structural shocks behind the common factors and assess their transmission to individual EMU countries. Our most important findings are the following. EMU countries share five common trends. However, the source of non-stationarity of individual countries' key macroeconomic variables is not only pervasive. Instead, most countries' output and inflation are also affected by long-lasting idiosyncratic shocks. Unweighted dispersion is primarily due to idiosyncratic shocks rather than the asymmetric spread of common shocks. However, the latter seems to be the main driving force of weighted dispersion of output at the end of the 1980s and the beginning of the 1990s and again from 1999 on and of inflation in the mid-1980s and the mid-1990s. To examine the transmission of common shocks to individual EMU countries in more detail, we identify five structural common shocks, namely two euro-area supply shocks, one euro-area demand shock, one common monetary policy shock and a US shock. We find similar output and inflation responses across countries (with some exceptions), and similarity generally increases with the horizon.

Keywords: Dynamic factor models, sign restrictions, common trends, common cycles, international business cycles, EMU, output and inflation differentials, inflation persistence, monetary policy

JEL Classification: C3, E32, F00, E5

Non-technical summary

Although the member states of the European Monetary Union (EMU) are closely linked through trade and financial markets, economic comovements are still far from perfect, and there is still persistent heterogeneity across individual countries' output and price movements. Comovements and heterogeneity were intensively investigated and discussed in the run-up to the EMU. They have recently returned to the focus of public interest in light of persistent output growth differentials between the large euro-area economies since the mid-1990s and in light of an increase in inflation differentials observed since 2000.

Heterogeneity in the euro area is not necessarily harmful and not automatically calls for policy intervention. Output and inflation differentials may partly reflect the catching-up process. In addition, adjustments in individual countries to asymmetric shocks naturally trigger temporary price dispersion. If, however, such adjustments are slow due to structural rigidities or if adjustments to common shocks differ across individual countries due to different structures, this may lead to long-lasting undesirable economic differentials. In addition, heterogeneity may also reflect inappropriate national economic policies. In these cases, if not counteracted by economic policies, heterogeneity may persist and result in large welfare losses for individual countries.

This paper aims at estimating the size and the persistence of comovements and heterogeneity in the euro area and approaches their determinants. More precisely, it addresses the following questions. (1) How many common factors or shocks drive the euro economy? (2) Do euro economies share common trends and, if yes, how many? (3) Is the source of non-stationarities in EMU economies pervasive (common), idiosyncratic or both? (4) Can the common factors or shocks be given an economic interpretation? (5) How important are these common shocks for variations of economic activity and inflation in individual EMU countries? How are they transmitted, i.e. do they spill over in a similar or a different manner to individual economies? (6) Is heterogeneity across individual countries' economic developments caused by idiosyncratic shocks or by the asymmetrical spread of common shocks?

A non-stationary dynamic factor model (Bai and Ng, 2004), augmented with a structural factor setup (Forni and Reichlin, 1998), is fitted to a large set of euro-area macroeconomic variables observed between 1982 and 2003. This framework allows us to estimate stationary and non-stationary common factors and idiosyncratic components, to identify the structural shocks behind the common factors and assess their transmission to individual EMU countries.

Our most important findings are the following. EMU countries share five common trends. But the source of non-stationarity of individual countries' key macroeconomic variables is not only pervasive. Instead, most countries' output and inflation are also hit by long-lasting idiosyncratic shocks. Unweighted dispersion is primarily due to idiosyncratic shocks rather than the asymmetric spread of common shocks. However, the latter seems to be the main driving force of weighted dispersion of output at the end of the 1980s and the beginning of the

1990s and again from 1999 on and of inflation in the mid-1980s and the mid-1990s. To examine the transmission of common shocks to individual EMU countries in more detail, we identify five structural common shocks, namely two euro-area supply shocks, one euro-area demand shock, one common monetary policy shock and a US shock. We find similar output and inflation responses across countries (with some exceptions), and similarity generally increases with the horizon.

Nicht-technische Zusammenfassung

Trotz enger Handels- und Finanzmarktverflechtungen ist der konjunkturelle und längerfristige ökonomische Gleichlauf zwischen den Mitgliedstaaten der Europäischen Währungsunion (EWU) noch unvollkommen, und Output und Inflation in den einzelnen Ländern verlaufen anhaltend heterogen. Ökonomischer Gleichlauf und Heterogenität im Euro-Raum wurden insbesondere vor Zustandekommen der EWU intensiv diskutiert. Sie sind auch neuerdings wieder ins öffentliche Interesse gerückt angesichts anhaltender Wachstumsunterschiede zwischen den großen EWU-Ländern seit Mitte der Neunziger Jahre sowie eines seit 2000 beobachteten Anstiegs des Inflationsdifferentials.

Heterogenität im Euro-Raum ist nicht notwendigerweise negativ zu beurteilen und erfordern nicht automatisch Politikintervention. Dies ist beispielsweise der Fall, wenn Output- und Inflationsdifferentiale natürliche Aufholprozesse widerspiegeln. Hinzu kommt, dass Anpassungen im Gefolge asymmetrischer Schocks automatisch zeitweise divergierende Preisentwicklungen mit sich bringen. Wenn sich solche Anpassungen aufgrund struktureller Rigiditäten allerdings langsam vollziehen oder wenn Anpassungen im Gefolge gemeinsamer Schocks in einzelnen Ländern aufgrund unterschiedlicher Strukturen stark divergieren, kann es zu unerwünschter anhaltender Dispersion kommen. Zudem kann Heterogenität auch unangemessene nationale Wirtschaftspolitiken widerspiegeln. Heterogenitäten können sich dann verfestigen und nicht unerhebliche Wohlfahrtsverluste nach sich ziehen.

Der vorliegende Artikel hat zum Ziel, das Ausmaß und die Persistenz von ökonomischem Gleichlauf und Heterogenität im Euro-Raum zu untersuchen und die Determinanten (zumindest teilweise) auszumachen. Insbesondere wird auf folgende Fragen eingegangen. (1) Wie viele gemeinsame Faktoren oder Schocks liegen der volkswirtschaftlichen Entwicklung im Euro-Raum zugrunde? (2) Haben die Volkswirtschaften des Euro-Raums gemeinsame Trends und, wenn ja, wie viele? (3) Haben Instationaritäten im Euro-Raum gemeinsame oder variablen (oder länder-)spezifische Ursachen? (4) Lassen sich die gemeinsamen Faktoren oder Schocks ökonomisch interpretieren? (5) Welche Bedeutung haben gemeinsame Schocks für Schwankungen realwirtschaftlicher Aktivität und von Inflation in einzelnen EWU-Ländern? Wie übertragen sie sich, beziehungsweise übertragen sie sich in ähnlicher oder unterschiedlicher Weise auf die einzelnen Mitgliedstaaten? (6) Lässt sich Heterogenität im

Euro-Raum eher durch variablen (oder länder-)spezifische Schocks oder die asymmetrische Übertragung gemeinsamer Schocks erklären?

Diese Fragen werden mit Hilfe eines dynamischen Faktormodells beantwortet, welches Instationaritäten berücksichtigt (Bai und Ng, 2004). Dieser Ansatz wird ergänzt durch das auf Forni und Reichlin (1998) zurückgehende strukturelle Faktormodell. Das Modell wird auf einen Datensatz angewandt, der eine Vielzahl makroökonomischer Variablen des Euro-Raums von 1982 bis 2003 enthält. Dieser Modellrahmen erlaubt es, stationäre sowie instationäre gemeinsame Faktoren und vairablenspezifische Komponenten zu schätzen, die den Faktoren zugrunde liegenden gemeinsamen Schocks zu identifizieren und deren Übertragung auf einzelne EWU-Mitgliedstaaten genauer zu untersuchen.

Die wichtigsten Ergebnisse der vorliegenden Untersuchung sind die folgenden. EWU-Länder teilen sich fünf gemeinsame Trends. Allerdings haben Instationaritäten von Output und Inflation einzelner Mitgliedstaaten nicht nur einen gemeinsamen Ursprung, sondern werden im Allgemeinen auch von persistenten variablenspezifischen Schocks beeinflusst. Die vorliegende Untersuchung findet zudem, dass die gewichtete Dispersion vor allem auf variablenspezifische Schocks und nicht so sehr auf die asymmetrische Übertragung gemeinsamer Schocks zurückzuführen ist. Letztere scheint allerdings Ende der Achtziger und Anfang der Neunziger Jahre sowie seit 1999 für Output und Mitte der Achtziger und Mitte der Neunziger Jahre für Inflation von Bedeutung gewesen zu sein. Um die Übertragung gemeinsamer Schocks auf einzelne EWU-Länder detaillierter zu betrachten, wurden fünf gemeinsame strukturelle, den Euro-Raum treffende Schocks identifiziert, darunter zwei Angebotsschocks, ein Nachfrageschock, ein geldpolitischer Schock sowie ein US-Schock. Die Untersuchung findet schließlich ähnliche Reaktionen von Output und Inflation in den einzelnen Ländern (mit wenigen Ausnahmen) auf diese Schocks. Die Ähnlichkeit scheint außerdem mit dem Horizont zuzunehmen.

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Comovements and Heterogeneity in the Euro Area Analyzed in a Non-Stationary Dynamic Factor Model*

1. Introduction

Although the member states of the European Monetary Union (EMU) are closely linked through trade and financial markets, economic comovements are still far from perfect, and there is still persistent heterogeneity across individual countries' output and price movements (Figure 1). Economic comovements (at business cycle and low frequencies) and heterogeneity were investigated and discussed intensively in the run-up to the EMU. This was reflected in the Maastricht criteria which stress common long-run tendencies (converged inflation and interest rates, a solid fiscal situation and stable exchange rates) and in other optimum currency area (OCA) criteria[1], including a high degree of business cycle synchronization. These criteria are now widely accepted as being important prerequisites for a successful monetary union and are currently being re-applied to the central and eastern European EMU accession candidates. Comovements and heterogeneity have recently returned to the focus of interest among the public, academics and policymakers in light of persistent output growth differentials between the large euro-area economies since the mid-1990s and in light of an increase in inflation differentials observed since 2000 (cf. EBC, 2003). This renewed interest is reflected in a growing literature on these issues, which we will review in Section 2, and numerous conferences on these issues organized by major European policy institutions.[2]

Heterogeneity in the euro area is not necessarily harmful and does not automatically call for policy intervention. Output and inflation differentials may partly reflect the catching-up process, in the course of which countries with lower initial incomes experience higher output growth and inflation and dispersion is inevitable. In addition, adjustments in individual countries to asymmetric shocks naturally trigger temporary price dispersion. If, however, such adjustments are slow due to nominal rigidities and imperfect factor mobility or if adjustments to common shocks differ across individual countries due to structural differences, this may lead to long-lasting undesirable output and inflation differentials. In addition, heterogeneity

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* Affiliations: Deutsche Bundesbank and University of Cologne. Address: Deutsche Bundesbank, Economic Research Center, Wilhelm-Epstein-Str. 14, 60431 Frankfurt/M., Germany, Email: sandra.eickmeier@bundesbank.de, Phone: +49 69 9566 4705, Fax: +49 69 9566 2983.
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1 The OCA criteria, based on Mundell (1961), MacKinnon (1963) and Kenen (1969), are partly reflected by the Maastricht criteria.

2 Conferences and workshops hosted and/or organized by the European Central Bank include "What effects is EMU having on the euro area and its member countries?" (June 2005) and "Monetary policy implications of heterogeneity in a currency area" (December 2004); see http://www.ecb.int/events/conferences/past/html/index.en.html. The themes of the first workshop of the Euro Area Business Cycle Network (EABCN) included "international business cycles" and "the euro area and the US". The European Commission, for example, hosted a conference on "Business Cycles and Growth in Europe" (October 2004).

may also reflect inappropriate national economic policies or other unwarranted domestic developments, such as wage increases out of line with productivity and employment considerations, or excessive profit margin and demand developments caused, for example, by overconfident investors in asset markets. In these cases, if not counteracted by economic policies, heterogeneity may persist and result in large welfare losses for individual countries.

With the EMU, national authorities have lost monetary policy instruments which they previously could employ to respond to undesired asymmetries in economic developments. The European Central Bank (ECB)'s primary mandate is to maintain aggregate price stability and "without prejudice to the objective of price stability […] to support general economic policies in the Community […]" which aim, among others, at achieving a "high level of [aggregate] employment" and "sustainable and non-inflationary [aggregate] growth"[3]. Therefore, its ability to reduce heterogeneity is limited at best. National economic policies may instead be able to stabilize economies and, to that extent, to contribute to more homogeneity across countries.

This paper seeks to estimate the size and the persistence of comovements and heterogeneity in the euro area and approaches their determinants. By heterogeneity (or dispersion), we mean the difference between euro-area countries' output (as deviations from a time trend) or output growth and inflation rates at a certain point in time, whereas comovements describe the parallel evolution of economic variables over a certain period of time.[4] The two concepts are related, as a lack of comovements will be reflected in heterogeneity. We will investigate both in our paper.

For this purpose, we will rely on a factor model, since we believe that this modelling framework is well suited to analyze these concepts. Moreover, numerous studies have shown that it is a fairly good approach to describe a large number of macroeconomic variables in an international context (cf. Kose, Otrok and Whiteman, 2003; Bayoumi and Helbling, 2003; Eickmeier and Breitung, 2006; Malek Mansour, 2003; Del Negro and Otrok, 2005). The model assumes that these variables are driven by a few common factors or shocks and by idiosyncratic shocks (as well as some idiosyncratic deterministic terms such as deterministic trends). Common shocks are defined here as shocks that either hit all variables or countries simultaneously or occur in one country and are transmitted to others. A common monetary policy shock is an example of a common shock. An external shock that affects all countries is another example. By contrast, idiosyncratic shocks are defined as shocks to specific variables.[5] These may include unexpected national economic policies and other country-specific economic developments such as those mentioned above. In this framework,

3 http://www.ecb.int/mopo/intro/html/objective.en.html.
4 Benalal, Diaz del Hoyo, Pierluigi and Vidalis (2006) use this definition (relying on the concepts of "synchronization of business cycles" and "dispersion").
5 Notice that the framework employed here does not allow us to model factors that load on subgroups of variables — variables of a certain country, for example — only.

idiosyncratic shocks lead to diverging economic developments, whereas common shocks are generally responsible for economic comovements. However, if the latter are spread asymmetrically to individual variables or countries — possibly due to differences in economic structures, such as nominal rigidities or factor mobility, economic policies or expectation formation processes — they might contribute to dispersion as well. The size and degree of persistence of heterogeneity depends on the relative size of the common and idiosyncratic shocks and their propagation through the system.

More precisely, this paper combines the recently developed PANIC (Panel Analysis of Nonstationarity in Idiosyncratic and Common components) approach of Bai and Ng (2004, henceforth BN) and the structural factor setup based on Forni and Reichlin (1998, henceforth FR) and Giannone, Reichlin and Sala (2002, henceforth GRS) and applies them to a newly constructed dataset containing a total of 172 stationary and non-stationary macroeconomic times series from 1982 to 2003, most of which capture economic developments in euro-area countries and some external influences. The former method allows us to estimate the common and idiosyncratic components and to assess their degree of persistence, while the latter enables us to perform structural analysis, i.e. to identify common structural shocks and assess their propagation through the system. We address, in particular, the following questions.

- How many common factors or shocks drive the euro economy?
- How persistent are these factors? And do euro economies share common trends and, if yes, how many?
- Is the source of non-stationarities in EMU economies pervasive (common), idiosyncratic or both? Put differently: are long-lasting shocks which hit individual euro-area countries common shocks or idiosyncratic shocks?
- Can the common factors or shocks be given an economic interpretation?
- How important are these common shocks for variations of economic activity and inflation in individual EMU countries? How are they transmitted, i.e. do they spill over in a similar or a different manner to individual economies?
- Related to the previous question, is heterogeneity across individual countries' economic developments caused by idiosyncratic shocks or by the asymmetrical spread of common shocks? And, if the latter is true, do some common shocks lead to greater heterogeneity than others?

Interesting as they are, we do not identify idiosyncratic shocks or provide structural reasons for the way shocks spread to different countries, as this is beyond the scope of the paper.

