DOCTORAL THESIS

Essays on International Transmission of Economic Policy Shocks

Ludmila Fadejeva

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY
TALLINN 2025

TALLINN UNIVERSITY OF TECHNOLOGY
DOCTORAL THESIS
22/2025

Essays on International Transmission of Economic Policy Shocks

LUDMILA FADEJEVA

TALTECH PRESS

TALLINN UNIVERSITY OF TECHNOLOGY
School of Business and Governance
Department of Economics and Finance

The dissertation was accepted for the defense of the degree of Doctor of Philosophy in Economics on 26 March 2024

Supervisors: Adjunct Professor Tairi Rõõm, Ph.D,
Department of Economics and Finance, School of Business and Governance,
Tallinn University of Technology,
Tallinn, Estonia

Associate Professor Konstantins Benkovskis, Ph.D,
Department of Economics,
Stockholm School of Economics in Riga,
Riga, Latvia

Opponents: Lenno Uusküla, Ph.D,
Associate Professor, University of Tartu,
Chief Economist, Luminor Group,
Tartu / Tallinn, Estonia

Julia Woerz, Ph.D,
Head of the Central, Eastern and Southeastern Europe Section, Economics Department,
Oesterreichische Nationalbank,
Vienna, Austria

Defence of the thesis: 28 April 2025, Tallinn

Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been submitted for any academic degree elsewhere.

Ludmila Fadejeva ________________________
signature

Copyright: Ludmila Fadejeva, 2025
ISSN 2585-6898 (publication)
ISBN 978-9916-80-281-6 (publication)
ISSN 2585-6901 (PDF)
ISBN 978-9916-80-282-3 (PDF)
DOI https://doi.org/10.23658/taltech.22/2025
Printed by Koopia Niini & Rauam

Fadejeva, L. (2025). *Essays on International Transmission of Economic Policy Shocks* [TalTech Press]. https://doi.org/10.23658/taltech.22/2025

TALLINNA TEHNIKAÜLIKOOL
DOKTORITÖÖ
22/2025

Esseed majanduspoliitiliste šokkide rahvusvahelisest edasikandumisest

LUDMILA FADEJEVA

Contents

List of Publications

The present Ph.D. thesis is based on the following publications that are referred to in the text by Roman numerals.

I Fadejeva, L., Feldkircher, M., and Reininger, T. (2017). International spillovers from Euro area and US credit and demand shocks: A focus on emerging Europe. *Journal of International Money and Finance*, 70(C):1–25, DOI 10.1016/j.jimonfin.2016.0

II Benecká, S., Fadejeva, L., and Feldkircher, M. (2020). The impact of Euro area monetary policy on Central and Eastern Europe. *Journal of Policy Modeling*, 42(6):1310–1333, DOI 10.1016/j.jpolmod.2020.05

III Fadejeva, L. and Kantur, Z. (2023). Wealth distribution and monetary policy. *Economic Modelling*, 125(C):106336, DOI 10.1016/j.econmod.2023.10

Author's Contributions to the Publications

I In publication I, we developed a GVAR model with sign restrictions to estimate the effects of US credit and demand shocks on new European countries. My primary contribution involved creating the MATLAB code by combining elements from the GVAR toolbox by Smith and Galessi (2014) and the sign restriction identification code for VAR models by Eickmeier and Ng (2015). I was also responsible for database collection and description (Section 3.2, *Data and General Model Specification*). The main contribution of Thomas Reininger was the construction of the trade weight matrix, using an in-house database compiled at the Austrian Central Bank. Martin Feldkircher prepared the detailed literature review (Section 2, *Related Literature*). The Introduction, as well as the model description and model results sections, were developed by Ludmila Fadejeva and Martin Feldkircher (Section 1, *Introduction*; Section 3, *The GVAR Model*; Section 4, *Identification of Structural Shocks*; Section 5, *Empirical Results*; and Section 6, *Conclusions*).

II In publication II, we adopted the GVAR approach to analyse the effects of monetary policy on Central and Eastern European countries by implementing a novel sign restriction approach for euro area countries. My main contribution was the development of this multi-level sign restriction mechanism for shock identification in the GVAR model, which applies restrictions to both euro area common variables and country-specific variables, yielding shocks that are consistent across both levels of aggregation (Sections 3, *Model*; Section 4, *Identification of Structural Shocks in the Euro Area*). I built the code for this mechanism using the previous code from Fadejeva et al. (2017) and the baseline code by Eickmeier and Ng (2015), adapting it to support the multi-level structure of the proposed sign restriction mechanism. Additionally, I estimated shadow rates for Central and Eastern European countries following the approach by Ajevskis (2016) (shadow rate analysis in Section 3.1). Sona Benecka contributed by compiling the database and providing expertise on monetary policy outcomes in Central Eastern and Southern Eastern European countries (data description in Section 3.1). Martin Feldkircher's contributions included preparing the detailed literature review (Section 2, *Literature Review*) and offering expertise on GVAR models. The sections discussing model results were co-authored by the three of us (Section 5, *Empirical Results*, and Section 6, *Conclusions*).

III In publication III, we modified a New Keynesian overlapping generations model by incorporating demographic and productivity-gap factors to analyse their interactions with monetary policy in a general equilibrium setting. My contribution to the paper involved formulating the hypothesis that a country's age and productivity profile can explain the shape of net wealth distribution across cohorts, thereby partly accounting for differences in monetary policy transmission across euro area countries. Using microdata from the HFCS and EU-SILC surveys, I developed the empirical and calibration sections of the paper (Section 3, *Empirical Evidence*, and Section 5, *Calibration*). The main contribution of Zeynep Kantur was adapting her previously developed OLG model with monetary policy Kantur (2013) to an OLG model with heterogeneous productivity across the population and monetary policy (Section 4, *The Model*). We discussed the results in detail and collaboratively wrote the Introduction, Literature Review, and Results (Section 1, *Introduction*; Section 2, *Related Literature*; Section 6, *Results*; and Section 7, *Conclusions* sections).

Approbation

I presented the results of the thesis at the following conferences:

1. L. Fadejeva, Z. Kantur. 'Wealth Distribution and Monetary Policy"', 10th UECE Conference: Economic and Financial Adjustments in Europe: 22 July 2022, Lisbon, Portugal (online)

2. L. Fadejeva, Z. Kantur. 'Monetary policy transmission to consumption and net wealth / age distribution of population', 4th CESEEnet research workshop: 25–27 March 2019, Vienna, Austria

3. L. Fadejeva, Z. Kantur. 'Aging, Wealth Distribution and Monetary Policy', 7th Luxembourg Workshop on Household Finance and Consumption, Central Bank of Luxembourg: 20–21 June 2019, Luxembourg, Luxembourg

4. L. Fadejeva, Z. Kantur. 'Aging, wealth distribution and monetary policy', ESCB Research Cluster on Monetary Economics, Third Annual Workshop, Bank of England: 31 October – 1 November 2019, London, The United Kingdom

5. L. Fadejeva, Z. Kantur. 'Aging, wealth distribution and monetary policy', Sixth Conference on Household Finance and Consumption, Central Bank of Ireland: 16–17 December 2019, Dublin, Ireland

6. L. Fadejeva, Z. Kantur. 'Aging, Wealth Distribution and Monetary Policy', Baltic Economic Conference: 10–11 June 2019, Riga, Latvia

7. L. Fadejeva, S. Benecka, and M. Feldkircher. 'Spillovers from Euro Area Monetary Policy: A Focus on Emerging Europe', Inaugural Baltic Economic Conference: 11–12 June 2018, Vilnius, Lithuania

8. L. Fadejeva, S. Benecka, and M. Feldkircher. *'Spillovers from Euro Area Monetary Policy: A Focus on Emerging Europe'*, CESEEnet Research Workshop, Národná banka Slovenska: 14–16 May 2018, Bratislava, Slovakia

9. L. Fadejeva, M. Feldkircher and T. Reininger. *'International Spillovers from Euro Area and US Credit and Demand Shocks: A Focus on Emerging Europe'*, 9th Nordic Econometric Meeting (NEM 2017): 24-27 May 2017, Tartu, Estonia

1 Introduction

The thesis comprises three studies that examine the transmission of international shocks, specifically those stemming from monetary policy, as well as credit demand and supply shocks. Publications I and II investigate the heterogeneity in both the speed and intensity of credit and monetary shock transmission across different regions using aggregate time series data. Publication III explores the heterogeneity of monetary shock transmission between Eastern and Western European countries, focusing on differences in the distribution of net wealth across age cohorts. Together, these studies advance the transmission literature by introducing novel approaches to shock identification and a new model specification for analysing regional discrepancies in shock transmission.