Performing macroeconomic analysis in general and studying international business cycles in a large-dimensional dynamic factor framework has various advantages over VAR models or structural models which are more frequently used in this context. Much information can be extracted from dynamic factor models; this should allow us to estimate the common driving forces and their propagation more precisely. VAR modelers, by contrast, rapidly face scarce degrees of freedom problems.[6] In addition, the potentially heterogeneous responses of many variables, i.e. all variables in the panel, to the common shocks can be assessed. It is also advantageous that we can remain relatively agnostic about the structure of the economy and do not need to rely on excessively tight restrictions, as is sometimes the case in structural models. The only restrictions we impose serve to give the common shocks an economic interpretation.[7]

Most previous applications of large dynamic factor models rely on datasets that contain only stationary variables and therefore only consider stationary factors and common and idiosyncratic components. The BN approach, in addition, allows us to work with a (at least partly) non-stationary dataset and to handle common trends and common stationary factors in an integrated and large framework. Bai (2004) demonstrates that a principal component analysis, which is easy to perform and not time-consuming, can be applied to a large vector of non-stationary variables to estimate non-stationary common factors. However, in this case, consistent estimation requires the idiosyncratic components to be stationary. Consequently, non-stationary factors or common trends could not be estimated in this framework without restricting the errors to being stationary. In reality, however, the source of non-stationarity of a macroeconomic time series need not be pervasive but can also be idiosyncratic, i.e. an economy can be hit by both permanent common and idiosyncratic shocks.[8] BN have taken this as a starting point and developed techniques which permit the estimation of both stationary and non-stationary factors with principal component analysis in a large-dimensional factor framework without imposing this restriction. Not restricting common and idiosyncratic components to be stationary is particularly favorable in our context, since it enables us to estimate freely their degree of persistence, which is one focus of this paper. Dealing with stationary and non-stationary factors and idiosyncratic components in an integrated setup, while simultaneously preserving the ability to utilize the information contained in a large dataset is, in our view, a great advantage of the BN approach, and applying it to our large euro-area dataset to study comovements and heterogeneity represents our most important contribution.

Our main results are:

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6 This and other drawbacks inherent in traditional small-scale VAR models are absent from both the Global VAR model recently presented by Dees, di Mauro, Pesaran and Smith (2005) and the panel VAR model of Canova, Ciccarelli and Ortega (2005).

7 Structural models naturally also have advantages over reduced form approaches like the one we employ here, in that, for instance, they allow counterfactual experiments to be performed.

8 The German unification in 1991 is one such example of a long-lasting, largely idiosyncratic shock. Germany has not fully closed the negative growth gap to its European neighbors, and more than a decade later, its poor economic performance was still (at least partly) explained by the consequences of unification such as the ongoing crisis in the construction sector and the increased public debt and tax ratios. Cf. Deutsche Bundesbank (2001), pp. 22-28, and German Council of Economic Experts (2002), pp. 205-240.

- EMU countries share five common trends.
- However, the source of non-stationarity of individual countries' key macroeconomic variables is not only pervasive. Instead, most individual countries' output and inflation are also hit by long-lasting idiosyncratic shocks.
- Unweighted dispersion seems to be primarily due to idiosyncratic shocks rather than the asymmetric spread of common shocks. However, the latter seems to be the main driving force of weighted dispersion of output at the end of the 1980s and the beginning of the 1990s and again from 1999 on and of inflation in the mid-1980s and the mid-1990s.
- To examine the transmission of common shocks to individual EMU countries in more detail, we identify five structural common shocks, namely two euro-area supply shocks, one euro-area demand shock, one common monetary policy shock and a US shock. We find similar output and inflation responses across countries (with some exceptions), and similarity generally increases with the horizon.

The paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the data. Section 4 presents the non-stationary factor model of BN and its estimation. It also investigates whether the sources of non-stationarity in individual countries' key macroeconomic variables are pervasive, idiosyncratic or both. Section 5 explains the structural dynamic factor setup suggested by FR and GRS and its estimation as well as characterizes the common structural shocks. Section 6 provides historical decompositions of individual countries' GDPs and inflation rates into their components and computes their dispersion. It also examines the transmission of the common shocks to individual countries. Section 7 concludes and gives policy implications.

2. Literature review

Our paper is related to the empirical literature on economic comovements (at business cycle and low frequencies) and heterogeneity in the euro area. This literature, especially the one on business cycle synchronization, is vast and still growing. Therefore, our review is by no means exhaustive; we present merely a selection of papers. We will begin by presenting first present some work on economic comovements, including the transmission of common shocks to individual euro-area countries. We will then mention papers that focus explicitly on dispersion of output and output growth as well as of inflation in the euro area. Finally, we will relate our work to other similar dynamic factor model applications covering methodological similarities.

Studies based on static and dynamic correlations generally find evidence that business cycles in the euro area are highly synchronized (cf. Giannone and Reichlin, 2006; Bergman, 2004; Croux, Forni and Reichlin, 2001; Eickmeier and Breitung, 2006). By applying large factor models to euro-area datasets, Marcellino, Stock and Watson (2000), Forni and

Reichlin (2001), Eickmeier (2005), Eickmeier and Breitung (2006), Altissimo, Bassanetti, Cristadoro, Forni, Hallin, Lippi and Reichlin (2001) and Beck, Hubrich and Marcellino (2006) find that much of economic variation (i.e. variation in economic activity and inflation) in individual countries is explained by euro-area common factors,[9] pointing to a high degree of synchronization. Nevertheless, evidence is mixed as to whether a separate euro-area business cycle exists. While Artis (2003), Artis and Zhang (1999) and Montfort, Renne, Rüffer and Vitale (2003) find evidence of a euro-area business cycle, the results presented by Camacho, Pérez-Quirós and Saiz (2006) suggest that "European countries [are not] close enough to be just one". The latter results are supported by Kose, Otrok and Whiteman (2003), who find that a separate European factor does not contribute much to output fluctuations in European countries. Based on small-scale unobserved component models, Luginbuhl and Koopman (2004) and Carvalho and Harvey (2005) focus not only on business cycle linkages, but also on common trends. They find evidence that euro-area countries share both common cycles and trends. While all these studies focus on economic linkages during a specific period of time, a literature on heterogeneity or dispersion has emerged as well.

Various studies investigate the propagation of common shocks to individual euro-area countries. Most do not find huge cross-country differences. However, as will be apparent from the following presentation of previous findings, papers sometimes lack consensus on the ordering of individual countries in terms of deviations from the euro-area average response to common shocks. Most of this literature assesses the transmission of a common monetary policy shock by means of VAR models (cf. Ciccarelli and Rebucci, 2005; Clements, Kontolemis and Levy, 2001), but also by means of a large dynamic structural factor model similar to the one used here (Sala, 2003).[10] Overall, reactions to a common monetary policy shock do not seem to differ much across EMU countries. However, Ciccarelli and Rebucci (2005) find that economic activity in France responds somewhat more weakly than economic activity in Germany, Italy and Spain. In Clements, Kontolemis and Levy (2001), Portugal exhibits the weakest, and France and Finland the strongest response (cumulated after 5 years). The findings by Sala (2003) suggest that industrial production in Spain and Germany is more sensitive to a common monetary policy shock than in the Netherlands, France and Italy.

Eickmeier and Breitung (2006) go beyond the work by Sala (2003) by identifying, besides a common monetary policy shock, common euro-area supply and demand shocks and assessing their propagation to individual EMU member states (as well as to central and east European economies). They also find quite small differences in the propagation, reflected by low cross-country standard deviations of impulse responses.

[9] Beck, Hubrich and Marcellino (2006) only focus on inflation.
[10] In the pre-EMU period, a common euro-area monetary policy is proxied by German monetary policy in these studies.

Another large segment of the literature examines the propagation of external shocks to individual EMU countries. In this literature overview, we only focus on US shocks, since these will be the only external shocks identified in our paper. As was the case for responses to a common monetary policy shock, most studies, again, find that responses to a US shock do not differ much. Based on large macroeconometric multi-country models (the model of the Deutsche Bundesbank and the OECD Interlink model), rather homogeneous responses to a US demand shock are found for output in France, Germany, Italy and the Netherlands by the German Council of Economic Experts (2001) and to US tax cut and monetary policy shocks for the three largest EMU countries by Dalsgaard, André and Richardson (2001). Using a VAR model, Artis, Osborn and Perez (2004) also find similar output responses in France, Germany and Italy to a US output shock between 1980 and 2001, with Germany exhibiting a somewhat larger contemporaneous response than the other two. Results by Canova and Ciccarelli (2006), however, suggest some differences: based on a panel VAR model with time-varying parameters, estimated for the period 1980 to 2004, the authors find no significant response of Germany GDP growth to a shock to US GDP growth, whereas such a shock has a positive and significant (but temporary) impact on France and Italy. Eickmeier (2006) suggests that the transmission of US shocks may depend on the type of shock. She finds that positive US supply shocks do not affect German output significantly, but lead to lower prices, whereas US positive demand shocks seem to be transmitted positively to German output, but have no significant effect on prices.

As regards heterogeneity, the ESCB has launched an ambitious research project on inflation dispersion. ECB (2003) provides a comprehensive overview on the literature and performs its own computations. Inflation differentials are found to have declined in the run-up to EMU, but have gone back up since 2000. As regards individual countries' developments, Greece, Spain, Ireland, the Netherlands and Portugal seem to have experienced relatively large and persistently positive inflation differentials to the euro-area average since 1999. In this period, inflation in Italy also exceeded euro-area inflation, but by a smaller margin. By contrast, negative inflation gaps could be observed for Germany, France and Austria. Besides different cyclical positions, the impact of the move to Stage Three of EMU, which lowered interest rates in some countries and raised them in others, with non-negligible effects on inflation dispersion, income convergence and structural rigidities, have caused these persistent inflation differentials according to ECB (2003). Among the many studies dealing with inflation dispersion in the euro area, the study by Altissimo, Benigno and Palenzuela (2004) is worth highlighting since it is closely related to ours in that it also relies on a large factor setup. According to this analysis, there are noticeable and persistent inflation differentials in the euro area. Based on a dataset, which contains a large number of highly disaggregated inflation differentials and other macroeconomic variables, the authors find that inflation dispersion is mostly related to the asymmetric spread of common shocks rather than idiosyncratic shocks:

the share of inflation differentials accounted for by the common component is 66%. However, the increase in inflation differentials in 2000 seems to be due to idiosyncratic shocks.

There are fewer studies which focus explicitly on output or output growth dispersion in the euro area: specifically, Benalal, Diaz del Hoyo, Pierluigi and Vidalis (2006), Buisán and Restoy (2005) and Giannone and Reichlin (2006). The two former analyses find that output growth dispersion in the euro area does not exhibit a clear upward or downward trend for more than two decades. Giannone and Reichlin (2006) find that per capita output differentials across euro-area countries are small but persistent and have remained relatively stable since 1970. Buisán and Restoy (2005) observe a relatively large output gap dispersion in the late 1980s and the early 1990s and smaller dispersion thereafter. Based on bivariate VAR models and counterfactual correlations, Giannone and Reichlin (2006) suggest that idiosyncratic shocks explain the bulk of output growth dispersion. This result is confirmed by Buisán and Restoy (2005) who find — based on a large macroeconometric model (NIGEM) — only moderately heterogeneous responses of individual countries' output and prices to common shocks. Benalal, Diaz del Hoyo, Pierluigi and Vidalis (2006) also shed some light on which countries drive the heterogeneity and find that, potentially due to a catching-up process, Greece, Spain and Ireland outperform the euro-area average since the mid-1990s, whereas Germany and Italy perform persistently below average. The authors argue that long-standing structural factors such as unfavorable demographic developments in both countries, weak domestic demand, especially weak investment in the construction sector, in Germany and modest total factor productivity developments and poor export performance in Italy seem to be responsible. Weighted standard deviations seem to be lower than unweighted standard deviations (Benalal, Diaz del Hoyo, Pierluigi and Vidalis, 2006; Buisán and Restoy, 2005).

From a methodological point of view, our paper is finally also related to other large dynamic factor applications some of which we have already mentioned: see Breitung and Eickmeier (2006) for a recent survey. Some adopt the structural dynamic factor framework. Besides monetary policy applications (cf. Giannone, Reichlin and Sala, 2002, 2004; Cimadomo, 2003; Sala, 2003), there are also some international business cycle applications, namely Eickmeier and Breitung (2006) whose main focus is the transmission of aggregate structural euro-area shocks to central and east European economies, and Eickmeier (2006) who assesses the transmission of shocks from the US to Germany with a particular interest in international transmission channels. Other less structural or non-structural analyses that focus on the euro area include Marcellino, Stock and Watson (2000) who estimate factors from a large euro-area dataset and try to give them an economic meaning by correlating them with national factors; Altissimo, Bassanetti, Cristadoro, Forni, Hallin, Lippi and Reichlin (2001), who estimate a coincident indicator out of a large set of euro-area variables; Forni and Reichlin (2001), who fit a large dynamic factor model to a panel of European regions' output, extract a common factor and assess its relevance; Beck, Hubrich and Marcellino (2006), who aim at explaining regional inflation in the euro area; and Altissimo, Benigno and

Palenzuela (2004), already discussed in some detail above. Other non-structual international business cycle applications with a somewhat different country coverage are those by Malek Mansour (2003), Bayoumi and Helbling (2003), Lumsdaine and Prasad (2003) and Kose, Otrok and Whiteman (2003) and the time-varying parameters factor model. Notice that all these factor studies work with stationary datasets, whereas we rely on an (at least partly) non-stationary panel, as will be apparent from the next section.

3. Data

We rely on a large dataset which contains between 20 and 22 macroeconomic time series for each of the core euro-area countries (Austria, Belgium, France, Germany, Italy, the Netherlands and Spain). The variables are selected so that the real and the nominal domestic sides as well as the external side of each of the different countries are represented in a balanced way if possible. In addition, we include GDP and consumer prices from the other small and mostly more peripheral euro-area countries (Finland, Ireland, Greece, Luxembourg and Portugal). These countries' economies have exhibited somewhat different developments compared to the core EMU countries. We therefore do not include as many variables for these countries in the dataset as variables for the core countries, so that they won't affect euro-area factor estimates to such a large extent. The dataset also comprises a few global variables which possibly have an impact on economic activity in the euro area: world energy prices, world non-energy commodity prices, US GDP, consumer prices and short-term nominal interest rates, UK and Japanese GDP, the nominal US dollar/euro exchange rate, and world trade. Most series are taken from OECD statistics. We further add four aggregate euro-area variables, taken from the dataset underlying the ECB's area-wide model (AWM): GDP, the harmonized consumer price index, the nominal short-term interest rate and real wages. Including these variables will help us to identify common structural euro-area macro shocks as will be apparent below. The dataset contains a total of $N = 172$ variables. The variables are listed in more detail in Table 1.

Data are quarterly, and our observation period ranges from 1982Q4 to 2003Q4; hence our time dimension T equals 85. One of the reasons for the choice of this period is data availability.[11] The CEPR also declared 1982Q4 to be the beginning of the expansionary phase in the euro area.[12] Moreover, our reporting period is roughly the same as the period considered by Cavalho and Harvey (2005), termed stabilization and restructuring period by the authors, and it is long enough to comprise at least two entire business cycles according to the CEPR definition. Where necessary, the series were seasonally adjusted using the X-11 method and/or converted from monthly to quarterly series. Logarithms were taken of all non-

[11] Different time spans and missing observations can be dealt with by employing the EM algorithm (Stock and Watson, 1998). However, we have decided to use a balanced panel here.

[12] http://www.cepr.org/data/Dating/.

negative series that were not already in ratios or percentage form. In constructing the dataset, one problem that needed to be addressed was the break in some series caused by German unification in 1990. Those German series for which a break was apparent were extended by applying West German growth rates to the German levels retroactively from the end of 1991 on. After this transformation, visual inspection of these series did not suggest a break anymore.

Importantly, the dataset may include I(0) and I(1) variables. For many countries, we tested prices, unit labor costs and monetary aggregates to be I(2) by means of the standard unit root tests. We therefore include the first differences of these variables for all countries in the set. According to standard univariate unit root tests, almost all variables of the final dataset were tested to be I(1).

The first differences are normalized to have a mean of zero, i.e. we focus on deviations of the levels from the trend[13], which needs to be kept in mind when interpreting results. In doing so, we eliminate differences in mean growth rates over the entire sample and, hence, also eliminate some of the heterogeneity. This, however, does not prevent heterogeneity to exit and persist for sustained periods of time, and it is still interesting to look at that dispersion. In order to receive an impression of the eliminated heterogeneity, we report the mean growth rates of output and inflation in Table 2. They are all significantly different from zero, with the exceptions of the mean changes of inflation in Germany and the Netherlands, suggesting that the fact that the data were de-trended previously to the analysis should be kept in mind when interpreting the results shown below.

Notice, in addition, that variances are normalized to unity to account for the difference in measurement units in the dataset, which can influence factor estimates. Moreover, it guarantees that the variables with a relatively large variance do not dominate the common factor estimates. Finally, outliers were removed.

4. The non-stationary factor model and sources of non-stationarities — pervasive or idiosyncratic?

As pointed out in the introduction, our analysis combines two dynamic factor setups suitable to analyze large datasets, the non-stationary (non-structural) factor model developed by BN and the structural factor setup of FR and GRS. We begin this section by briefly introducing and estimating the former and investigating whether sources of non-stationarities of key

[13] This is done by differencing and simply de-meaning the differences when conducting the BN tests to determine the number of common trends and panel unit root tests. As will be outlined in detail below, the BN procedure involves then cumulating the differenced series. This implies, however, that the first and the last observations of the cumulated series (and components) are zero and, hence, that the series and components are not reliable at the beginning and at the end of the sample. When focussing on the series and components themselves, we therefore remove the mean growth rate by carrying out a OLS regression of the series on a constant and a linear trend. A detailed description can be found in Appendix A.

macroeconomic variables of euro-area countries are pervasive, idiosyncratic or both, or, put differently, whether permanent shocks to euro-area economies are common or idiosyncratic shocks. A structural analysis is then carried out in the next section.

All series in the dataset are collected in the $N \times 1$ vector $\mathrm{Y}_t = [y_{1t} \quad \cdots \quad y_{Nt}]'$. It is assumed that Y_t follows an approximate dynamic factor model (e.g. Stock and Watson, 1998, 2002; Bai and Ng, 2002, 2004) and can be represented as:

$$\mathrm{Y}_t = \mathrm{X}_t + \Xi_t = \Lambda(L)\mathrm{f}_t + \Xi_t = \Lambda \mathrm{F}_t + \Xi_t, \tag{1}$$

where $\mathrm{X}_t = [x_{1t} \quad \cdots \quad x_{Nt}]'$ and $\Xi_t = [\xi_{1t} \quad \cdots \quad \xi_{Nt}]'$ are $N \times 1$ vectors of common and idiosyncratic components, and the latter are allowed to be weakly cross-correlated in the sense of Bai and Ng (2002). f_t is a $q \times 1$ vector of common dynamic euro-area factors and $\Lambda(L) = \Lambda_0 + \Lambda_1 L + ... + \Lambda_g L^g$ denotes the lag polynomial of $N \times q$ matrices of factor loadings associated with lags 0 to g. The loadings can differ across variables. F_t is a vector of $r \geq q$ "static factors" that comprises the dynamic factors f_t and all lags of the factors that enter with at least one non-zero weight in the factor representation. The $N \times r$ matrix Λ comprises all non-zero columns of $(\Lambda_0, ..., \Lambda_m)$. Typically, $r << N$.

This model differs from models typically used (cf. Stock and Watson, 2002; Forni, Hallin, Lippi and Reichlin, 2000; Kapetanios and Marcellino, 2004) mainly in that the factors may be stationary, non-stationary or both.[14] Let r_0 denote the number of stationary and $r_1 (= r - r_0)$ the number of non-stationary factors or common trends. In addition, the idiosyncratic components can be I(0) for some variables and I(1) for others. The source of non-stationarity in Y_t can thus be pervasive, idiosyncratic or both.

Let us now turn to the estimation of the model. As pointed out above, F_t cannot be estimated directly from equation (1) (i.e. by simply applying principal component analysis to Y_t), since Ξ_t may contain non-stationary elements. When ξ_{it} is I(1), a regression of y_{it} on F_t is spurious, even if F_t has been observed, and estimates for the loadings and thus of ξ_{it} are not consistent. Following BN, we avoid this problem by differencing the whole dataset, which leads to $\Delta \mathrm{Y}_t = \Lambda' \Delta \mathrm{F}_t + \Delta \Xi_t$. Now, $\Delta \Xi_t$ contains only stationary elements, and $\Delta \mathrm{F}_t$ can be estimated consistently by applying static principal component analysis to $\Delta \mathrm{Y}_t$.[15] The static factor estimates and estimates for the components are then obtained by cumulating the estimated differenced factors and the estimated differenced components, respectively. The estimation is described in more detail in Appendix A.

[14] Kapetanios and Marcellino (2004) point out that their approach could be extended to cope with non-stationary factors.

[15] BN state that, if ξ_{it} is I(0), $\Delta\xi_{it}$, although over-differenced, is still stationary and weakly correlated, and hence, the conditions for the consistent estimation of the number of factors and the factors themselves are not violated.

The dimension of F_t (and ΔF_t), r, was estimated to be 5 on the basis of the Bai and Ng (2002) IC_{p3} criterion, although the criteria IC_{p1} and IC_{p2} suggest estimates for r of 2 and 1, respectively.[16] One reason for our choice is that F_t is estimated consistently if the number of common factors is correctly or overestimated, but not if it is underestimated (Stock and Watson, 1998; Kapetanios and Marcellino, 2004; Artis, Banerjee and Marcellino, 2005). Another reason is that five (differenced) factors combine to explain 32% of the total variance (of the differenced dataset), whereas the shares accounted for by the first or the first two (differenced) factors are relatively low (13% and 19%): see Table 3. Table 4 shows that also the variance shares of key euro-area aggregate variables explained by the (differenced) common factors are large, at 82% for GDP growth and at 42% for changes in inflation. Finally, our choice is roughly in line with the previous results. Luginbuhl and Koopman (2004) find among five euro-area countries six common factors between 1970 and 2001 and four between 1987 and 2001. Marcellino, Stock and Watson (2000) select $r = 6$ factors for their set of euro-area countries, explaining 37% of the total variance between 1982 and 1997 and 47% in the 1990s. In Altissimo, Bassanetti, Cristadoro, Forni, Lippi, Reichlin and Veronese (2001), four dynamic factors account for 55% of the total variation in a large euro-area dataset between 1987 and 2001. On the basis of a similar dataset, yet using many macro variables of the core EMU member states, a larger number of aggregate euro-area variables as well as output, inflation, exchange rates and interest rates of central and east European countries and more peripheral EMU countries, Eickmeier and Breitung (2006) find that five static factors explain 44% of the total panel. Five static factors also drive the panel of euro-area inflation differentials and macroeconomic variables of Altissimo, Benigno and Palenzuela (2004).

To determine the number of common stationary factors or trends r_1, we apply the criteria proposed by BN. These build on criteria proposed earlier by Stock and Watson (1988) and are designed to test whether the real part of the smallest eigenvalue of an autoregressive coefficient matrix is unity. See BN for a detailed description. Based on these tests, r_1 is estimated to be five, i.e. all static factors are non-stationary and none is stationary: see Table 5. Our results differ somewhat from the findings by LK, who find three common trends between 1970 and 2001 and two between 1987 and 2001; this is possibly due to the fact that they have included the output of five core euro-area countries in their dataset, whereas we work with a much larger dataset.

We now examine whether the source of non-stationarity of individual countries' GDP and CPI inflation is purely pervasive[17] or also idiosyncratic, i.e. whether persistent shocks to these

[16] Applying the Bai and Ng (2002) criteria involves minimizing the sum of the average residual variance when a certain number of factors is assumed for each cross-section unit and a term that penalizes over-parameterization. Unlike the information criteria typically used in time-series analysis, the latter term depends not only on *T*, but also on *N*. Bai and Ng (2002) also suggest three other criteria which, however, depend on the maximum number of factors allowed for and which are not considered here.

[17] The common components which are linear combinations of the factors will be I(1) since the factors themselves were tested to be all I(1).

variables are only common or can also be country- (or series-) specific. For this purpose, we construct two panels, one containing the idiosyncratic components of individual countries' GDPs and one of individual countries' inflation rates. We then employ the panel unit root tests suggested by Harvey and Bates (2003) and Breitung and Das (2005). We use panel rather than univariate unit root tests since the former have been shown to be more powerful (cf. Breitung and Pesaran, 2006). Notice further that both tests are robust with respect to cross-section dependence. This is appropriate for our panels of idiosyncratic components, since those are allowed to be weakly cross-correlated in the sense of Bai and Ng (2002, 2004) in approximate factor models. We describe the tests in Appendix B. We needed to simulate the critical values, something which is also outlined in that appendix.

Idiosyncratic components of GDP are clearly tested to be all I(1), suggesting that GDPs in euro-area countries are not only driven by permanent common shocks, but also by permanent idiosyncratic shocks (Table 6). The results are less clear cut for inflation. The test of Harvey and Bates (2003) indicates that all idiosyncratic components are I(1), whereas the Breitung and Das (2005) test rejects the null that all idiosyncratic components have a unit root at the 5% significance level, but not at the 1% level. This is consistent with our impression from visual inspection of the lower panel of Figure 2, where some idiosyncratic components of inflation look stationary. Standard univariate (Augmented Dickey-Fuller) unit root tests[18] applied to each individual country's idiosyncratic inflation component suggest that Portuguese, Greek, Austrian, French and Finish inflation rates are hit by transitory idiosyncratic shocks, whereas the other countries are affected by permanent idiosyncratic shocks to inflation.

Two remarks are in order before we go on to the next section. First, our modeling framework assumes constant factor loadings. One might ask whether our model is also still applicable if the European integration process has changed comovements within the euro area. The underlying hypothesis is that economic comovements are, like other optimum currency area criteria, endogenous, i.e. a monetary union should enhance trade and the integration of financial markets, which should tighten economic linkages between member states (cf. Frankel and Rose, 1998).[19] Based on bivariate VAR models and structural break tests, Eickmeier and Breitung (2006) find no evidence that EMU has altered linkages between changes in output and inflation of individual euro-area countries and the corresponding euro-area aggregates which supports our constant parameter approach. Similarly, according to Canova, Ciccarelli and Ortega (2005) who use a time-varying panel VAR approach, the Maastricht Treaty and the inception of the European Central Bank do not represent structural breaks. Disregarding this evidence, our model is robust in the sense that the principal

[18] Where a linear trend and a constant are included.

[19] Although theoretically not clear (cf. Kose, Prasad and Terrones, 2003), trade and financial market linkages have been shown in empirical studies to enhance business cycle synchronization (cf. Imbs, 2004; Otto, Voss and Willard, 2001; Kose, Otrok and Whiteman, 2003; Baxter and Kouparitsas, 2005).

component estimator remains consistent with respect to mild time variation in Λ as long as $T/N \to 0$, as shown by Stock and Watson (1998).

Second, the individual factors are not interpretable as such, since they are identified only up to a rotation. Recently, researchers have attempted to give them an economic meaning. Some focus on the factors themselves: see, for example, Marcellino, Stock and Watson (2000) who investigate the relationship between the set of factors and individual variables or groups of variables or other factors, using multivariate correlation measures, such as canonical correlations or the trace R^2; Bai and Ng (2006) have developed formal tests to assess such relationships; Eickmeier (2005) has rotated factors to give individual factors an economic meaning. Others give the factors an economic meaning by identifying the shocks, which drive the factors. This is the way we go here and describe in detail in the next section.

5. The structural factor model and the common shocks

In this section, we complement the BN model with the structural dynamic factor setup based on FR and GRS. This modeling setup and its estimation are described, and common structural shocks that drive the euro economy are identified.

By construction, the common factors are driven by q shocks that result from the VAR(*p*) representation of the factors:

$$\mathrm{A}(L)\mathrm{f}_t = \mathrm{Q}\mathrm{v}_t, \tag{2}$$

with $\mathrm{A}(L) = \mathrm{I} - \mathrm{A}_1 L - \ldots - \mathrm{A}_p L^p$. Matrix Q is chosen such that the innovations v_t are orthonormal. The shocks w_t are related to v_t through the structural equation

$$\mathrm{w}_t = \mathrm{R}\mathrm{v}_t, \tag{3}$$

where $\mathrm{R}'\mathrm{R} = \mathrm{I}_q$. Provided that there are enough identifying restrictions on R, the structural shocks w_t can be recovered from the factor innovations. The $N \times q$ matrix of impulse responses to the shocks $\mathrm{w}_t = (\mathrm{w}_{1t} \quad \ldots \quad \mathrm{w}_{qt})$ at horizon h, $\partial \mathrm{Y}_{t+h} / \partial \mathrm{w}_t' = \Theta_h$, is obtained from

$$\Theta(L) = \Theta_0 + \Theta_1 L + \Theta_2 L^2 + \ldots = \Lambda(L)\mathrm{A}(L)^{-1}\mathrm{Q}\mathrm{R}'. \tag{4}$$

One important objective of the analysis is to identify w_t and to assess impulse responses of individual variables to these shocks.

To estimate the innovations v_t, we fit a VAR(3) model to the estimated vector of static factors $\hat{\mathrm{F}}_t$. The lag order of the VAR model was estimated with the Akaike information criterion. We estimated a VAR model in levels of the factors and not in differences, mainly because, although all factors were tested to be I(1), some uncertainty remains about their degree of integration. By fitting a VAR model to levels, we avoid possible over-differencing which would result in a misspecified regression in the sense that no VAR representation exists (cf. Hamilton, 1994, p. 562).

It is important to note that the VAR representation for $\hat{\mathrm{F}}_t$ is singular if the r-dimensional vector $\hat{\mathrm{F}}_t$ is driven by $q < r$ shocks. To estimate the q-dimensional vector v_t from the r-dimensional vector of residuals of the fitted VAR based on $\hat{\mathrm{F}}_t$, a principal component analysis is employed. This yields the linear combination of the q non-zero components in the residual vector of the VAR model. Let $\hat{\mathrm{v}}_t$ denote the resulting vector of orthogonal factor innovations.

In our case, however, there is no need to employ any of the criteria proposed in the literature to estimate q formally (cf. Breitung and Kretschmer, 2005; Bai and Ng, 2005; Amengual and Watson, 2006) or informally (cf. Forni, Hallin, Lippi and Reichlin, 2000). Instead, we set q equal to 5, which is consistent with our estimate of $\hat{r}_1 = \hat{r}$. Let us explain this reasoning with an example. Suppose that the vector of static factors F_t comprises four dynamic factors and one lagged dynamic factor, i.e. $\mathrm{F}_t = \begin{bmatrix} f_{1t} & f_{1t-1} & f_{2t} & f_{3t} & f_{4t} \end{bmatrix}'$. Suppose further that all elements of F_t, i.e. all static factors, are I(1). Then, there exists a linear combination of F_t, which is stationary, namely $\begin{bmatrix} 1 & -1 & 0 & 0 & 0 \end{bmatrix} \times \mathrm{F}_t$, which would have been detected by the BN tests as a stationary factor, i.e. $\hat{r}_1$ would have been 4. However, this was not the case, which suggests that all static factors are also dynamic factors. It thus follows from our estimate of $\hat{r}_1 = \hat{r}$ that $\hat{q} = \hat{r} = 5$.

The common structural shocks w_t can now be recovered as in the structural VAR literature. The matrix R is chosen such that certain identifying restrictions that need to be specified are satisfied. This is achieved by applying the identification scheme initially proposed by Uhlig (2005) and Faust (1998) and extended by Peersman (2005) and Canova and de Nicoló (2003) which consists in imposing sign restrictions on short-run impulse responses. This prevents us from using the zero restrictions commonly employed in the structural VAR (and structural dynamic factor) literature which are at odds with some theoretical models.

We identify four domestic euro-area shocks, a productivity shock, a labor supply shock, an aggregate real demand shock and a monetary policy shock, and one external shock, namely a US shock which is transmitted to the euro economy.[20] This is done by restricting the signs of impulse responses of key variables, i.e. euro-area real GDP, consumer prices, short-term nominal interest rates and real wages as well as US GDP. Our decision to concentrate on these specific shocks was mainly driven by previous findings that the four domestic shocks were major sources of euro-area output fluctuations (cf. Smets and Wouters, 2002; Peersman and

[20] It is not unusual to identify euro-area monetary policy shocks even before the ECB superseded the national central banks as monetary authorities in 1999. Peersman and Smets (2002), for example, also identified common monetary policy shocks using synthetic euro-area data.

Straub, 2006). In addition, economic fluctuations in the US have been shown to determine the euro economy considerably by many studies (cf. Canova, Ciccarelli and Ortega, 2005; Artis, Galvão and Marcellino, 2005; Osborn, Perez and Artis, 2003; Eickmeier, 2006; IMF, 2001; André, Dalsgaard and Richardson, 2001; Montfort, Renne, Rüffer and Vitale, 2004). We also tried alternative shock combinations, such as an oil price shock or an exchange rate shock based on sign restrictions suggested in the literature (Peersman, 2005; Farrant and Peersman, 2005). However, we either did not find rotations satisfying these restrictions or found results which were difficult to interpret in terms of variance decompositions.