In the interconnected global economy, policy decisions in one country or region can have profound effects on the others. This phenomenon, known as international policy shock transmission, is characterized by the propagation of economic and financial disturbances across borders. However, the impact of such shocks is not uniform; rather, it exhibits significant heterogeneity based on factors such as economic structure, financial integration, and trade linkages. From the methodological aspect, the Global Vector-Autoregressive (GVAR) approach put forward among others in Pesaran et al. (2004), Dees et al. (2007a,b), Garrat et al. (2006) allows for the exploration of the propagation of a country or region specific shock between countries taking into account the complex structure of financial and trade linkages.

In the aftermath of the 2008–2009 financial crisis, many economies experienced banking sector shocks, marked by tightened credit, increased loan loss provisions, and diminished confidence among banks (Busch et al., 2010). On the one hand, some argued that the decline in new lending was primarily driven by a sharp reduction in loan demand. On the other hand, banks were criticized for tightening credit standards and displaying excessive reluctance to engage in new lending as part of efforts to clean up their balance sheets. Banking policy shocks in advanced economies generated significant spillover effects on emerging markets, especially those with high levels of foreign bank penetration. These banking sector shocks also contributed to a pronounced decline in global real activity. Even countries not directly impacted by shocks to their credit sectors experienced output deterioration due to adverse aggregate demand shocks on exports and/or a surge in international investor risk aversion, prompting a "flight to safety" in investment (Chudik and Fratzscher, 2011).

Monetary policy shocks, particularly those originating from major economies such as the United States and the euro area, can exert substantial effects on the global economy. These shocks typically manifest through changes in interest rates, exchange rates, and capital flows, influencing economic conditions in other countries. Nations with stronger trade linkages, financial openness, and flexible exchange rates tend to experience more pronounced effects (Georgiadis, 2015). Emerging European economies, given their high level of economic integration with the euro area, are especially susceptible to euro area monetary policy shocks. Additionally, within a monetary union, the transmission of monetary policy shocks presents unique challenges. While a common monetary policy fosters economic integration and stability, it may not fully address the diverse economic conditions and structural differences among member countries, leading to potentially varied impacts across member states.

Another challenge in analysing monetary policy transmission arises from the fact that, following the global financial crisis, major central banks—including the European Central Bank (ECB) and the Federal Reserve—reached the zero lower bound on interest rates and thus had to implement unconventional monetary policies to stimulate economic growth and inflation. The introduction of these non-standard monetary policies has raised concerns regarding the differing strengths of conventional versus unconventional monetary policy effects, a topic subsequently explored in the literature (e.g., Hauzenberger et al. 2021, Rostagno et al. 2021, Zlobins 2022).

The strength of policy transmission can be analysed not only through macro-level time series but also via micro-level indicators, such as demographic structures, life-cycle saving trajectories, and cohort productivity. For instance, focusing on household-level effects allows for a deeper exploration of how monetary policy shocks relate to income inequality. Studies have shown that the impact of monetary policy varies across age cohorts (e.g., Kantur 2013, Wong 2016, Bielecki et al. 2018, Berg et al. 2019, Leahy and Thapar 2019, Bielecki et al. 2021). Households with mortgages, especially under flexible interest rates, are more sensitive to monetary policy (Calza et al. 2013, Cloyne et al. 2018). Monetary policy easing tends to redistribute welfare from older to younger generations (Bielecki et al., 2021), with nominal assets and labour income being the primary channels of redistribution, while real financial assets and housing play relatively smaller roles. The heterogeneous effects of monetary policy across population cohorts, along with the unique structure and characteristics of these cohorts, shape the domestic transmission of monetary shocks. Therefore, when cohort characteristics differ between countries, the effectiveness of monetary policy may also vary.

The issues discussed above are examined in this thesis. The three publications comprising the thesis focus on the transmission of shocks into European economies. Central, Eastern, and South- Eastern European (CESEE) countries are of particular interest, as these economies, due to their volatility and relatively small size, are less frequently studied compared to the euro area as a whole.

Publication I examines the international spillovers of credit and demand shocks originating from the euro area and the United States, focusing on their effects on CESEE countries. The global financial crisis of 2008–2009 underscored the interconnectedness of global financial markets and the international transmission of shocks. This study employs a GVAR model to analyse these spillovers, accounting for trade and financial linkages and distinguishing among loan supply shocks, loan demand shocks, and aggregate demand shocks. The results show that adverse credit supply and demand shocks from the euro area and the United States generally lead to reductions in international output and credit. The study emphasizes the vulnerability of CESEE economies due to their strong economic ties with the euro area, demonstrating that these regions experience more pronounced spillover effects compared to other European countries. Historical decomposition analysis highlights the significant role of U.S. shocks in explaining growth deviations in CESEE countries. Publication I uses time series data covering the period from 1995 to 2013, which predominantly reflects the period of conventional monetary policy.

Publication II examines a longer time horizon, encompassing both conventional and unconventional monetary policy periods (1995-2017). In the aftermath of the global financial crisis, major central banks, including the ECB, reached the zero lower bound on interest rates and consequently implemented unconventional monetary policies to stimulate economic growth and inflation. The adoption of non-standard monetary policies by the ECB and the Federal Reserve has raised concerns regarding negative external spillovers, such as substantial capital inflows, exchange rate appreciation, and increased financial fragility in neighbouring economies, particularly small open economies. This study explores these spillovers using a GVAR model and introduces a novel method for integrating euro area monetary policy shocks into a multi-country euro area framework that accounts for cross-country heterogeneity.

The findings indicate that monetary tightening in the euro area results in declines in both prices and output, with notable variation in the impact across countries. The transmission of euro area monetary policy shocks to CESEE countries operates through both direct and indirect channels. Direct channels include trade and financial linkages with the euro area, while indirect channels involve spillovers through third countries. The CESEE economies are highly susceptible to shocks originating in the euro area due to their strong economic connections, experiencing substantial spillover effects, often more pronounced than those within the euro area itself.

Both Publication I and Publication II highlight the importance of trade and financial linkages in the transmission of economic shocks, as well as the varied responses of different countries to similar shocks. These findings are especially relevant for policymakers within the euro area, where coordinated and consistent responses to economic shocks are essential to maintain stability in the monetary union. Understanding and predicting these heterogeneous responses can aid in formulating policies that mitigate adverse spillover effects while strengthening the resilience of the interconnected global economy.

Publication III also examines the transmission of monetary policy shocks within the euro area, but from a different perspective. It investigates how heterogeneous net wealth distributions across countries impact the effectiveness of monetary policy, with a focus on the distinctions between Western and Eastern Europe. Using data from the Household Finance and Consumption Survey (HFCS), the study identifies distinct patterns of net wealth accumulation across age cohorts in these regions. Notably, Western European countries generally align with the life-cycle hypothesis, with wealth peaking around retirement, whereas Eastern European countries display maximum wealth accumulation at younger ages. Publication III seeks to uncover the underlying causes of these disparities and assess how these differences shape the transmission of monetary policy.

To account for cohort-specific net wealth accumulation and monetary policy transmission, the study employs a New Keynesian overlapping generations (NK-OLG) model developed by Kantur (2013). The novelty of our approach is the integration of both productivity and old-age dependency factors, offering a comprehensive theoretical approach for analysing the interactions between wealth accumulation and cohort-specific characteristics. Specifically, the paper demonstrates how differences in productivity growth across cohorts lead to variations in permanent income levels, thereby influencing individual wealth accumulation trajectories. The study's findings indicate that the effectiveness of monetary policy is correlated with the age-cohort distribution of net wealth. As net wealth distribution skews toward older age groups, sensitivity to interest rate changes diminishes, thereby reducing the overall impact of monetary policy.