Following Peersman and Straub (2006), we impose the following restrictions. A positive productivity shock has non-negative effects on output and on real wages and non-positive effects on prices. An expansionary labor supply shock differs from the productivity shock in that it has non-positive effects on real wages. A positive demand shock affects output and prices non-negatively; the effect on the short-term interest rate is non-negative. A positive monetary policy shock, finally, does not raise the short-term interest rate; output and prices do not decrease. These conditions are consistent with the standard aggregate supply-aggregate demand framework and with more complex structural models such as the DSGE model of Smets and Wouters (2003). The US shock is required to have a larger impact on US than on euro-area GDP. The US output response after the US shock exceeds US output responses to the four euro-area shocks. Finally, the responses of euro-area output to the four domestic shocks are larger than the responses of US output to these shocks. All these restrictions are required to hold contemporaneously and one quarter after the shock occurred. We report the median impulse responses and 90% confidence bands which were constructed using bootstrap techniques. For details on the structural analysis, including the identification of the shocks, and the bootstrap, see Appendix A.

In the following, we briefly characterize the main sources of economic fluctuations in the euro area before assessing their transmission to individual EMU economies. The common structural shock series can be seen from Figure 3. Impulse responses of euro-area output, inflation, short-term interest rates and real wages as well as US output — the variables which helped us to identify the euro-area shocks — are shown in Figure 4. Shocks and impulse responses appear roughly consistent with those found in the literature (Peersman, 2005; Peersman and Straub, 2006; Canova, Ciccarelli and Ortega, 2005).[21] Euro-area demand, monetary policy shocks and as well as the US shock were largely positive by the end of the 1990s and possibly contributed to the relatively good performance in the euro area. During the economic slowdown in 2001, all shocks exhibited negative values. This is consistent with the

[21] Notice that the restrictions imposed to identify the shock labeled “productivity shock” are consistent with both a technology shock and a price markup shock (cf. Peersman and Straub, 2006). In order to investigate the nature of this shock, we included euro-area labor productivity in our dataset and re-ran the structural factor analysis. Factor estimates remained unaffected. Productivity rises relative to wages after this shock suggesting that it should be interpreted as a productivity (or technology) rather than a price markup shock which would lead to a decline in this difference.

literature: Peersman (2005) also finds that the slump is due not only to a single shock but to several shocks. While he does not explicitly consider US shocks, Artis, Galvão and Marcellino (2005) and Eickmeier (2006) do and attribute an important negative role to them. A more rigorous analysis to explain economic developments in the euro area, and in particular the "millennium slowdown" (cf. Peersman, 2005), could be carried out based on historical decompositions. However, this is beyond the scope of this paper.

Much of the variance of the forecast error of the common component of euro-area GDP can be explained by the euro-area demand and supply shocks (between 15% and 22% each) at forecast horizons of zero to five years (Table 7). Only 14% is accounted for by the monetary policy shock. Interestingly, the labor supply shock seems to affect euro-area output more in the medium than in the short run (up to one year), where only 11% is explained.

The US shock accounts for 18% of the five years ahead forecast error variance of the common component of euro-area GDP which is roughly consistent with previous findings (Osborn, Perez and Artis, 2003 for Europe; Eickmeier, 2006 for Germany). The explanatory power of the US shock for US GDP itself seems to be quite low at first sight, at 32% at the zero to five and 60% at the zero to one year forecast horizons. Remember, however, that we refer to the variance share of the forecast error of the common component of US GDP and not of US GDP itself. The variance share of US GDP growth explained by the common component only amounts to 38%. The US shock identified here only refers to those US shocks that affect the euro-area economy, but not to those that do not spill over to the euro area. To further characterize that shock, we have plotted impulse response functions of US inflation and interest rates to the US shock which suggests a US demand shock: US inflation rises, albeit not significantly, shortly after the shock; the US interest rate increases immediately, the response turns insignificant after roughly a year.[22]

Finally, the common component of euro-area inflation was driven mainly by the productivity shock (31%) and the labor supply shock (22%). The remaining forecast error variance shares are explained in similar parts by the other three shocks.

6. Common and idiosyncratic components, the transmission of common shocks and dispersion in the euro area

In this section, we illustrate the evolution of common and idiosyncratic components of individual EMU countries' GDPs and CPI inflation rates over time. We investigate how important common shocks are for individual economies and how they are transmitted. We finally focus on the determinants of dispersion in the euro area. We look at standard deviations across individual countries' output and inflation series themselves, their common and idiosyncratic components and impulse responses. This allows us to examine whether

[22] Impulse responses of US inflation and interest rates are not shown here, but can be provided by the author upon request.

heterogeneity is due to idiosyncratic shocks or the heterogeneous transmission of common shocks. Put differently, standard deviations of the common/idiosyncratic components indicate how large heterogeneity would have been in the absence of idiosyncratic/common shocks. Heterogeneity in common components is finally decomposed into heterogeneity in the transmission of individual common shocks.

Three issues arise concerning dispersion. First, not only dispersion in levels (generally output gaps or output per capita), but also in growth rates of output is discussed in the literature (cf. Benalal, Diaz del Hoyo, Pierluigi and Vidalis, 2006; Buisán and Restoy, 2005). We therefore also present results on the latter. Second, since one aim of our study is to provide stylized facts on dispersion in the euro area, we first present unweighted standard deviations. However, the euro area is a weighted concept, and weighted standard deviations are probably more relevant for monetary policy (cf. Benalal, Diaz del Hoyo, Pierluigi and Vidalis, 2006). We therefore also look at weighted standard deviations. We use as weights for output series real GDP shares and for inflation series HICP weights for 2003.[23] Third, we not only focus on the dispersion across all EMU members states (E12), but look at the dispersion across the core seven countries (E7) and the largest four countries (E4) — Germany, France, Italy and Spain — separately. This allows us to gain deeper insight into which countries deviate most from the euro-area average. It turns out that differences across weighted standard deviations of E12, E7 and E4 are barely visible. This is not surprising given the large weights of the E4 (78% and 81%) and the E7 (both 92%) in total euro-area GDP and HICP, respectively, in 2003. Weighted standard deviations for the E7 and E4 are therefore not reported.

In the following, we present the results. Figure 2 shows the historical decomposition of individual countries' output and inflation series (i.e. deviations from the linear trend) as well as output growth (i.e. first differences of these deviations) into common and idiosyncratic components. From the upper panel, it is apparent that GDPs of France and Belgium, but also Austria, Spain and the Netherlands, are most closely related to the euro-area average, suggested by the fact that common components and series move in close parallel. Important idiosyncratic output movements are found for Ireland and Greece, which may be explained by catching-up processes. Finish and German output also diverged temporarily from the euro-area average. In Finland, the banking crisis at the beginning of the 1990s represented a strong negative idiosyncratic shock; in addition, Finland had tied trade links with the USSR and was affected more than other euro-area economies by the collapse of the Soviet economic system at the end of the 1980s. Germany first experienced a post-unification boom after 1991, which was largely idiosyncratic. Interestingly, Germany's weak economic performance in the second half of the 1990s is due primarily to idiosyncratic influences: unlike the common component, the idiosyncratic component of German output almost continuously exhibits a negative slope. As concerns historical decompositions for inflation, French and Spanish

[23] ECB (2004), p 36.

inflation are largely driven by the common factors, whereas inflation in Greece, Portugal, the Netherlands and Luxembourg is dominated by idiosyncratic factors representing the other extreme.

These findings based on visual inspection are confirmed by Table 3 where variance shares of output and inflation growth explained by their components are reported. Common (differenced) factors are most important for output growth in the largest two economies (France and Germany), but also in Belgium, Austria and, surprisingly, Portugal with variance shares between 51% and 65%, whereas they are relatively unimportant in Greece, Luxembourg and Ireland with shares at 13%, 14% and 16%, respectively. Common (differenced) factors play a relatively important role for changes in inflation in Germany, Luxembourg, Belgium and France (between 45% and 55%), whereas they are rather unimportant for changes in inflation in Greece (4%), Portugal (6%) and the Netherlands (9%). The low variance share for changes in Dutch CPI inflation can be explained by increases in value added tax and ecological tax in the 1990s, which led to movements of consumer prices that were widely unrelated to movements of euro-area prices.

Figure 5 shows unweighted and weighted standard deviations between output series (in levels, i.e. deviations from the linear trend, and differences of these deviations) and inflation series and between common and idiosyncratic components for the different country groups. With regard to output, unweighted E12 dispersion looks very persistent: see the upper left panel of Figure 5. It rises until the beginning of the 1990s, declines thereafter, before rising again since the end of the 1990s. Weighted standard deviations which are much smaller than unweighted standard deviations, confirming previous results from the literature, and exhibit a similar development. However, the rise until the early 1990s begins later and the subsequent decline earlier compared to unweighted standard deviations. No clear pattern arises when comparing unweighted standard deviations across E4, E7 and E12. With regard to output growth, no clear trend appears from the middle panels of Figure 5, consistent with Benalal, Diaz del Hoyo, Pierluigi and Vidalis (2006).

Unweighted standard deviations clearly suggest that output and output growth dispersion are due to idiosyncratic shocks, which is in line with findings by Giannone and Reichlin (2006) and Buisán and Restoy (2005): dispersion of idiosyncratic components moves very much in parallel with overall dispersion, whereas dispersion of common components is relatively low and stable. Interestingly, findings differ a bit when looking at weighted standard deviations. During most of the time, idiosyncratic components are the dominant forces of dispersion. However, between 1987 and the end of 1992 and again from 1999 on, most output dispersion can be explained by the asymmetric transmission of common shocks. During these periods, dispersion of common components even exceeded dispersion of idiosyncratic components.

Let us now turn to inflation differentials. The downward trend in dispersion across all euro-area countries that one might be used to observe during the 1990s is much less pronounced here — see the right panels of Figure 5 — which is due to fact that we work with de-trended inflation rates. However, inflation dispersion increases at the end of the sample are apparent from all graphs. As for output, weighted inflation differentials are much lower compared to unweighted inflation differentials which is good news for monetary policy. Interestingly, though, inflation dispersion does not differ much across country groups.

As regards historical decompositions of unweighted inflation dispersion into their components, a dominant role is clearly attributed to idiosyncratic shocks. This holds for the entire period, and idiosyncratic shocks seem to be responsible for the increase in inflation differentials at the end of the sample. Results differ when one focuses on weighted inflation differentials. Most of the time, those are determined by the asymmetric spread of common shocks, exceptions being the beginning of the 1990s and the last three years of the sample when idiosyncratic shocks played the major role. It is not clear how these results compare to Altissimo, Benigno and Palenzuela (2004) who attribute most of inflation differentials to the common component. There exist several differences between their and our approaches. The authors focus on a different period (1990 to 2004) and on year-on-year inflation rates, whereas we have included quarter-on-quarter inflation in our analysis; inflation dispersion is measured as the unweighted average of differences between individual inflation rates and weighted euro-area inflation; their underlying dataset is different, including, among others, 60 time series of disaggregated inflation dispersion. Our results math those of Altissimo, Benigno and Palenzuela (2004) insofar, as they also find that the increase in inflation differentials in 2000 is due to an increase in the idiosyncratic component of dispersion rather than the common component.

In the following, we leave apart idiosyncratic components and focus only on the common components. We illustrate the transmission of individual common shocks. Figure 6 shows impulse responses of output and inflation of individual euro-area countries to euro-area macro shocks and Table 8 the corresponding forecast error variance decompositions. Overall, impulse responses look quite similar across countries, which is in line with the literature. But there are a few exceptions.

The euro-area productivity shock triggers output responses which are similar across countries. In general, the impact peaks immediately after the shock occurs, with the exception of Luxembourg and Portugal, where responses are negative and zero, respectively, although not significant. The productivity shock explains most of the forecast error variance of the common component of output in Greece, Germany and Austria. The labor supply shock leads to immediate significant output increases in Italy and Portugal, whereas it displays delayed effects in the other countries that generally die out after two to three years. The variance shares explained by this shock are largest for the south European countries (Portugal, Spain, Greece and Italy). In response to the demand shock, Luxembourg's GDP does not change significantly. The demand shock seems to be most important for Ireland, Belgium and France.

The euro-area monetary policy shock explains relatively large forecast error variance shares of output in the Netherlands, Luxembourg, Germany and Austria. Output responses to this shock are not significant in Belgium, France, Ireland, Italy, Finland and Greece. Median short-run output responses in the latter four countries are even negative, which is somewhat counterintuitive.[24] The US shock, finally, raises output in most countries significantly, except for Greece and Portugal, where responses are not significant. The variance shares explained by this shock are largest in the small open economies of Finland and Belgium, whereas the US shock seems to be least important in the peripheral and less open southern European countries of Greece, Portugal and Spain, but also in Germany where only 13% of the forecast error variance is explained.

As concerns inflation responses, the euro-area productivity shock instantaneously raises Austrian and Dutch inflation — although responses are not significant — , whereas inflation declines on impact in all other countries. The labor supply shock does not significantly lower inflation in Portugal, in contrast to the other countries. Inflation responses to the demand shock and the monetary policy shock are similar across countries, but clear positive and significant short-run responses after the former are only found for Austria, Germany, Italy, Spain and Luxembourg, and responses to the latter shock are negative in Finland and Greece and not significant in Ireland, Luxembourg and Portugal. Inflation responses to the US shock, finally, are not significant in Italy and the Netherlands, and only marginally significant in most other countries.

To assess the heterogeneity of the propagation of individual common shocks more formally, we compute standard deviations of impulse responses. According to Figure 7, heterogeneity across impulse response functions is larger at shorter horizons than at longer horizons, which is consistent with the results of Ciccarelli and Rebucchi (2006). An exception is unweighted standard deviations of output impulse responses to the euro-area labor supply and demand shocks which are relatively persistent. It is not clearly apparent from the figure that some shocks are transmitted to individual euro-area economies more or less heterogeneously than other shocks. Notice, finally, that unweighted dispersion of both output and inflation responses clearly exceeds weighted dispersion, which is, again, encouraging for monetary policy. Finally, there is evidence that unweighted output impulse responses' dispersion across all euro-area countries is larger than unweighted output responses' dispersion across smaller country groups suggesting that the smaller countries respond in a more heterogeneous way to common shocks than the larger economies. Such a pattern, albeit less pronounced, can also be observed for inflation responses.

[24] Our analysis is not the only one to find a counterintuitive impact of a euro-area monetary policy shock to several EMU countries: cf. Angeloni, Kashyap, Mojon and Terlizzese (2002).

7. Conclusion

In our paper, we have applied the PANIC approach recently developed by BN to a set of 172 stationary and non-stationary quarterly euro-area macroeconomic variables. This approach allows us to estimate stationary and non-stationary common factors and idiosyncratic components. We have complemented this framework with the structural dynamic factor setup suggested by FR and GRS, which enables us to identify the structural shocks behind the common factors and assess their transmission to individual EMU member states.

We find that five factors or shocks drive the euro economy and have identified four common domestic (euro-area) shocks — a productivity, a labor supply, an aggregate real demand and a monetary policy shock — as well as a US shock. All five factors were tested to be non-stationary and none to be stationary, i.e. euro-area countries share five trends. Our analysis further suggests that the source of non-stationarities of individual countries' key macro variables is not only common but also idiosyncratic. Idiosyncratic components of individual countries' output were tested to be all non-stationary. The results for inflation are less clear cut. Most countries' inflation rates seem to be also hit by persistent idiosyncratic shocks, except for Portugal, Greece, France, Austria and Finland where idiosyncratic shocks to inflation seem to be transitory.

As regards heterogeneity, dispersion across EMU members' output and inflation seems to have declined in the run-up to EMU, and we also find an increase in inflation dispersion from 1999 on. It turns out that the answer to the question whether dispersion is due to idiosyncratic shocks or the asymmetric propagation of common shocks depends on the measure used. Our results based on unweighted standard deviations suggest that movements of output and inflation in individual countries in the euro area are heterogeneous due more to idiosyncratic shocks rather than to the asymmetric transmission of common shocks. Conclusions drawn from weighted standard deviations, which may be more relevant for monetary policy, depend on the period considered: output dispersion between 1987 and the end of 1992 and again from 1999 on seems to be due to the asymmetric transmission of common shocks, whereas idiosyncratic shocks play the dominant role in the remaining period; over most of the period, inflation dispersion is determined by the asymmetric spread of common shocks rather than idiosyncratic shocks, except for the early 1990s and the end of the sample. A further finding is that weighted dispersion is lower than unweighted dispersion, which is good news for monetary policy. Output and inflation impulse responses, finally, are similar across countries, with a few exceptions, and similarity increases in most cases with the horizon. In addition, we do not find evidence that some common shocks are transmitted in a more or less heterogeneous way than others.