Publication III underscores the importance of considering demographic characteristics and productivity differences across cohorts when designing and implementing monetary policy. The atypical pattern of net wealth distribution in Eastern European countries may signal cohort-specific productivity differences, which could partly explain why monetary policy transmission in Eastern Europe has been more pronounced compared to Western European countries.

The thesis contributes to three distinct areas of applied macroeconomics. First, it focuses on emerging European countries: all three publications investigate shock transmission from the USA or the euro area to CESEE countries. Such analyses are rare, given the volatility and limited time series data available for these economies. Second, it advances empirical research by proposing new modelling strategies to explore the transmission of monetary and credit shocks within GVAR and OLG model frameworks. In Publication I, MATLAB code was developed by combining maximum likelihood estimation routines from the GVAR toolbox by Smith and Galessi (2014) with a sign restriction identification code for VAR models by Eickmeier and Ng (2015). Extending the model from Publication I, Publication II introduces a two-level sign restriction mechanism for shock identification in the GVAR model, applying restrictions on both euro area common variables and country-specific variables to maintain economic interpretability across both levels of aggregation. In Publication III, an extended NK-OLG model with generational heterogeneity assumptions is developed. This model enables replication of the net wealth distribution by age cohorts, explaining distinct outcomes at both individual and aggregate levels in response to euro area monetary policy shocks across Western and Eastern European countries. Third, the thesis promotes the broader use of survey microdata in calibrating theoretical models. In Publication III, two databases are employed: the HFCS database provides data on net wealth distribution by age cohort and enables estimation of key ratios, while the EU-SILC microdata facilitates the estimation of wage ratios by age cohort. Both datasets offer essential statistics for calibrating the theoretical model.

The three publications employ two main quantitative methods. In Publications I and II, a GVAR approach is used, which accounts for trade and financial linkages between countries and enables the use of relatively short time series to assess the transmission of regional and country-specific shocks to other economies. Orthogonal shocks in the GVAR models are identified using sign restrictions. In Publication II, a novel two-level procedure is introduced to define consistent region- and country-specific shocks. In Publication III, the NK-OLG model by Kantur (2013) is extended to incorporate generational heterogeneity. This model is calibrated to align with statistics on wealth and income distributions by cohort for Eastern and Western European countries. The monetary policy shock is applied through the Taylor rule.

As Publication I and Publication II were published in 2017 and 2020, empirical methods for multi-country VAR analysis have advanced since then. Two primary development avenues were: the refinement of shock identification techniques and the expansion of Bayesian methodologies in GVAR and large-panel VAR models. In Publication I and II, directional sign restrictions following Rubio-Ramírez et al. (2010) were employed for shock identification. Recent studies, however, have introduced additional approaches. For instance, zero sign restrictions have been proposed by Arias et al. (2018), and narrative sign restrictions by Antolín-Díaz and Rubio-Ramírez (2018). Moreover, monetary policy shocks are now increasingly identified outside VAR models using high-frequency financial-market data surrounding key policy announcements, as initially suggested by Kuttner (2001) and Gürkaynak et al. (2005), with subsequent applications by Cesa-Bianchi et al. (2020), Jarociński and Karadi (2020), and Altavilla et al. (2019). The resulting shocks can then be exogenously incorporated into estimated VAR systems or local projection models.

At the same time, Bayesian estimation methods for large VAR models have become more prevalent. The first Bayesian GVAR toolbox was introduced by Feldkircher and Huber (2016) and later updated by Cuaresma et al. (2016), Huber and Feldkircher (2019), and Boeck et al. (2022). Another promising direction involves the application of Bayesian shrinkage methods in multi-country panel VAR models, such as the global–local shrinkage (Koop and Korobilis, 2016). Although these methods typically require computationally demanding Markov chain Monte Carlo techniques, recent developments—such as the integrated rotated Gaussian approximation proposed by Feldkircher et al. (2022)—have improved estimation speed and enabled the inclusion of a larger number of variables per country. The Bayesian framework is particularly beneficial in settings with shorter time series, as it incorporates prior information, handles parameter uncertainty more effectively, and improves inference in small-sample contexts.

The thesis is organised as follows. The Introduction, in Section 1, provides a brief description of the three research papers. Section 2 summarizes the studies. Section 2.1 presents an overview of Publication I, Section 2.2 provides an overview of Publication II, Section 2.3 summarizes the main points of Publication III. Finally, Section 3 concludes by outlining the thesis's contributions and discussing potential avenues for future research. Appendices 1–3 contain the three publications.

2 Summaries of the Studies

2.1 International Spillovers from Euro Area and US Credit and Demand Shocks

In the aftermath of the global financial crisis, research on the transmission of credit supply and demand shocks from region- or country-specific origins garnered considerable attention. Early studies, such as those by Lown and Morgan (2006), Ciccarelli et al. (2010), Meeks (2012), and Bassett et al. (2014), primarily focused on shocks originating in the United States. Initial analyses using euro area data were typically country-specific, such as Busch et al. (2010) on Germany, or approached the euro area as a single region to examine the effects of the financial crisis, as seen in Gambetti and Musso (2012), Chudik and Fratzscher (2011), and Eickmeier and Ng (2015). At the time this paper was developed, no studies had specifically examined the transmission of US and euro area credit shocks to CESEE countries. Consequently, the paper "International Spillovers from Euro Area and US Credit and Demand Shocks: A Focus on Emerging Europe" aims to fill this gap in the literature.

The paper examines the transmission of the shocks to real GDP and total credit in CESEE countries. To analyse these spillovers, it employs a GVAR model, initially developed by Pesaran et al. (2004), Dees et al. (2007a,b), and Garrat et al. (2006), which is well-suited for capturing interactions between multiple countries through trade and financial linkages. The example of the GVAR model including CESEE countries are Feldkircher (2015) and Galesi and Lombardi (2013). Our model includes 41 countries (comprising 12 CESEE countries) and one regional aggregate (the euro area), using quarterly data from 1995Q1 to 2013Q4. Shocks are identified using sign restrictions based on the specifications of Hristov et al. (2012) and Eickmeier and Ng (2015), distinguishing among loan supply shocks, loan demand shocks, and aggregate demand shocks. Technically, the MATLAB code for this paper was developed by combining maximum likelihood routines from the GVAR toolbox by Smith and Galessi (2014) with the sign restriction identification code for VAR models by Eickmeier and Ng (2015).

Emerging Europe, particularly the CESEE region, shows high susceptibility to shocks originating from the euro area and the USA. The economic integration of these regions with the euro area means they are significantly influenced by euro area-specific shocks, such as changes in monetary policy or financial market conditions. Following Eickmeier and Ng (2015), two sets of weights are implemented in the GVAR model: bilateral trade flow weights for economic variables and bilateral banking sector exposure weights for financial variables.

The paper shows that negative credit supply and aggregate demand shocks in both the euro area and the USA generally lead to decreases in international output and total credit. The effects of US shocks induce negative spillovers on total credit with broader global reach compared to similar euro area shocks. Additionally, US shocks generate comparatively stronger international effects in the short run. This study reveals that the euro area plays a significant role not only as a source of shocks but also as a conduit for transmitting third-country shocks. This mechanism helps explain why CESEE economies are particularly vulnerable to US-originated shocks. Strong economic integration with the euro area, coupled with trade openness, amplifies these effects on CESEE countries.

The historical decomposition reveals that foreign shocks have historically played an important role in explaining movements in real GDP and total credit growth for CESEE economies. Loan supply shocks contributed positively to output and total credit in 2008, when the US Federal Reserve sharply reduced interest rates to counter the recession. Loan demand shocks made positive contributions during the period from 2004 to 2007, coinciding with a significant expansion in mortgage credit in the USA. However, with the onset of the global financial crisis, the impact of credit-related shocks turned negative, a pattern observed in CESEE economies. Generally, contributions from euro area shocks are smaller than those from the USA. The contributions of aggregate demand shocks exhibit a somewhat different pattern. They are mostly negative, peaking during the global financial crisis. In the aftermath of the crisis, US aggregate demand shocks positively contributed to output and credit growth in CESEE, while euro area shocks had a slightly negative impact. This contrast may reflect the faster recovery in the USA compared to the more subdued growth in the euro area.

The findings of this study have several important policy implications. First, they highlight the need for CESEE economies to strengthen their financial systems to better withstand the adverse effects of external shocks. Second, the study underscores the importance of international coordination in monetary policy to manage and mitigate the cross-border transmission of shocks. Policymakers in CESEE economies must consider the external economic environment and the potential spillover effects when formulating domestic monetary policies.

As always in empirical studies, choices were made. The number of bootstrap replications was kept relatively low, in part due to the computer power available at the time of writing. More bootstrap replications could have provided more reliable significance intervals. It might have also been possible to provide details on the results for all five identified shocks; in the published version of the paper, we focused on three—aggregate demand, loan supply, and loan demand—out of five, which also include monetary policy and aggregate supply shocks. The motivation for identifying all five shocks, rather than leaving some as residuals in the analysis, was to pin down the shocks more clearly, as increasing the number of restrictions enhances the identification of the shock of interest (Paustian, 2007).

2.2 The Impact of Euro Area Monetary Policy Shock

Publication II builds on the findings of Publication I by further exploring the transmission of international shocks. In this paper, we focus on euro area monetary policy shocks and their impacts on CESEE countries. The strong economic ties between the CESEE region and the euro area make these countries highly susceptible to changes in monetary policy originating from the larger economic centre.

The analysis of monetary policy spillovers, an important topic in the context of a monetary union, has gained increased attention since the global financial crisis of 2008-2009. As the ECB, like other central banks, sought to stimulate the economy while constrained by near-zero interest rates, it implemented unconventional monetary policies to foster economic growth and increase inflation. These measures—including long-term refinancing operations, large-scale asset purchase programmes, and moves into negative interest rate territory—were designed to address persistent economic stagnation within the euro area.

The bulk of the literature has focused on quantifying the domestic effects of unconventional euro area monetary policy. Studies by Gambacorta et al. (2014) and Boeckx et al. (2017), using a panel VAR framework, and Burriel and Galesi (2018), using a GVAR setup, found positive effects on output and prices from unconventional monetary policy shocks in the main euro area countries. At the time of our study, few analyses had examined the spillovers from these unconventional measures to CESEE countries within a GVAR framework, and none had focused on the Baltic countries. Some examples using a country-specific block-restricted VAR framework include Babecka Kucharcukova et al. (2016) for the Czech Republic, Hungary, and Poland, and Bluwstein and Canova (2016) employing a structural BVAR for the Czech Republic, Hungary, Poland, and Romania. Feldkircher et al. (2020) applied a Bayesian GVAR to study CESEE, though the Baltic countries were not included.

Publication II, "The Impact of Euro Area Monetary Policy on Central and Eastern Europe", addresses a gap in the literature by examining spillovers to a broader set of CESEE countries. To capture the effects of international interlinkages, a GVAR model is utilized, as in Publication I. The study's novelty lies in a new method for incorporating euro area monetary policy shocks into a multi-country euro area block within the model. In many GVAR-type models, a common assumption is to treat the euro area block as a single entity (e.g., Dees et al. (2007a), Hájek and Horváth (2018)), which simplifies the application of common euro area shocks, such as a monetary policy shock. However, in the context of spillovers, this assumption overlooks intra-euro area heterogeneity, potentially resulting in misleading outcomes, as neighbouring countries do not all share equally strong economic and financial ties.

There are various ways to incorporate euro area country-specific and region-specific information within the GVAR framework. For instance, Georgiadis (2015) and Feldkircher et al. (2020) employ a mixed cross-section GVAR to account for the common monetary policy within the euro area. This approach involves adding an extra country model that determines euro area monetary policy based on macroeconomic data feedback from individual member states. A monetary policy shock, defined using sign restrictions, can then be implemented by placing a restriction on statistics, such as the average behaviour of macroeconomic variables across individual euro area countries. However, placing restrictions only on the aggregate variable does not fully address the heterogeneity in country-specific responses.

In Publication II, we propose a new approach to identifying euro area monetary policy shock within a GVAR framework within a multi-country euro area block. In this setup, a euro area monetary policy shock is identified using sign restrictions, with the rotation matrix adjusted to ensure consistency between the aggregate euro area level and the country-specific level. First, we collect the orthogonal impulse responses of the euro area countries by using the Cholesky factor. Second, we draw a rotation matrix with dimensions equal to the number of unique variables in the individual euro area countries plus the number of common euro area variables. Third, we expand the part of the rotation matrix which corresponds to individual EA country models along the variable dimension using country weights and combine the obtained matrix with the part corresponding to the common variables. Next, we apply the rotation matrix obtained to the orthogonal impulse responses and collect country impulse responses to shocks. Lastly, we aggregate the collected impulse responses with weights and check if the sign restrictions (regional or country-specific) are met. The sign restrictions are defined for two blocks of variables: first, for euro area common variables – namely, the shadow rate and the exchange rate – and second, for aggregates of the euro area country-specific variables – output, prices, and the long-term interest rate. This approach allows for heterogeneity in the aggregate effect of euro area countries as a whole.

The dataset comprises quarterly observations for 37 countries from 2001Q1 to 2016Q4, including the 12 euro area countries that adopted the common currency before 2007 and 10 CESEE and the Baltic countries, totalling 17 euro area member states. At the country level, data on real activity, consumer prices, the real exchange rate, short-term interest rates, long-term government bond yields, and oil prices are used. At the aggregated euro area level, variables common to all euro area countries are selected, specifically a measure of monetary policy and the euro-dollar exchange rate. Short-term interest rates are represented through corresponding shadow rates to maintain consistent sign restrictions for identifying monetary policy shocks across both conventional and unconventional policy periods. Following Chudik and Pesaran (2013), oil prices are included as a dominant unit in the GVAR model.

The results indicate substantial regional heterogeneity both within the euro area and among neighbouring countries. For the euro area, the analysis reveals clusters of countries that extend beyond a simple core-periphery distinction. In CESEE economies, significant negative effects on output and prices are observed, with the impact on prices being relatively weaker. This may be related to higher import prices following the depreciation of local currencies against the euro. Additionally, short-term interest rates in CESEE countries tend to decline, suggesting that domestic policymakers attempt to offset the spillover-induced shortfall in output and prices. The transmission of euro area monetary policy shocks to CESEE countries operates through both direct and indirect channels. Direct channels include trade and financial linkages with the euro area, while indirect channels involve spillovers through third countries. Due to their strong economic ties with the euro area, CESEE economies are highly susceptible to euro area-originated shocks, often experiencing spillover effects that are more pronounced than those within the euro area itself.

Historical decomposition analysis reveals that euro area shocks have played a significant role in explaining deviations from trend growth in CESEE countries. For the Baltic countries, the effects of a euro area monetary policy shock are largely attributable to second-round effects through other non-euro area countries. By contrast, the Czech Republic and Poland are more directly affected due to their high levels of integration with the euro area. These findings underscore the significant influence of euro area monetary policy on economic conditions within these regions.

This study contributes to the literature on international economic spillovers by offering valuable insights into the transmission of euro area monetary policy shocks and their impacts on CESEE countries through both direct and indirect effects. The main methodological contribution of Publication II is a novel approach to identifying shocks within a GVAR framework simultaneously for both individual and aggregated variables in a group of countries with common variables. This multi-level procedure allows for the preservation of the economic interpretation of shocks at the individual country level.