What are the policy implications? As we have explained above, not all observed heterogeneity, for example heterogeneity that goes along with the convergence process, leads to welfare losses and calls for policy intervention. However, even after (partly) prescinding from this type of heterogeneity, there seems to be considerable and persistent heterogeneity left. Given our finding that the remaining heterogeneity is, to a considerable extent, explained by idiosyncratic shocks which only slowly spread to individual countries' output and inflation, national economic policies designed to carry out structural reforms to enhance factor mobility and to foster nominal flexibility would be well suited to speed up the adjustment to shocks and, in this way, to reduce such heterogeneities.

Comovements and heterogeneity in the euro area are, of course, also intensively studied in central banks, and there is a lively debate on the role of the ECB in the light of observed output and inflation differentials. Some papers find that monetary policy could improve overall welfare in a currency union if it gave a larger weight in the objective function to countries in which economic developments are more persistent (cf. Benigno, 2004; Benigno and López-Salido, 2002, who focus on inflation persistence). Other results suggest that heterogeneity could be lowered if cross-country differences in the transmission of a common monetary policy shock were exploited (Angelini, Siviero and Terlizzese, 2004). But those papers also acknowledge that such active and complex policies involve important risks not to be ignored. The first type of policy may reduce incentives for national governments to make necessary structural adjustments to increase flexibilities. The second type of policy would be difficult to implement given the relatively large uncertainty involved with the effects of monetary policy. This is even more true if monetary policy effects do not differ much across countries, one of our results in this paper. The ECB tries to achieve price stability in the medium run. Insofar individual countries have enough time to adjust to shocks.[25] In addition, by aiming at keeping the inflation rate below, but close to 2%, the ECB ensures a safety margin which should avoid the possibility of individual countries encountering deflation.

Two possible extensions of this paper come to our mind. First, in our framework, we could investigate heterogeneity and non-stationarities at a more disaggregated level. For example, the analysis could be performed for the components of GDP, i.e. consumption, investment, government spending and external trade, which should help us to understand the determinants of dispersion. Second, as pointed out in Section 4, previous work suggests that the European integration process did not considerably change the transmission mechanism in the euro area. Nevertheless, future work could be devoted to estimating a time-varying model such as the Bayesian dynamic factor model of Del Negro and Otrok (2005) to explicitly test for changes in economic comovements. Such a framework would also permit the modeling of factors which drive only subsets of variables and, hence, distinguish between variable-specific and country-specific driving forces.

[25] See the speech by Otmar Issing at the ECB workshop on "Monetary policy implications of heterogeneity in a currency area", Frankfurt, 13-14 December 2004.

Appendix A (estimation of the model and identification of shocks)

This appendix describes the estimation of the factor model and the identification of the structural shocks. Suppose that Y_t refers to the vector of de-trended time series and, hence, ΔY_t to the vector of demeaned growth rates of the series. Following BN, we first difference the dataset, which yields

$$\Delta Y_t = \Lambda' \Delta F_t + \Delta \Xi_t . \tag{A-A1}$$

$\Delta \Xi_t$ now contains only stationary elements. We estimate ΔF_t by applying static principal component analysis to ΔY_t, i.e.

$$\Delta \hat{F}_t = \hat{V}' \Delta Y_t , \tag{A-A2}$$

where $\hat{V}$ is the $N \times r$ matrix of eigenvectors corresponding to the largest r eigenvalues of the correlation matrix of ΔY_t. $\hat{V}$ is an estimate of the matrix of factor loadings Λ. Our factor estimates are obtained from

$$\hat{F}_t = \hat{V}' Y_t , \tag{A-A3}$$

and the estimated common and idiosyncratic components are

$$\hat{X}_t = \hat{V} \hat{F}_t \tag{A-A4}$$

and

$$\hat{\Xi}_t = Y_t - \hat{X}_t . \tag{A-A5}$$

Following BN, we have previously de-trended the series by taking first differences of the original vector of time series, denoted by $\tilde{Y}_t$, and subtracting the means, i.e. $\Delta Y_t = \Delta \tilde{Y}_t - \overline{\Delta \tilde{Y}_t}$. The demeaned series are then cumulated, yielding $Y_t = \sum_{s=2}^{t} \Delta Y_s$, and Y_1 is set to zero. We employ the BN tests to determine the number of non-stationary factors to $\hat{F}_t$ which were estimated as outlined above and based on this de-trending procedure, and rely on critical values reported in BN. We also employ the panel unit root tests to the so estimated idiosyncratic components, see Appendix B. This de-trending procedure, however, implies that the first and the last observations of Y_t and hence $\hat{F}_t$ and the components' estimates are zero and, hence, the series are not reliable at the beginning and the end of the sample. This is not a problem when one is only interested in testing the degree of integration of the factors and components PANIC was originally designed to. Focusing, however, on the series of the factors and components themselves (and the dispersion across countries) requires a different de-trending procedure. In this case, we rely on OLS de-trending, and $\mathrm{Y}_t = \widetilde{\mathrm{Y}}_t - \hat{\mathrm{C}} - \hat{\mathrm{B}}t$, where $\hat{\mathrm{C}}_t$ and $\hat{\mathrm{B}}_t$ are $N \times 1$ vectors of variable-specific coefficients obtained from an OLS regression of $\widetilde{\mathrm{Y}}_t$ on a constant and a linear time trend. Y_t then does not have the properties of zero values at the beginning and the end of the sample. This also hold for $\hat{\mathrm{F}}_t$, $\hat{\mathrm{X}}_t$ and $\hat{\Xi}_t$, which are now readily interpretable.

The estimated vector of static factors $\hat{\mathrm{F}}_t$ has the VAR(3) representation

$$\Psi(L)\hat{\mathrm{F}}_t = \mathrm{u}_t, \tag{A-A6}$$

with $\Psi(L) = \mathrm{I} - \Psi_1 L - \Psi_2 L^2 - \Psi_3 L^3$. OLS is applied to each equation, yielding the reduced form VAR residuals $\hat{\mathrm{u}}_t$. The q-vector of orthogonalized residuals v_t is estimated as

$$\hat{\mathrm{v}}_t = \hat{\mathrm{M}}^{-1/2}\hat{\mathrm{P}}'\hat{\mathrm{u}}_t, \tag{A-A7}$$

where $\hat{\mathrm{M}}$ is a $q \times q$ matrix with the largest q eigenvalues of $\mathrm{cov}(\hat{\mathrm{u}}_t)$ on the main diagonal and zeros elsewhere such that $\mathrm{cov}(\hat{\mathrm{v}}_t) = \mathrm{I}_q$. $\hat{\mathrm{P}}$ is the corresponding $r \times q$ matrix of eigenvectors. The vector $\hat{\mathrm{v}}_\mathrm{t}$ is a consistent estimator of v_t. The estimated vector of structural shocks $\hat{\mathrm{w}}_t$ is related to $\hat{\mathrm{v}}_\mathrm{t}$ through the $q \times q$ rotation matrix R:

$$\hat{\mathrm{w}}_t = \mathrm{R}\hat{\mathrm{v}}_t, \tag{A-A8}$$

where $\mathrm{R}'\mathrm{R} = \mathrm{I}_q$. Notice that, by construction, $\mathrm{cov}(\hat{\mathrm{w}}_t) = \mathrm{I}_q$. The matrix of impulse response functions at horizon h with respect to the structural shocks, $\partial \mathrm{Y}_{t+h} / \partial \mathrm{w}_t^{'} = \Theta_h$, is obtained from

$$\Theta(L) = \Theta_0 + \Theta_1 L + \Theta_2 L + ... = \Lambda\Psi(L)^{-1}\mathrm{P}\mathrm{M}^{1/2}\mathrm{R}' \tag{A-A9}$$

(cf. GRS). The rotation matrix R has to be chosen such that the identifying restrictions specified in the main text are satisfied.

Any q-dimensional rotation matrix can be parametrized as follows:

$$
\mathrm{R}(\theta)=\prod\nolimits_{l,n}\begin{bmatrix} 1 & 0 & \cdots & & & \cdots & 0 \\ 0 & \ddots & & & & & 0 \\ \vdots & & \cos(\theta) & & -\sin(\theta) & & \vdots \\ & & & \ddots & & & \\ & & & 1 & & & \\ & & & & \ddots & & \\ & & \sin(\theta) & & \cos(\theta) & & \vdots \\ \vdots & & & & & \ddots & 0 \\ 0 & \cdots & & & \cdots & 0 & 1 \end{bmatrix}, \qquad \text{(A-A10)}
$$

where only rows l and n are rotated by the angle θ_i, and there are $q(q-1)/2=10$ possible bivariate rotations. Hence, $\theta=\theta_1,\ldots,\theta_{q(q-1)/2}$ and each rotation angle is varied on a grid from 0 to π. The number of grids is chosen to be 24, and the rotation angles are fixed to satisfy the imposed restrictions. Canova and de Nicoló (2003), who apply a similar identification scheme, suggest, in this case, imposing more restrictions which allow the fixing of only one rotation. We decide not to do so but give equal probability to all of them. One reason is that we will not focus on the point estimates but on the median impulse responses and the confidence bands below. As we will explain below, those are obtained with bootstrap techniques, and for each draw, a different number of rotations satisfying the restrictions may arise. Imposing more restrictions in order to get one single point estimate therefore would not help much.

Since $N>>T$, the uncertainty involved with the factor estimation can be neglected (cf. Bernanke, Boivin and Eliasz, 2005). In order to account for the uncertainty involved with the estimation of the VAR model on the factors, we construct confidence bands by means of the bootstrap-after-bootstrap techniques based on Kilian (1998). These techniques allow us to remove a possible bias in the VAR coefficients which can arise due to the small sample size of the VAR model. Most draws deliver not just one, but a set of shocks which all satisfy the restrictions. In this case, we follow Peersman (2005) and draw and save one of them. Some draws, however, do not deliver any shocks satisfying the restrictions. We draw until we have saved 300 shocks (578283 draws were needed). For more details on the identification, the reader is referred to Peersman (2005).

Appendix B (panel unit root tests)

This appendix describes the panel unit root tests of Harvey and Bates (2003) and Breitung and Das (2005) and how they were applied to the sets of idiosyncratic components of individual countries' output and inflation. Let us consider a panel of $\widetilde{N}=12$ idiosyncratic components denoted by ξ_{it}, where $i=1,...,\widetilde{N}$, and focus on the following model

$$\Delta\xi_{it}=\phi\xi_{it-1}+\sum_{l=1}^{\widetilde{p}_i}\alpha_{il}\Delta\xi_{it-l}+\varepsilon_{it} \tag{A-B1}$$

for each unit. We then aim at testing the null hypothesis that all series have a unit root:

$$H_0:\phi=0. \tag{A-B2}$$

The short-term dynamics, i.e. the lags of $\Delta\xi_{it}$ on the right hand side of equation (A-B1), are removed through a "pre-whitening" procedure suggested by Breitung and Das (2005). This involves estimating equation (A-B1) with OLS for each i, where $\widetilde{p}_i$ is determined with the Akaike criterion and is allowed to be specific for each i.[26] The pre-whitened idiosyncratic components are then computed as

$$\widetilde{\xi}_{it}=\xi_{it}-\sum_{l=1}^{\widetilde{p}_i}\hat{\alpha}_{il}\xi_{it-l}\ , \tag{A-B3}$$

where $\hat{\alpha}_{il}$ denotes the parameter estimate for unit i and lag l.[27] The model can be written as a SUR system of equations

$$\begin{bmatrix}\Delta\widetilde{\xi}_{1t}\\ \vdots\\ \Delta\widetilde{\xi}_{\widetilde{N}t}\end{bmatrix}=\phi\begin{bmatrix}\widetilde{\xi}_{1t}\\ \vdots\\ \widetilde{\xi}_{\widetilde{N}t}\end{bmatrix}+\begin{bmatrix}\varepsilon_{1t}\\ \vdots\\ \varepsilon_{\widetilde{N}t}\end{bmatrix} \tag{A-B4}$$

or

$$\Delta\widetilde{\xi}_t=\phi\widetilde{\xi}_{t-1}+\varepsilon_t\,. \tag{A-B5}$$

[26] Our results regarding output remain the same if we use the Schwarz criterion to determine $\widetilde{p}_i$. As regards inflation, both tests reject the unit root that all idiosyncratic components are I(1) when the Schwarz criterion is employed.

[27] Notice that the model does not include a constant. Breitung and Das (2005) suggest removing the constant by subtracting the first value of the series to be tested from itself. Since the first value is zero here, this can be disregarded.

The first test statistic we employ, t_{gls}, has been developed by Harvey and Bates (2003) and is the t-statistic based on a GLS regression.

$$t_{gls} = \frac{\sum_{t=1}^{\widetilde{T}} \widetilde{\xi}'_{t-1} \Omega^{-1} \Delta\widetilde{\xi}_t}{\sqrt{\sum_{t=1}^{\widetilde{T}} \widetilde{\xi}'_{t-1} \Omega^{-1} \widetilde{\xi}_{t-1}}}, \tag{A-B6}$$

where the unknown covariance matrix is replaced by its estimator

$$\hat{\Omega} = \frac{1}{T} \sum_{t=1}^{T} (\Delta\widetilde{\xi}_t - \hat{\phi}\widetilde{\xi}_{t-1})(\Delta\widetilde{\xi}_t - \hat{\phi}\widetilde{\xi}_{t-1})' \tag{A-B7}$$

and $\hat{\phi}$ denotes the OLS estimator of ϕ.

The second test statistic, t_{rob}, has been developed by Breitung and Das (2005) and can be computed as

$$t_{rob} = \frac{\sum_{t=1}^{T} \widetilde{\xi}'_{t-1} \Delta\widetilde{\xi}_t}{\sqrt{\sum_{t=1}^{T} \widetilde{\xi}'_{t-1} \Omega \widetilde{\xi}_{t-1}}}. \tag{A-B8}$$

Critical values were obtained with a Monte Carlo simulation. The series were simulated under the null for $\widetilde{N}$ and T. The residuals were assumed to be normally distributed, and we rely on the empirical covariance matrix $\hat{\Omega}$. The simulated series were differenced, standardized and re-cumulated, as we did for the factor analysis. For this reason, our critical values may differ from the critical values reported in Harvey and Bates (2003) and Breitung and Das (2005). The number of replications was 5000. As for the structural factor analysis, we neglect the uncertainty involved with the estimation of the factors and, hence, the idiosyncratic components, since N is large (cf. Bernanke, Boivin and Eliasz, 2005). Results and critical values are reported in Table 6.

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Table 1: Data

Country/region	Variable	Country/region	Variable
Core EMU member countries (AUT, BEL, FRA, GER, ITA, NLD, ESP)	GDP, real	Remaining EMU countries (FIN, GRC, IRE, LUX, PRT)	GDP, real
	Private final consumption expenditure		CPI, harmonized
	Private total fixed capital formation, vol.		
	Industrial production		
	Capacity utilization rate manufacturing	World	Energy prices
	Total employment		World trade
	Unit labor costs (business sector)		Euro/US Dollar nominal
	Productivity		US GDP, volume
	CPI, harmonized		US CPI
	PPI		US nominal short-term interest rate
	GDP deflator		UK GDP, volume
	Short-term interest rate nominal		JPN GDP, volume
	Long-term int. rate (gvt. bonds) nom.		
	M1	Aggregate euro-area variables	GDP, real
	M3		CPI, harmonized
	Main stock price index		Short-term interest rate nominal
	Imports (goods and services), vol.		Real wages
	Exports (goods and services), vol.		
	Bilat. exch. rate with US Dollar nom.		
	Current account balance		

Notes: The dataset does not contain private total fixed investment, but total fixed investment for Spain. Productivity in Belgium, Italy and Spain are not included. Not PPI, but WPI for Austria is included.

Table 2: Mean growth rates

	GDP	Inflation
AUT	0.61	-0.01
BEL	0.56	-0.01
FRA	0.52	-0.02
GER	0.57	0.00
ITA	0.47	-0.02
NLD	0.70	0.00
ESP	0.76	-0.02
FIN	0.50	-0.02
GRC	0.53	-0.06
IRE	1.49	-0.01
LUX	1.34	-0.01
PRT	0.80	-0.06
EA	0.56	-0.01

Notes: Estimated coefficient of the linear trend from an OLS regression of the GDP and inflation on a constant and a linear trend, multiplied by 100.