Similarly to Publication I, it might have been beneficial if the number of bootstrap replications had been increased as this might have provided more reliable significance intervals. In retrospect, greater accuracy in the mathematical notation used to explain the proposed sign restriction approach would have been warranted. Finally, since the CESEE region results include both countries that adopted the euro and countries that did not, presenting results separately for two groups—SK, SI, EE, LV, and LT in addition to CZ, PL, BU, HU, and RO—may have provided additional insights.

2.3 Wealth Distribution and Monetary Policy Transmission

The effects of monetary policy are heterogeneous across different population groups. Previous studies have examined variations in responses to monetary policy shocks due to differences in consumption patterns among age groups (e.g., Wong (2016) and Berg et al. (2019)), as well as differing debt exposures across age cohorts (e.g., Leahy and Thapar (2019) and Selezneva et al. (2015)). Life-cycle saving motives are explored in Bielecki et al. (2018) and Braun and Ikeda (2021). Bielecki et al. (2018) showed that the primary drivers of redistribution are nominal assets and labour income, with real financial assets and housing having a relatively smaller impact. Their findings suggest that monetary policy easing redistributes welfare from older to younger generations. In Braun and Ikeda (2021), household portfolio decisions are endogenized, demonstrating that consumption responses vary by age: tighter monetary policy increases consumption among older households, while all households tend to invest less in illiquid assets during periods of tight monetary policy.

Publication III, "Wealth Distribution and Monetary Policy", builds on previous studies by examining the complex relationship between wealth distribution across age cohorts and the effectiveness of monetary policy in European countries. Data from the Household Finance and Consumption Survey reveal significant variations in net wealth distribution among age cohorts across Europe. In Western EU countries, net wealth accumulation follows the life-cycle hypothesis, peaking around retirement age, whereas in Eastern EU countries, wealth tends to peak at much younger ages. This paper investigates the underlying reasons for these differences and assesses their implications for the transmission of monetary policy.

The differences in net wealth distribution by age cohorts in Eastern and Western EU countries can be partly attributed to a historical context. Eastern Europe operated under a centrally planned economic system until the end of the 20th century. The collapse of this system created substantial productivity disparities across generations. Younger generations have adapted more rapidly to the post-communist economic environment, resulting in higher productivity and income levels compared to older cohorts. This generational heterogeneity in productivity contributes to the observed differences in wealth accumulation patterns. The purpose of this paper is to examine how the productivity gap across generations, along with demographic factors, shapes net wealth distribution and influences the effectiveness of monetary policy.

To achieve these objectives, the New Keynesian model incorporating a multiperiod OLG framework, as developed by Kantur (2013), is extended with an assumption of generational heterogeneity in productivity levels. The model is calibrated using data from the HFCS to accurately replicate the net wealth distribution patterns in the two groups of European countries. In Western Europe, the productivity gap between generations is less pronounced, leading to a more conventional pattern of wealth accumulation in line with the life-cycle hypothesis. The model's robustness is tested through various specifications, ensuring that the results are not sensitive to particular assumptions or data limitations.

The paper concludes that the shape of net wealth distribution by age is a critical determinant of monetary policy effectiveness. It provides evidence that monetary policy's impact on output and inflation weakens as net wealth distribution shifts toward older age groups. In Western Europe, where wealth is concentrated among older individuals, monetary policy has a limited effect on consumption and investment decisions. In contrast, in Eastern Europe, where younger individuals hold a larger share of wealth, monetary policy is more effective. Younger individuals tend to be more responsive to interest rate changes, leading to significant variations in aggregate consumption and investment.

Additionally, the paper shows that consumption responses to monetary policy shocks differ among younger agents in Western and Eastern EU countries. These findings suggest that differences in net wealth distribution, driven by generational productivity disparities, play a key role in the effectiveness of monetary policy at both individual and aggregate levels. The study also demonstrates that the natural interest rate decreases monotonically as the old-age dependency ratio rises and the productivity gap among generations narrows.

This study contributes to the literature on monetary policy transmission by age cohorts, focusing on how the shape of net wealth distribution — driven by productivity differences across cohorts — affects policy effectiveness. The augmented framework is used to analyse the impact of wealth accumulation on the effectiveness of monetary policy within a coherent general equilibrium model. The study underscores the importance of accounting for heterogeneity in country responses to euro area monetary shocks.

The findings of Publication III enhance the understanding of results presented in Publications I and II, which demonstrate that the impact of policy rate changes in Eastern European countries exceeds that observed in their Western counterparts.

Publication III leaves a number of areas that could be explored in future research. One such area would be a deeper investigation into the reasons behind the differences in the shape of the net wealth distribution in Eastern and Western European countries. Since net wealth primarily consists of housing value, lower pensions and weaker social security systems in Eastern Europe do not directly affect its distribution. However, relatively lower pensions and social security would result in reduced financial savings for the pension-age population, thus reducing the share of total net wealth held by the older population. Another topic that could be explored is the potential effect of negative population growth in Europe when modelled using an OLG framework. In neoclassical growth theory, OLG models suggest that negative population growth is expected to lead to a sharp reduction in output and national welfare in the long run. However, Sadahiro and Shimasawa (2003) demonstrated that if the human capital growth rate is endogenously determined, it can offset negative population growth rates in the OLG model, preventing a decline in output.

3 Concluding Remarks

This thesis was motivated by the aftermath of the global financial crisis, a period when understanding the international transmission of credit and monetary policy shocks became especially critical. It closely examines the transmission of shocks originating from the euro area and the USA to CESEE countries, contributing to the empirical literature on international shock transmission and structural shock identification within a group of countries in a monetary union. The thesis extends beyond the country level; in the final section, it explores differences in wealth accumulation across cohorts in Eastern and Western European countries, investigating how these differences can be explained and how they impact the effectiveness of monetary policy transmission.

The thesis makes several key contributions. Publication I, "International Spillovers from Euro Area and US Credit and Demand Shocks: A Focus on Emerging Europe", adds to the literature on international economic spillovers by providing evidence on the transmission of credit and demand shocks from the USA and the euro area to CESEE countries. The use of a GVAR model enables a comprehensive analysis of these spillovers, capturing the complex trade and financial linkages between countries. This study reveals that the euro area plays a significant role not only as a source of shocks but also as a conduit for transmitting third-country shocks, which helps explain the particular vulnerability of CESEE economies to US credit shocks. Both economic integration with the euro area and trade openness amplify the effect through indirect transmission channels, underscoring the susceptibility of CESEE economies to external shocks from the USA and the euro area.

Publication II, "The Impact of Euro Area Monetary Policy on Central and Eastern Europe", examines the transmission of euro area monetary policy shocks to CESEE countries, encompassing both conventional and unconventional monetary policy periods. The paper's main contribution is a novel method for euro area shock identification within a GVAR framework, ensuring consistency in impulse responses between the aggregate euro area and country-specific levels. The study highlights the heterogeneity of responses to euro area monetary policy shocks, with spillovers to CESEE countries often exceeding those within the euro area itself. For the Baltic countries, much of the impact of a euro area monetary policy shock can be attributed to second-round effects from non-euro area countries, while Central European countries tend to be affected directly due to their high degree of integration with the euro area.

Publication III, "Wealth Distribution and Monetary Policy", investigates the transmission of shocks by examining the complex relationship between wealth distribution across age cohorts and the effectiveness of monetary policy in European countries. The main contribution of the paper is the extension of the NK-OLG model by Kantur (2013) with a productivity factor, providing a comprehensive theoretical framework to explain differences in net wealth accumulation across age cohorts in Eastern and Western Europe. Specifically, the paper highlights how disparities in productivity growth across cohorts can lead to differences in permanent incomes across generations, which in turn affects individual wealth accumulation. The findings of the paper suggest that the effectiveness of monetary policy correlates with the distribution of net wealth by age cohorts. As net wealth distribution increasingly skews toward older age groups, sensitivity to interest rates diminishes, reducing the overall impact of monetary policy. This dynamic partly explains why monetary policy transmission in Eastern Europe is more pronounced compared to Western European countries.

The potential avenues for future studies using multi-country VAR methodology are numerous. For example, Bayesian estimation approaches applied to GVAR (Boeck et al. 2022) and panel VAR (Feldkircher et al. 2022) facilitating the use of a shorter time series and allowing for the use of prior information on coefficients. New shock identification strategies have developed, such as zero sign restriction (Arias et al., 2018) and narrative sign restriction (Antolín-Díaz and Rubio-Ramírez, 2018), allowing for more varied restrictions on coefficients and impulse responses. High-frequency identification of shocks, following the methodology originally proposed by Kuttner (2001) and Gürkaynak et al. (2005) (e.g., Cesa-Bianchi et al. 2020, Jarociński and Karadi 2020), enables the identification of euro area monetary policy shocks outside of the vector autoregression model, allowing these shocks to be applied exogenously to the estimated system.

To explore the distributional aspects of policy shocks, the output of the GVAR model can be combined with microsimulation models like EUROMOD (e.g., Lenza and Slacalek (2021)). This approach allows for the extrapolation of the macroeconomic effects at the country level down to the household level, enabling the study of unequal policy transmission impacts on labour income and consumption across different household income and wealth groups. Another potential avenue for GVAR modelling research on the distributional aspects of monetary policy shocks is the use of Distributional Wealth Accounts (DWA) statistics, developed by the European System of Central Banks, as a model variable. The DWA integrates HFCS estimates with national accounts to produce a quarterly time series of net wealth, facilitating the analysis of the distributional effects of monetary policy transmission across income and wealth deciles. Finally, recent geopolitical and climate-related shocks, such as the war in Ukraine and extreme weather events, may have disparate effects across the European Union, potentially influencing the effectiveness of international shock transmission. To account for these impacts, new weighting schemes beyond traditional trade and financial linkages—based on proximity to and severity of such events—could be applied.

Regarding the inclusion of productivity heterogeneity in the NK-OLG model, this approach can be extended to address other topical issues. The rapid pace of technological development may lead to productivity differences between generations, which could alter the life-cycle income profile and, consequently, the net wealth distribution across cohorts. If some countries are less effective in educating both younger and older generations compared to others, this could lead to varying monetary policy transmission effects for the same age cohorts across countries—a potential drawback in the context of a monetary union. Broadening the scope, another avenue for NK-OLG modelling relates to recent research on inflation expectation formation by households. The European Consumer Expectation Survey, conducted by the ECB, and the Survey of Consumer Expectations, run by the Federal Reserve, offer valuable data for understanding the heterogeneity and rationality of households' inflation expectations. Incorporating this information into models could enhance the formalization of decisions on savings, labour supply, and liabilities across different cohorts.

Finally, as the period of high inflation concludes and interest rates return to more typical levels, the analysis of conventional monetary policy shocks is once again becoming highly relevant. Advances in technology and improved access to databases detailing the heterogeneity of household decisions enable researchers to move beyond the international transmission of shocks, allowing for a deeper examination at the country level and a closer look at the distributive effects of policies.

References

Ajevskis, V. (2016). A term structure of interest rates model with zero lower bound and the european central bank's non-standard monetary policy measures. Working Papers 2016/02, Latvijas Banka.

Altavilla, C., Brugnolini, L., Gürkaynak, R. S., Motto, R., and Ragusa, G. (2019). Measuring euro area monetary policy. *Journal of Monetary Economics*, 108(C):162–179.

Antolín-Díaz, J. and Rubio-Ramírez, J. F. (2018). Narrative Sign Restrictions for SVARs. *American Economic Review*, 108(10):2802–29.

Arias, J. E., Rubio-Ramírez, J. F., and Waggoner, D. F. (2018). Inference based on structural vector autoregressions identified with sign and zero restrictions: Theory and applications. *Econometrica*, 86(2):685–720.

Babecka Kucharcukova, O., Claeys, P., and Vasicek, B. (2016). Spillover of the ecb's monetary policy outside the euro area: How different is conventional from unconventional policy? *Journal of Policy Modeling*, 38(2):199–225.

Babecký, J., Berson, C., Fadejeva, L., Lamo, A., Marotzke, P., Martins, F., and Strzelecki, P. (2019). Non-base wage components as a source of wage adaptability to shocks: evidence from European firms, 2010–2013. *IZA Journal of Labor Policy*, 8(1):1–18.

Bassett, W. F., Chosak, M. B., Driscoll, J. C., and Zakrajšek, E. (2014). Changes in Bank Lending Standards and the Macroeconomy. *Journal of Monetary Economics*, forthcoming.

Benecká, S., Fadejeva, L., and Feldkircher, M. (2020). The impact of Euro area monetary policy on Central and Eastern Europe. *Journal of Policy Modeling*, 42(6):1310–1333, DOI 10.1016/j.jpolmod.2020.05.

Benkovskis, K. and Fadejeva, L. (2014). The effect of VAT rate on inflation in Latvia: evidence from CPI microdata. *Applied Economics*, 46(21):2520–2533.

Benkovskis, K., Fadejeva, L., and Kalnberzina, K. (2012). Price setting behaviour in Latvia: Econometric evidence from CPI micro data. *Economic Modelling*, 29(6):2115–2124.

Benkovskis, K., Fadejeva, L., and Wörz, J. (2013). How Important Is Total Factor Productivity for Growth in Central, Eastern and Southeastern European Countries? *Focus on European Economic Integration*, (1):8–27.

Berg, K. A., Curtis, C. C., Lugauer, S., and Mark, N. C. (2019). Demographics and monetary policy shocks. Working Paper 25970, National Bureau of Economic Research.

Bielecki, M., Brzoza-Brzezina, M., and Kolasa, M. (2018). Demographics, monetary policy, and the zero lower bound. NBP Working Papers 284, Narodowy Bank Polski, Economic Research Department.

Bielecki, M., Brzoza-Brzezina, M., and Kolasa, M. (2021). Intergenerational Redistributive Effects of Monetary Policy. *Journal of the European Economic Association*. jvab032.

Bluwstein, K. and Canova, F. (2016). Beggar-thy-neighbor? the international effects of ecb unconventional monetary policy measures. *International Journal of Central Banking*, 12(3):69–120.

Bodnár, K., Fadejeva, L., Hoeberichts, M., Peinado, M. I., Jadeau, C., and Viviano, E. (2021). The impact of credit shocks on the European labour market. *Baltic Journal of Economics*, 21(1):1–25.

Bodnár, K., Fadejeva, L., Iordache, S., Malk, L., Paskaleva, D., Pesliakaitė, J., Jemec, N. T., Tóth, P., and Wyszyński, R. (2018). How do firms adjust to rises in the minimum wage? Survey evidence from Central and Eastern Europe. *IZA Journal of Labor Policy*, 7(1):1–30.

Boeck, M., Feldkircher, M., and Huber, F. (2022). Bgvar: Bayesian global vector autoregressions with shrinkage priors in r. *Journal of Statistical Software*, 104(9):1–28.

Boeckx, J., Dossche, M., and Peersman, G. (2017). Effectiveness and transmission of the ecb's balance sheet policies. *International Journal of Central Banking*, 13(1):297–333.

Braun, R. A. and Ikeda, D. (2021). Monetary Policy over the Life Cycle. FRB Atlanta Working Paper 2021-20a, Federal Reserve Bank of Atlanta.

Brinke, A., Fadejeva, L., Siliverstovs, B., and Vilerts, K. (2023). Assessing the informational content of card transactions for nowcasting retail trade: Evidence for Latvia. *Journal of Forecasting*, 42(3):566–577.

Burriel, P. and Galesi, A. (2018). Uncovering the heterogeneous effects of ecb unconventional monetary policies across euro area countries. *European Economic Review*, 101:201–229.

Busch, U., Scharnagl, M., and Scheithauer, J. (2010). Loan supply in germany during the financial crisis. Discussion Paper Series 1: Economic Studies 05/2010, Deutsche Bundesbank.

Calza, A., Monacelli, T., and Stracca, L. (2013). Housing Finance And Monetary Policy. *Journal of the European Economic Association*, 11:101–122.