Table 3: Determining *r*

k	IC_{p1}	IC_{p2}	IC_{p3}	cumulated variance shares
1	-0.0764	-0.0694 *	-0.0951	0.13
2	-0.0809 *	-0.0668	-0.1184	0.19
3	-0.0725	-0.0513	-0.1286	0.24
4	-0.0596	-0.0314	-0.1344	0.28
5	-0.0420	-0.0068	-0.1356 *	0.32
6	-0.0168	0.0255	-0.1291	0.35
7	0.0100	0.0593	-0.1210	0.38
8	0.0360	0.0924	-0.1137	0.41
9	0.0604	0.1239	-0.1080	0.43
10	0.0848	0.1553	-0.1023	0.46

Notes: '*' denotes the minimum. For a description of the criteria see Bai and Ng (2002).

Table 4: Variance of individual countries' and euro-area macro variables explained by the common (differenced) factors

	ΔGDP	ΔInflation
AUT	0.57	0.30
BEL	0.51	0.51
FRA	0.65	0.45
GER	0.59	0.55
ITA	0.38	0.35
NLD	0.33	0.09
ESP	0.31	0.14
FIN	0.35	0.22
GRC	0.13	0.04
IRE	0.16	0.20
LUX	0.14	0.53
PRT	0.52	0.06
EA	0.82	0.42

Table 5: Determining r_1 according to Bai and Ng (2004)

m	MQ_c^c	MQ_f^c
1	-5.857	-8.185
2	-8.103	-12.317
3	-18.724	-16.302
4	-23.098	-23.042
5	-27.640	-23.618

Notes: A description of the criteria can be found in BN. Notations follow BN. The values shown in this table need to be compared with the critical values reported in BN, Table I, p. 1136. To compute the MQ_c^c criterion, we set $J = 4\text{ceil}[\min(N,T)/100]^{1/4}$. The VAR order for the computation of MQ_f^c is determined with the Akaike criterion, but results do not change when we employ the Schwarz criterion.

Table 6: Determining the degree of integration of individual countries' idiosyncratic components

		Test statistic	Critical values		
			1%	5%	10%
GDP	t_{gls}	-3.717	-5.894	-5.372	-5.123
	t_{rob}	-3.299	-5.399	-4.921	-4.658
Inflation	t_{gls}	-5.092	-5.778	-5.340	-5.100
	t_{rob}	-5.258	-5.366	-4.838	-4.614

Notes: Details on the tests and the simulation of critical values are described in Appendix B.

Table 7: Forecast error variance decomposition of key euro-area macro variables

	EA productiv. shock	EA labor sup. shock	EA demand shock	EA mon. policy shock	US shock
	Forecast horizon of 0 to 5 years				
EA GDP	0.15 (0.06 0.35)	0.19 (0.06 0.46)	0.22 (0.06 0.45)	0.14 (0.03 0.35)	0.18 (0.05 0.48)
EA inflation	0.31 (0.11 0.57)	0.22 (0.05 0.53)	0.12 (0.03 0.34)	0.10 (0.02 0.28)	0.15 (0.05 0.33)
EA short-term int.	0.12 (0.03 0.29)	0.14 (0.05 0.36)	0.31 (0.06 0.59)	0.13 (0.03 0.31)	0.21 (0.06 0.50)
EA real wages	0.35 (0.14 0.58)	0.14 (0.04 0.34)	0.22 (0.07 0.49)	0.12 (0.03 0.35)	0.09 (0.02 0.25)
US GDP	0.12 (0.03 0.29)	0.16 (0.05 0.36)	0.21 (0.06 0.41)	0.10 (0.02 0.30)	0.32 (0.14 0.60)
	Forecast horizon of 0 to 1 year				
EA GDP	0.17 (0.08 0.39)	0.11 (0.01 0.38)	0.22 (0.03 0.53)	0.13 (0.02 0.42)	0.21 (0.04 0.59)
EA inflation	0.33 (0.09 0.67)	0.22 (0.03 0.58)	0.11 (0.02 0.37)	0.08 (0.02 0.26)	0.14 (0.04 0.34)
EA short-term int.	0.07 (0.01 0.26)	0.17 (0.04 0.51)	0.37 (0.05 0.70)	0.11 (0.02 0.36)	0.16 (0.03 0.54)
EA real wages	0.46 (0.18 0.69)	0.06 (0.02 0.17)	0.23 (0.05 0.61)	0.10 (0.02 0.34)	0.06 (0.02 0.19)
US GDP	0.09 (0.02 0.24)	0.05 (0.01 0.24)	0.10 (0.02 0.30)	0.06 (0.01 0.27)	0.60 (0.38 0.82)

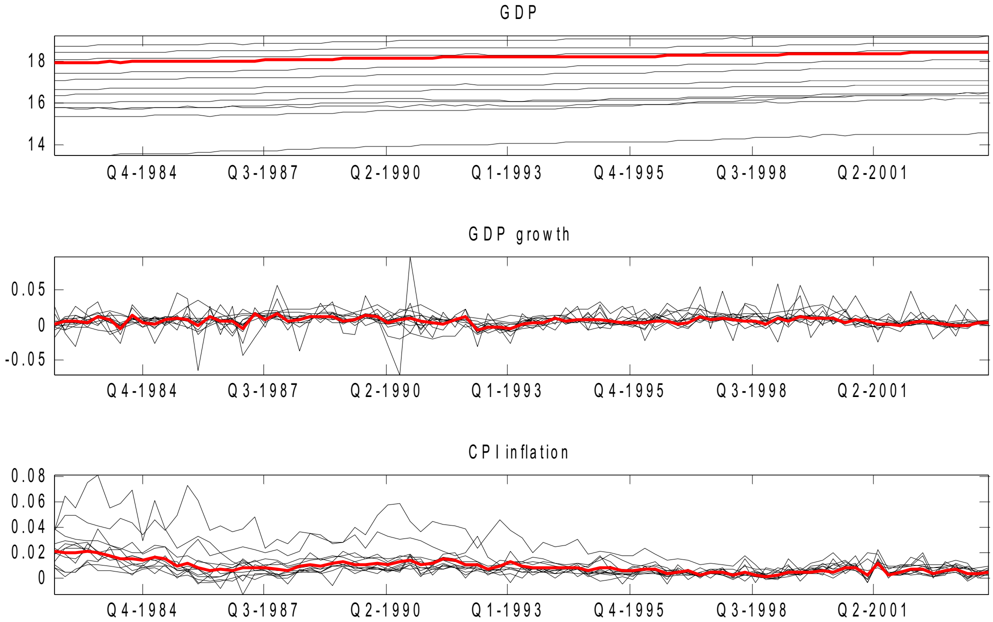
Notes: We show the median, and the 90% confidence intervals are reported in parentheses.

Table 8: Forecast error variance decomposition of individual countries' macro variables

	EA product. shock	EA labor sup. shock	EA dem. shock	EA mon. pol. shock	US shock
	GDP				
AUT	0.22 (0.09 0.43)	0.14 (0.04 0.34)	0.19 (0.05 0.42)	0.18 (0.05 0.43)	0.16 (0.04 0.42)
BEL	0.14 (0.03 0.31)	0.13 (0.03 0.32)	0.27 (0.07 0.53)	0.10 (0.02 0.32)	0.26 (0.07 0.55)
FRA	0.14 (0.04 0.35)	0.19 (0.05 0.44)	0.26 (0.07 0.48)	0.12 (0.02 0.30)	0.19 (0.06 0.48)
GER	0.23 (0.09 0.43)	0.17 (0.05 0.40)	0.18 (0.05 0.39)	0.19 (0.05 0.41)	0.13 (0.03 0.40)
ITA	0.12 (0.03 0.32)	0.21 (0.05 0.48)	0.23 (0.07 0.43)	0.11 (0.02 0.30)	0.23 (0.07 0.52)
NLD	0.13 (0.04 0.32)	0.12 (0.04 0.31)	0.19 (0.04 0.42)	0.23 (0.05 0.47)	0.24 (0.07 0.51)
ESP	0.11 (0.02 0.36)	0.24 (0.07 0.54)	0.24 (0.08 0.46)	0.15 (0.03 0.37)	0.15 (0.03 0.44)
FIN	0.12 (0.02 0.33)	0.16 (0.04 0.38)	0.24 (0.07 0.44)	0.10 (0.02 0.31)	0.28 (0.10 0.57)
GRC	0.28 (0.10 0.48)	0.21 (0.06 0.45)	0.24 (0.10 0.46)	0.10 (0.02 0.32)	0.10 (0.02 0.30)
IRE	0.13 (0.02 0.34)	0.19 (0.05 0.42)	0.27 (0.08 0.48)	0.10 (0.02 0.31)	0.22 (0.06 0.49)
LUX	0.10 (0.01 0.30)	0.23 (0.04 0.50)	0.15 (0.04 0.36)	0.20 (0.06 0.47)	0.21 (0.03 0.59)
PRT	0.11 (0.01 0.37)	0.29 (0.08 0.63)	0.21 (0.06 0.44)	0.12 (0.02 0.36)	0.15 (0.02 0.47)
	Inflation				
AUT	0.09 (0.02 0.23)	0.27 (0.09 0.51)	0.22 (0.06 0.53)	0.16 (0.04 0.40)	0.15 (0.05 0.36)
BEL	0.31 (0.11 0.59)	0.19 (0.05 0.50)	0.11 (0.03 0.31)	0.12 (0.03 0.36)	0.16 (0.05 0.34)
FRA	0.27 (0.10 0.53)	0.27 (0.06 0.57)	0.12 (0.04 0.31)	0.10 (0.02 0.28)	0.14 (0.04 0.31)
GER	0.30 (0.10 0.57)	0.23 (0.05 0.54)	0.12 (0.03 0.34)	0.10 (0.02 0.29)	0.15 (0.05 0.34)
ITA	0.16 (0.05 0.36)	0.29 (0.11 0.56)	0.22 (0.10 0.43)	0.11 (0.03 0.30)	0.13 (0.04 0.34)
NLD	0.14 (0.04 0.37)	0.22 (0.06 0.42)	0.16 (0.06 0.45)	0.25 (0.06 0.55)	0.12 (0.03 0.33)
ESP	0.19 (0.05 0.40)	0.24 (0.07 0.51)	0.18 (0.06 0.40)	0.13 (0.04 0.31)	0.17 (0.06 0.35)
FIN	0.35 (0.17 0.53)	0.20 (0.07 0.39)	0.14 (0.05 0.26)	0.13 (0.05 0.28)	0.14 (0.05 0.30)
GRC	0.18 (0.06 0.34)	0.30 (0.10 0.52)	0.17 (0.06 0.33)	0.12 (0.05 0.26)	0.18 (0.06 0.37)
IRE	0.39 (0.18 0.63)	0.18 (0.03 0.45)	0.11 (0.04 0.28)	0.09 (0.02 0.24)	0.15 (0.05 0.34)
LUX	0.15 (0.04 0.38)	0.30 (0.09 0.62)	0.18 (0.05 0.45)	0.09 (0.03 0.24)	0.17 (0.06 0.39)
PRT	0.23 (0.09 0.46)	0.13 (0.03 0.33)	0.16 (0.05 0.35)	0.11 (0.02 0.31)	0.28 (0.09 0.58)

Notes: The forecast horizon is 0 to 5 years. Results for the 0 to 1 year forecast horizon are available upon request.
We show the median, and the 90% confidence intervals are reported in parentheses.

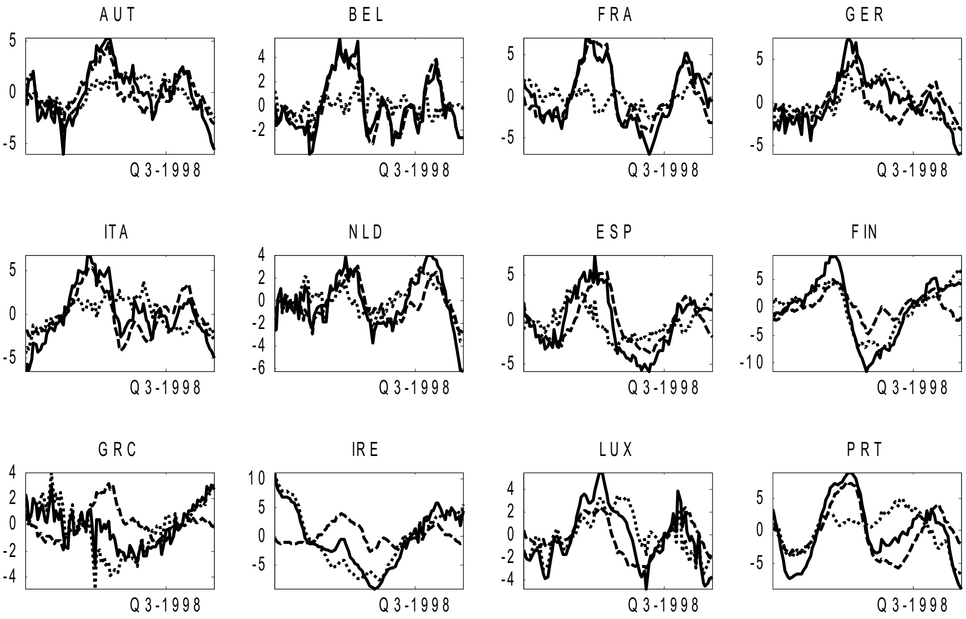
Figure 1: Economic developments in the euro area



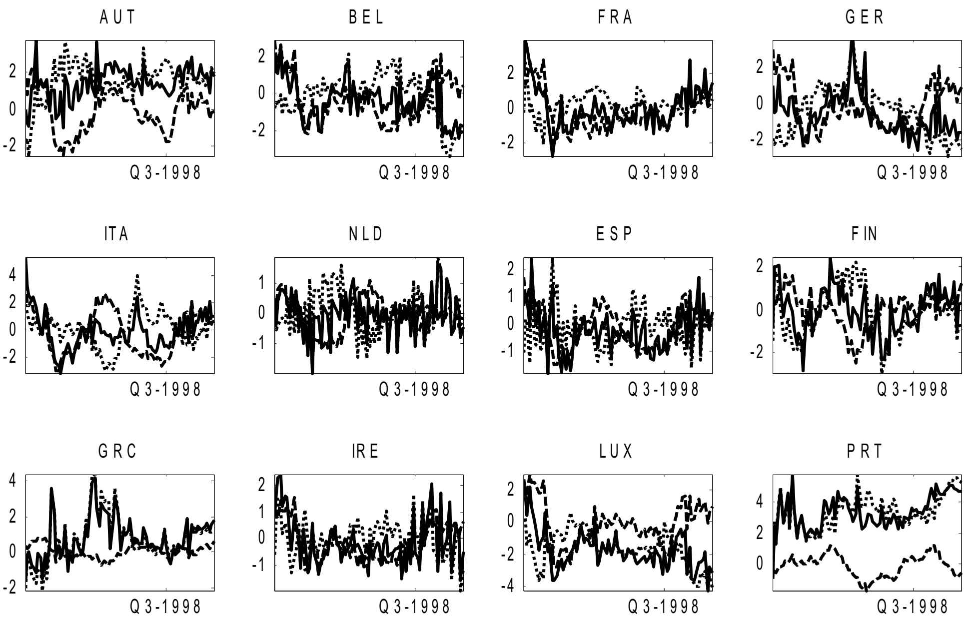
Notes: The series shown here are raw data, i.e. they are not yet standardized nor outlier adjusted. Individual countries (black), euro area aggregate (red). GDP is in logs of 10 000 Euros.

Figure 2: Macroeconomic series and common and idiosyncratic components

GDP



Inflation



Notes: Series (solid), common components (dashed), idiosyncratic components (dotted).