Cesa-Bianchi, A., Thwaites, G., and Vicondoa, A. (2020). Monetary policy transmission in the united kingdom: A high frequency identification approach. *European Economic Review*, 123:103375.

Chudik, A. and Fratzscher, M. (2011). Identifying the global transmission of the 2007-2009 financial crisis in a GVAR model. *European Economic Review*, 55(3):325–339.

Chudik, A. and Pesaran, M. H. (2013). Econometric analysis of high dimensional vars featuring a dominant unit. *Econometric Reviews*, 32(5-6):592–649.

Ciccarelli, M., Peydró, J.-L., and Maddaloni, A. (2010). Trusting the bankers: a new look at the credit channel of monetary policy. Working Paper Series 1228, European Central Bank.

Cloyne, J., Ferreira, C., and Surico, P. (2018). Monetary policy when households have debt: new evidence on the transmission mechanism. Working Papers 1813, Banco de España; Working Papers Homepage.

Cuaresma, J. C., Feldkircher, M., and Huber, F. (2016). Forecasting with Global Vector Autoregressive Models: a Bayesian Approach. *Journal of Applied Econometrics*, 31(7):1371–1391.

Dees, S., di Mauro, F., Pesaran, H. M., and Smith, L. V. (2007a). Exploring the international linkages of the euro area: a global VAR analysis. *Journal of Applied Econometrics*, 22(1).

Dees, S., Holly, S., Pesaran, H. M., and Smith, V. L. (2007b). Long Run Macroeconomic Relations in the Global Economy. *Economics - The Open-Access, Open-Assessment E-Journal*, 1(3):1–20.

Eickmeier, S. and Ng, T. (2015). How do credit supply shocks propagate internationally? A GVAR approach. *European Economic Review*, 74:128–145. Issue C.

Fadejeva, L., Feldkircher, M., and Reininger, T. (2017). International spillovers from Euro area and US credit and demand shocks: A focus on emerging Europe. *Journal of International Money and Finance*, 70(C):1–25, DOI 10.1016/j.jimonfin.2016.0.

Fadejeva, L. and Kantur, Z. (2023). Wealth distribution and monetary policy. *Economic Modelling*, 125(C):DOI 10.1016/j.econmod.2023.10.

Fadejeva, L. and Melihovs, A. (2008). The Baltic states and Europe: common factors of economic activity. *Baltic Journal of Economics*, 8(1):75–96.

Fadejeva, L. and Melihovs, A. (2010). Measuring Total Factor Productivity and Variable Factor Utilization. *Eastern European Economics*, 48(5):63–101.

Fadejeva, L. and Opmane, I. (2016). Internal labour market mobility in 2005–2014 in Latvia: the micro data approach. *Baltic Journal of Economics*, 16(2):152–174.

Fadejeva, L. and Tkacevs, O. (2022). The effectiveness of tax incentives to encourage private savings. *Baltic Journal of Economics*, 22(2):110–125.

Feldkircher, M. (2015). A global macro model for emerging Europe. *Journal of Comparative Economics*, 43(3):706–726.

Feldkircher, M., Gruber, T., and Huber, F. (2020). International effects of a compression of euro area yield curves. *Journal of Banking & Finance*, 113(C).

Feldkircher, M. and Huber, F. (2016). The international transmission of US shocks—Evidence from Bayesian global vector autoregressions. *European Economic Review*, 81(C):167–188.

Feldkircher, M., Huber, F., Koop, G., and Pfarrhofer, M. (2022). Approximate Bayesian Inference and Forecasting in Huge-Dimentional Multicountry VARs. *International Economic Review*, 63(4):1625–1658.

Galesi, A. and Lombardi, M. J. (2013). *The GVAR Handbook: Structure and Applications of a Macro Model of the Global Economy for Policy Analysis*, chapter External shocks and international inflation linkages, pages 255–270. Oxford University Press.

Gambacorta, L., Hofmann, B., and Peersman, G. (2014). The effectiveness of unconventional monetary policy at the zero lower bound: A cross-country analysis. *Journal of Money, Credit and Banking*, 46(4):615–642.

Gambetti, L. and Musso, A. (2012). Loan Supply Shocks and the Business Cycle. Technical Report 1469, ECB Working Paper Series.

Garrat, A., Lee, K., Pesaran, M. H., and Shin, Y. (2006). *Global and National Macroeconometric Modelling: A Long-Run Structural Approach*. Oxford University Press.

Gautier, E., Conflitti, C., Faber, R. P., Fabo, B., Fadejeva, L., Jouvanceau, V., Menz, J.-O., Messner, T., Petroulas, P., Roldan-Blanco, P., Rumler, F., Santoro, S., Wieland, E., and Zimmer, H. (2024). New Facts on Consumer Price Rigidity in the Euro Area. *American Economic Journal: Macroeconomics*, 16(4):386–431.

Georgiadis, G. (2015). Examining asymmetries in the transmission of monetary policy in the euro area: Evidence from a mixed cross-section global var model. *European Economic Review*, 75(C):195–215.

Gürkaynak, R. S., Sack, B., and Swanson, E. (2005). Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements. *International Journal of Central Banking*, 1(1).

Hájek, J. and Horváth, R. (2018). International spillovers of (un)conventional monetary policy: The effect of the ecb and us fed on non-euro eu countries. *Economic Systems*, forthcoming.

Hauzenberger, N., Pfarrhofer, M., and Stelzer, A. (2021). On the effectiveness of the european central bank's conventional and unconventional policies under uncertainty. *Journal of Economic Behavior Organization*, 191:822–845.

Hristov, N., Hülsewig, O., and Wollmershäuser, T. (2012). Loan supply shocks during the financial crisis: Evidence for the euro area. *Journal of International Money and Finance*, 31(3):569–592.

Huber, F. and Feldkircher, M. (2019). Adaptive Shrinkage in Bayesian Vector Autoregressive Models. *Journal of Business & Economic Statistics*, 37(1):27–39.

Jarociński, M. and Karadi, P. (2020). Deconstructing Monetary Policy Surprises—The Role of Information Shocks. *American Economic Journal: Macroeconomics*, 12(2):1–43.

Kantur, Z. (2013). Aging and monetary policy. Technical report.

Koop, G. and Korobilis, D. (2016). Model uncertainty in Panel Vector Autoregressive models. *European Economic Review*, 81(C):115–131.

Kuttner, K. N. (2001). Monetary policy surprises and interest rates: Evidence from the Fed funds futures market. *Journal of Monetary Economics*, 47(3):523–544.

Leahy, J. V. and Thapar, A. (2019). Demographic Effects on the Impact of Monetary Policy. NBER Working Papers 26324, National Bureau of Economic Research, Inc.

Lenza, M. and Slacalek, J. (2021). How Does Monetary Policy Affect Income and Wealth Inequality? Evidence from Quantitative Easing in the Euro Area. CEPR Discussion Papers 16079, C.E.P.R. Discussion Papers.

Lown, C. and Morgan, D. P. (2006). The credit cycle and the business cycle: New findings using the loan officer opinion survey. *Journal of Money, Credit and Banking*, 38(6):1575–1597.

Meeks, R. (2012). Do credit market shocks drive output fluctuations? evidence from corporate spreads and defaults. *Journal of Economic Dynamics and Control*, 36(4):568–584.

Paustian, M. (2007). Assessing Sign Restrictions. *The B.E. Journal of Macroeconomics*, 7(1):1–33.

Pesaran, M. H., Schuermann, T., and Weiner, S. M. (2004). Modeling Regional Interdependencies Using a Global Error-Correcting Macroeconometric Model. *Journal of Business and Economic Statistics, American Statistical Association*, 22:129–162.

Rostagno, M., Altavilla, C., Carboni, G., Lemke, W., Motto, R., and Saint Guilhem, A. (2021). Combining negative rates, forward guidance and asset purchases: identification and impacts of the ECB's unconventional policies. Working Paper Series 2564, European Central Bank.