Figure 3: Common structural shocks

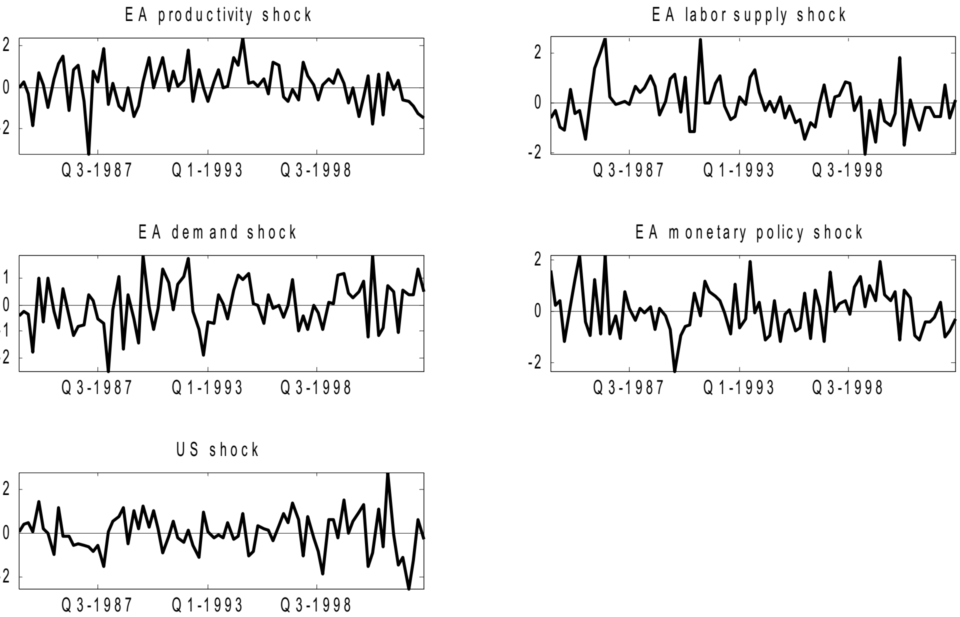
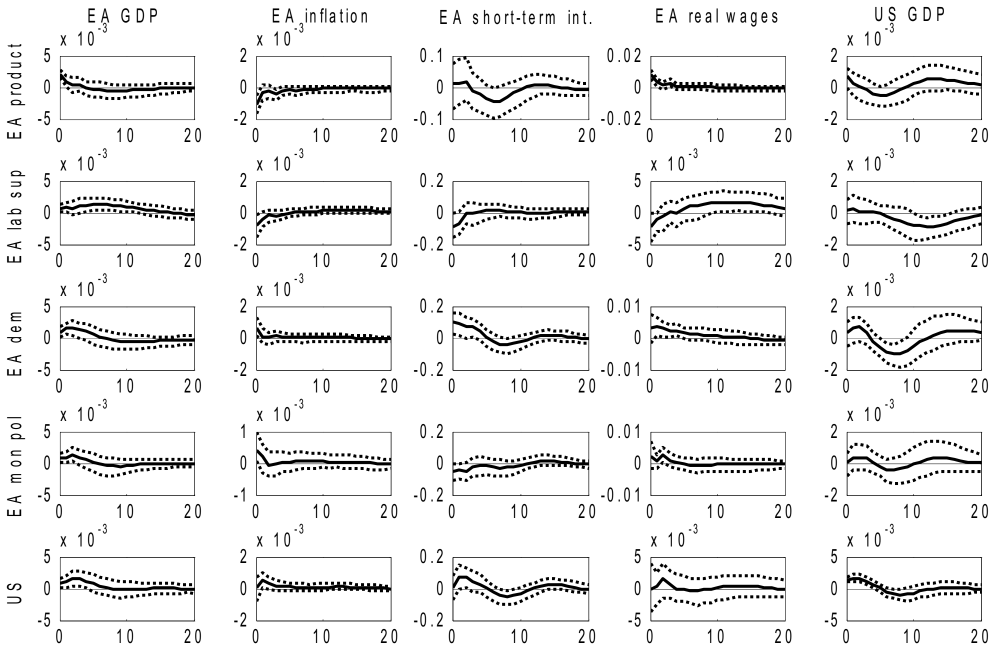
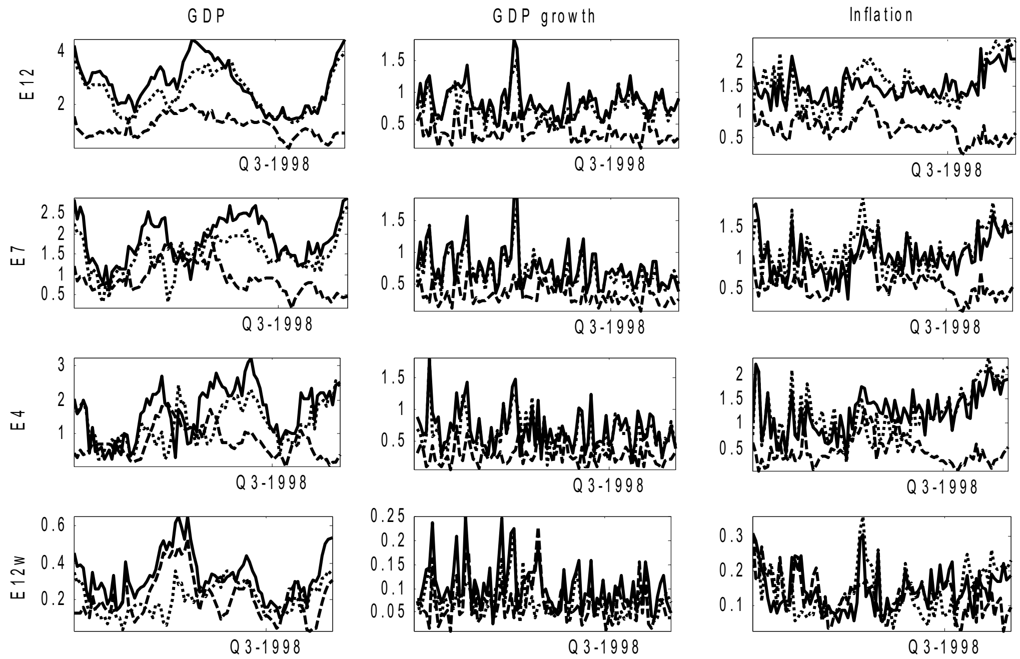


Figure 4: Impulse responses of key macro variables to structural shocks



Notes: Median (solid), 90% confidence bands (dotted). The shocks are a euro-area productivity shock (EA product), a euro-area labor supply shock (EA lab sup), a euro-area aggregate real demand shock (EA dem), a euro-area monetary policy shock (EA mon) and a US shock.

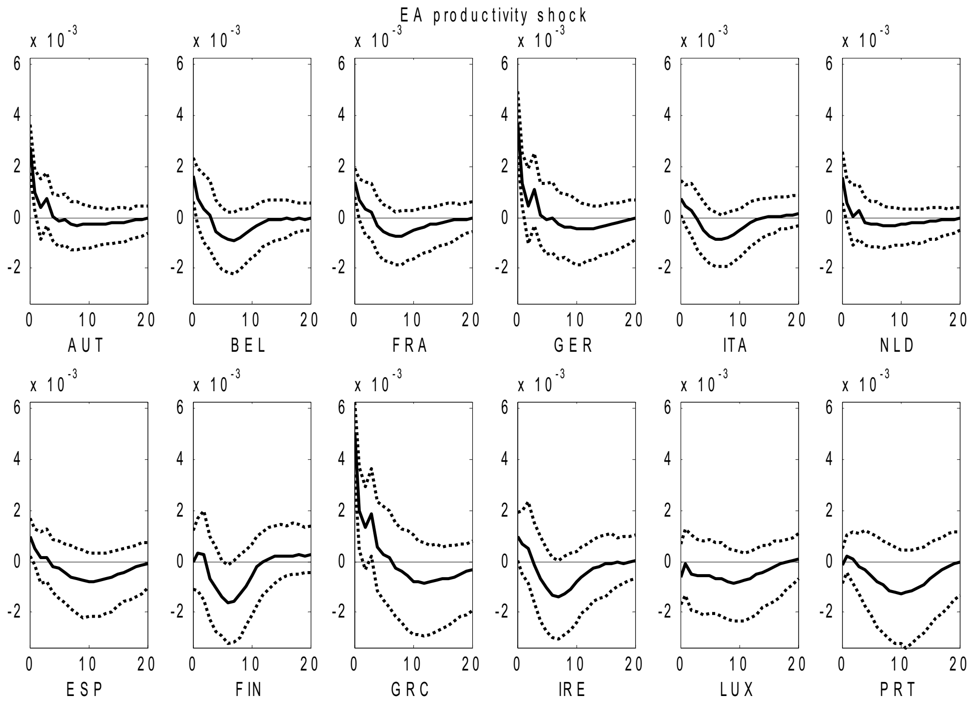
Figure 5: Dispersion of output and inflation and their components across EMU countries

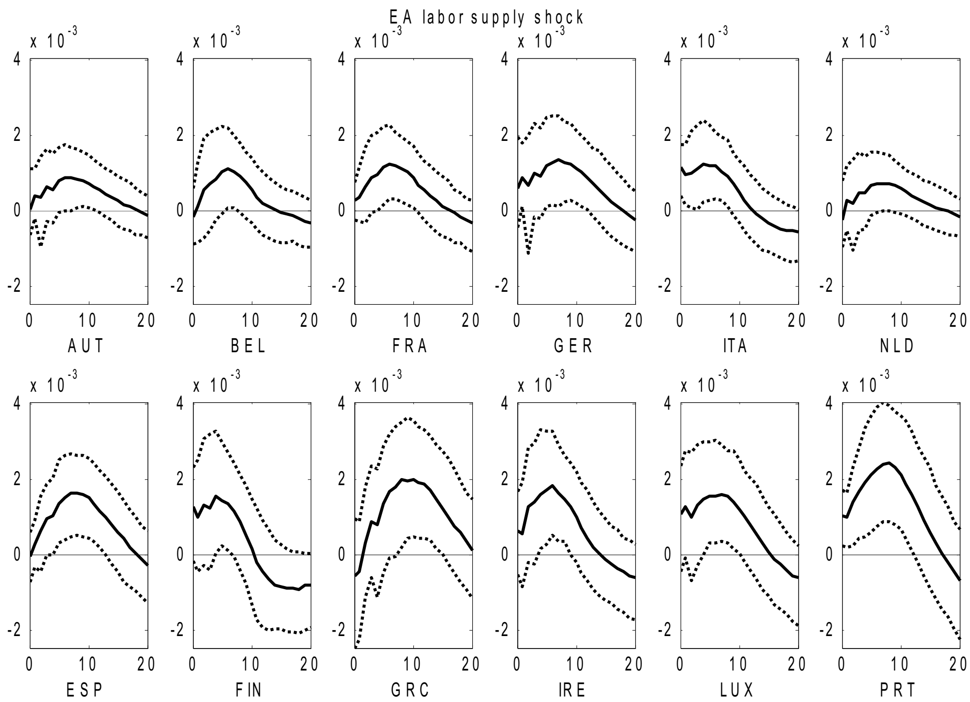


Notes: The panels shows standard deviations of individual countries' GDP, GDP growth and CPI inflation and their components. Series (solid), common component (dashed), idiosyncratic component (dotted). E12/7/4 refers to unweighted standard deviations of the groups of all 12 euro-area countries, the 7 core and 4 largest euro-area countries. E12w refers to weighted standard deviations.

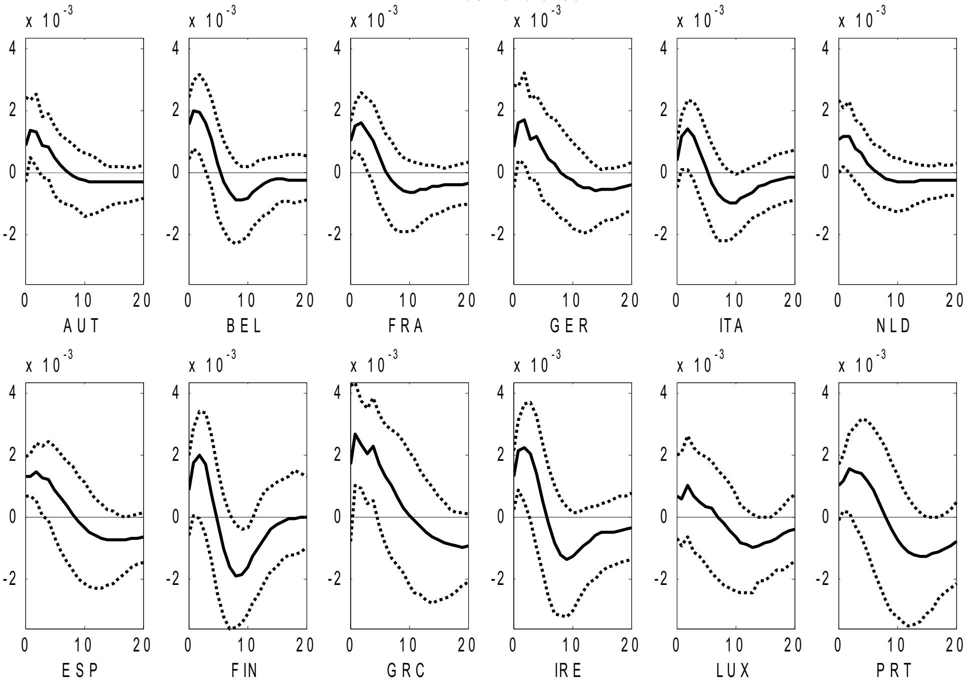
Figure 6: Impulse responses of individual countries' macro variables to euro-area shocks

GDP

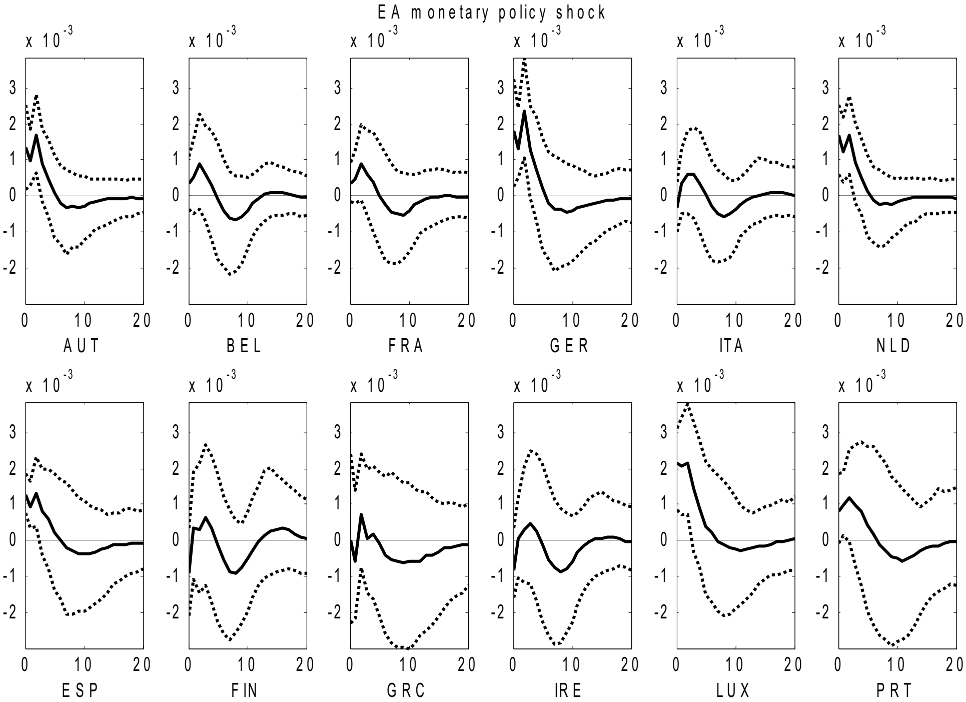


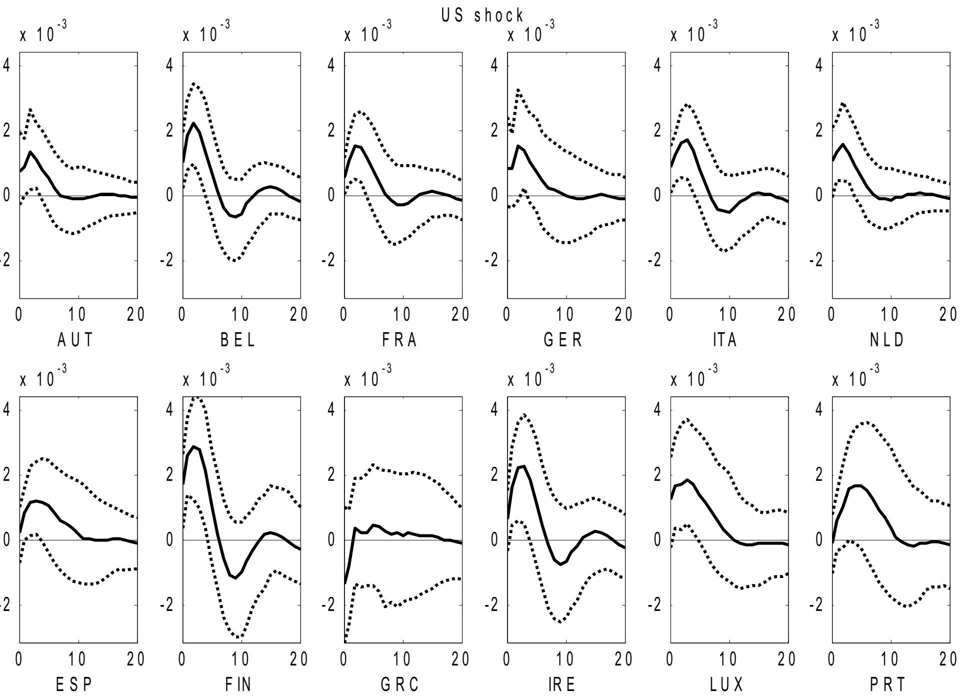


EA demand shock

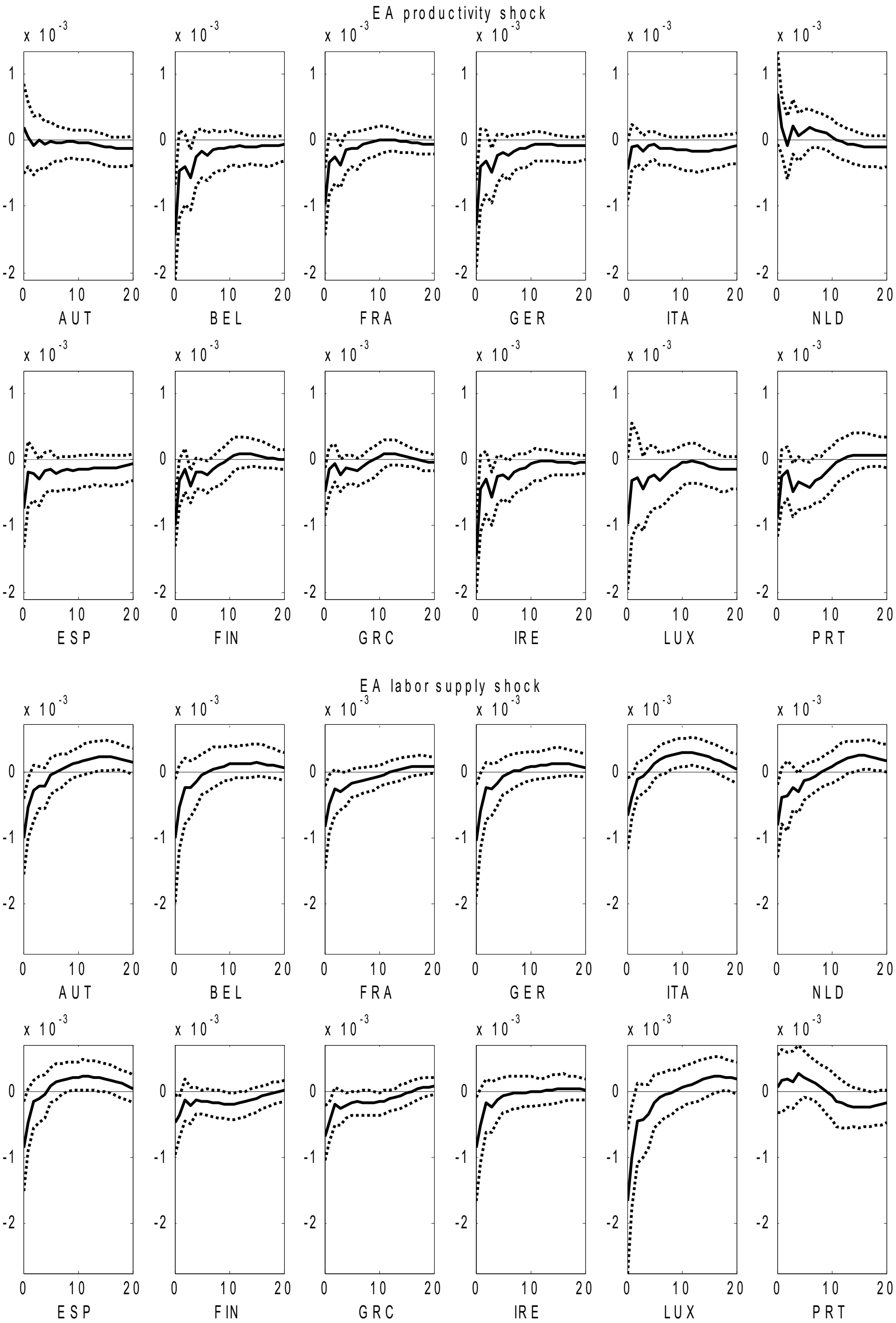


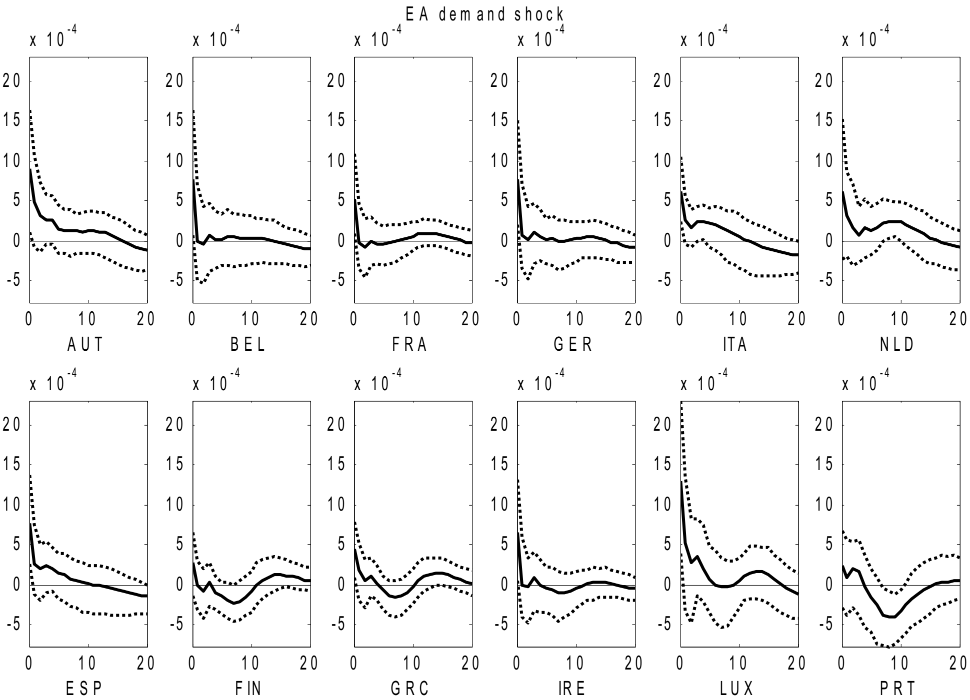
EA monetary policy shock

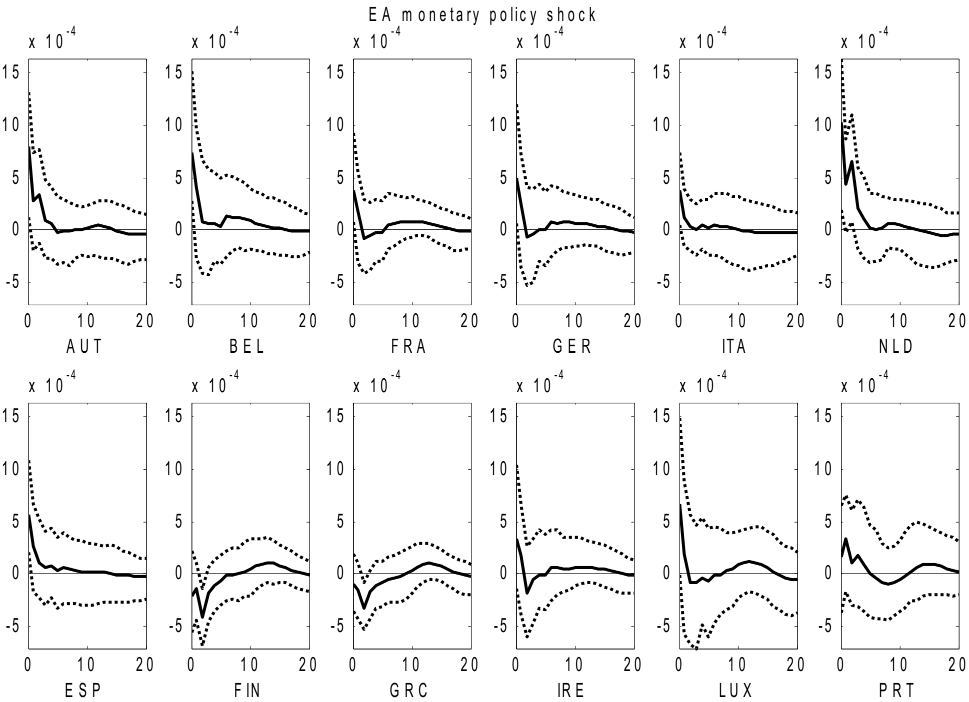



US shock
x 10^-3
AUT
BEL
FRA
GER
ITA
NLD
ESP
FIN
GRC
IRE
LUX
PRT

Inflation


EA productivity shock
x 10^-3
AUT
BEL
FRA
GER
ITA
NLD
ESP
FIN
GRC
IRE
LUX
PRT
EA labor supply shock
AUT
BEL
FRA
GER
ITA
NLD
ESP
FIN
GRC
IRE
LUX
PRT


EA demand shock
x 10^-4
AUT
BEL
FRA
GER
ITA
NLD
ESP
FIN
GRC
IRE
LUX
PRT


EA monetary policy shock
x 10^-4
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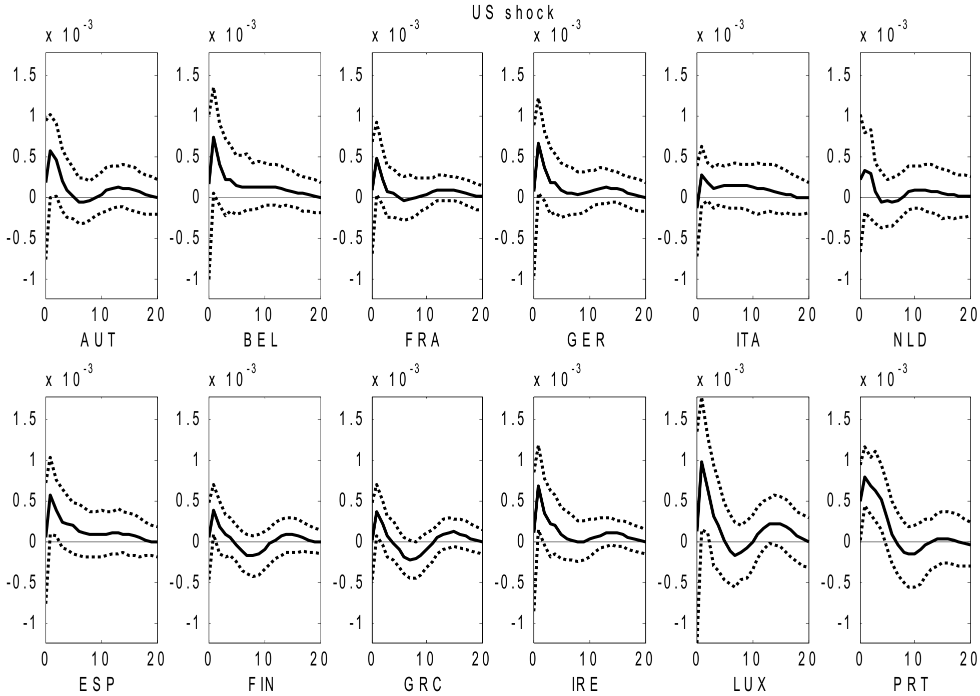
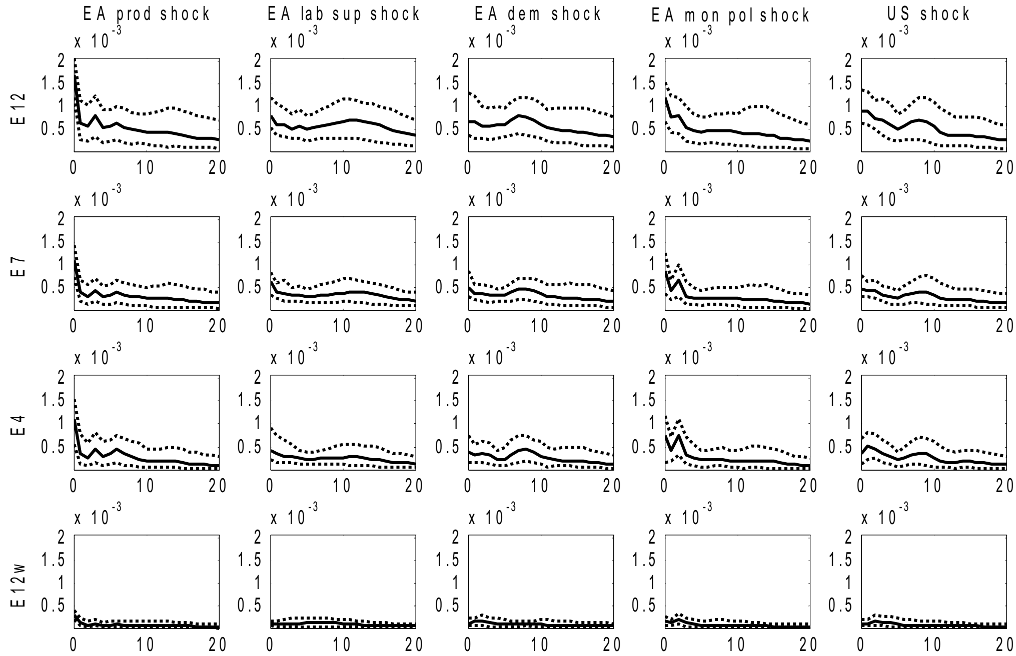


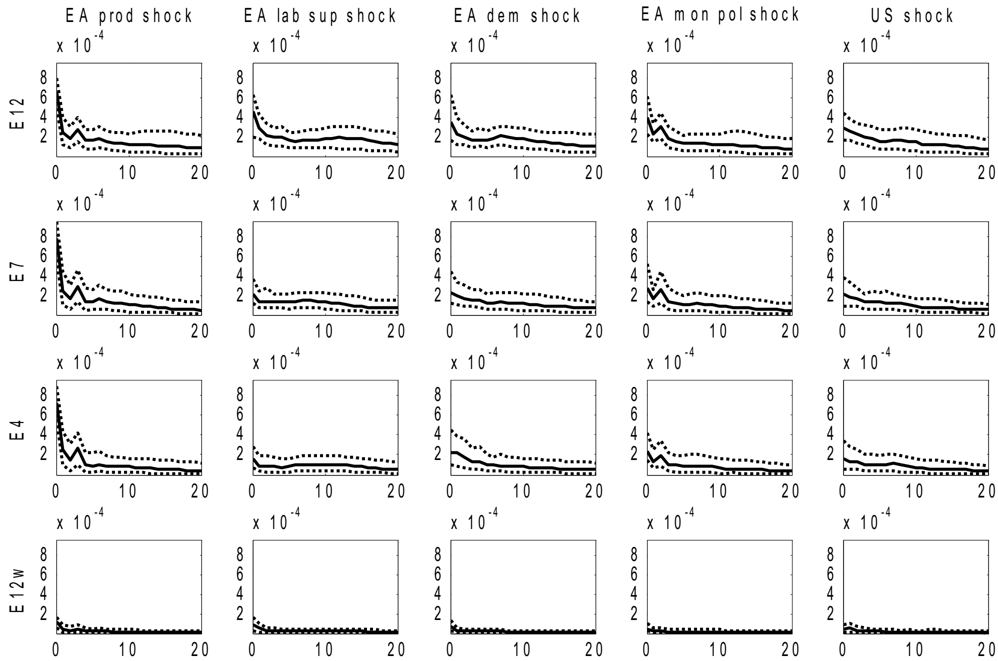
Notes: Median (solid), 90% confidence bands (dotted).

Figure 7: Standard deviation of individual countries' impulse response functions

GDP



Inflation



Notes: Standard deviation of individual countries' GDP and CPI inflation. Median (solid), 90% confidence bands (dotted). E12/7/4 refers to unweighted standard deviations of the groups of all 12 euro-area countries, the 7 core and 4 largest euro-area countries. E12w refers to weighted standard deviations.

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