Rubio-Ramírez, J. F., Waggoner, D. F., and Zha, T. (2010). Structural Vector Autoregressions: Theory of Identification and Algorithms for Inference. *The Review of Economic Studies*, 77(2):665–696.

Sadahiro, A. and Shimasawa, M. (2003). The computable overlapping generations model with an endogenous growth mechanism. *Economic Modelling*, 20(1):1–24.

Selezneva, V., Schneider, M., and Doepke, M. (2015). Distributional Effects of Monetary Policy. 2015 Meeting Papers 1099, Society for Economic Dynamics.

Smith, L. V. and Galessi, A. (2014). Gvar toolbox 2.0. Technical report.

Wong, A. (2016). Population aging and the transmission of monetary policy to consumption. 2016 Meeting Papers 716, Society for Economic Dynamics.

Zlobins, A. (2022). Into the Universe of Unconventional Monetary Policy: State-dependence, Interaction and Complementarities. Working Papers 2022/05, Latvijas Banka.

Acknowledgements

I would like to thank:

- My supervisor, Professor Tairi Room, for believing in me and encouraging me to complete my PhD studies at Tallinn University of Technology.
- My supervisor, Konstantins Benkovskis, for his friendship and collegial support at Latvijas Banka.
- My opponents, Aleksei Netšunajev, Dmitry Kulikov, Julia Wörz, and Lenno Uusküla for their questions, comments, and suggestions on how to improve my work.
- My wonderful co-authors, Zeynep Kantur and Martin Feldkircher, for generously sharing their knowledge and for their patience and support throughout our lengthy publishing journey.
- My professors at the University of Latvia, especially Ludmila Frolova and Daina Šķiltere, for their guidance during my early steps in academia.
- My colleagues at Latvijas Banka — Oļegs Tkačevs, Kristīne Petrovska, Andrejs Zlobins, Krista Kalnbērziņa, and Kārlis Vilerts — for their support and for helping me stay committed to my PhD goals.
- My colleagues in the Monetary Policy Department and Financial Stability Department at Latvijas Banka for creating a friendly, productive, and inspiring work environment.
- Maria Edur, at Tallinn University of Technology, for her invaluable help in resolving administrative issues.
- My family, for their unwavering support and optimism.

Abstract
Essays on International Transmission of Economic Policy Shocks

The thesis, titled "Essays on International Policy Shock Transmission", comprises three papers. Publications I and II focus on the heterogeneity in the speed and strength of credit and monetary shock transmission from the USA and euro area to CESEE countries, utilizing aggregate time series data. Publication III explores the heterogeneity of monetary shock transmission between Eastern and Western European countries by examining differences in net wealth distribution across age cohorts. Together, these studies contribute to the transmission literature by proposing new approaches for identifying shocks within a multi-country model and introducing model specifications to analyse regional discrepancies in shock transmission.

Publication I, "International Spillovers from Euro Area and US Credit and Demand Shocks: A Focus on Emerging Europe", examines the transmission of credit and demand shocks from the euro area and the USA to real GDP and total credit in CESEE countries during 1995-2013. The paper employs a GVAR model to capture the interactions among 41 countries and the euro area, accounting for trade and financial linkages. Key contributions of the paper include the application of sign restrictions to identify loan supply, loan demand, and aggregate demand shocks, as well as an extensive analysis of spillovers to CESEE countries. The findings indicate that aggregate credit supply and demand shocks originating in both the euro area and the USA generally led to reductions in international output and total credit, emphasizing the vulnerability of CESEE economies to such shocks. The study also reveals that the euro area plays a significant role not only as a source of shocks but also as a conduit for transmitting third-country shocks.

Publication II, "The Impact of Euro Area Monetary Policy on Central and Eastern Europe", continues the exploration of international shock transmission by focusing on the effects of euro area monetary policy shocks on CESEE countries over an extended period, covering both conventional and unconventional monetary policy phases (1995-2017). Given the strong economic ties between the CESEE region and the euro area, these coun-tries are highly sensitive to changes in euro area monetary policy. This paper introduces a novel multi-level approach for identification of euro area monetary policy shocks within a GVAR framework, enabling consistent shock incorporating across both individual countries and the euro area aggregate. The study makes a key contribution to the literature by addressing the limitations of previous models that did not account for intra-euro area heterogeneity. The results reveal significant regional variation in response to euro area monetary policy shocks, with CESEE countries experiencing substantial spillover effects, often with output and price impacts that exceed those within the euro area itself. The transmission occurs through both direct channels, such as trade and financial linkages, and indirect channels involving third-country effects. Overall, this research highlights the exposure of CESEE economies to euro area shocks, emphasizing the importance of transparent and well-communicated policy measures to mitigate adverse spillovers.

Publication III, "Wealth Distribution and Monetary Policy", extends the analysis of monetary policy transmission by examining how variations in wealth distribution across age cohorts influence policy effectiveness in European countries. Using HFCS data from 2017, the paper highlights significant differences in wealth accumulation patterns between Eastern and Western EU countries. In Western Europe, wealth peaks around retirement age, whereas in Eastern Europe, younger cohorts tend to accumulate wealth more rapidly. The paper's contribution lies in its hypothesis that these disparities are partly due to generational productivity differences shaped by the historical context of the post-communist transition in Eastern Europe. The study develops an augmented New Keynesian model

with an overlapping generations framework, incorporating generational productivity heterogeneity to capture these wealth distribution patterns. The model demonstrates that monetary policy is less effective in Western Europe, where wealth concentration among older individuals dampens the impact on consumption and investment. In contrast, Eastern European countries, with younger wealth holders, exhibit a stronger response to monetary policy changes, as younger individuals are more sensitive to interest rate adjustments, driving significant shifts in consumption and investment. This research underscores the importance of demographic and productivity factors in shaping country-specific responses to euro area monetary shocks and contributes to a deeper understanding of the heterogeneous effects observed in Publications I and II.

Kokkuvõte

Esseed majanduspoliitiliste šokkide rahvusvahelisest edasikandumisest

Doktoritöö „Esseed majanduspoliitiliste šokkide rahvusvahelisest edasikandumisest” sisaldab kolme artiklit. Artiklites I ja II uuritakse erinevusi krediidi- ja rahapoliitika šokkide ülekande kiiruses ning tugevuses USA-st ja euroalalt Kesk- ja Ida-Euroopa riikidesse, kasutades agregeeritud aegridade andmeid. Artikkel III selgitab rahapoliitika šokkide erinevat ülekandumist Ida- ja Lääne-Euroopa riikide võrdluses, lähtudes erinevustest netovara jaotuses üle vanusegruppide. Kolme uuringu peamised panused šokkide ülekandumist käsitlevasse teaduskirjandusse on uudsete lähenemisviiside rakendamine šokkide määratlemiseks mitme riigi mudelis ja metodoloogilised uuendused šokkide ülekande piirkondlike erinevuste analüüsil.

Artikkel I, „Euroala ja USA krediidi- ja nõudlusšokkide rahvusvahelise ülekandumise analüüs, mis keskendub arenevale Euroopale”, uurib euroala ja USA krediidi- ja nõudlusšokkide mõju ülekandumist reaalsele SKP-le ning agregeeritud laenumahule Kesk-, Ida ja Kagu-Euroopa (Central, Eastern and Southeastern Europe, CESEE) riikides aastatel 1995–2013. Uuring kasutab GVAR-mudelit, et kirjeldada ühelt poolt 41 erinevate maailmajagude riigi ja teiselt poolt euroala ning USA vahelisi suhteid, arvestades kaubandus- ja rahandusalaseid seoseid. Artikli peamised panused teaduskirjandusse on märgipiirangute rakendamine laenupakkumise, laenunõudluse ja kogunõudluse šokkide määratlemiseks ning põhjalik analüüs šokkide ülekandumisest areneva Euroopa riikidesse. Uuringu tulemused näitavad, et negatiivsed laenupakkumise ja laenunõudluse šokid nii euroalal kui USA-s viivad tavaliselt tootmis- ja laenumahtude vähenemiseni. Tulemused rõhutavad Kesk- ja Ida-Euroopa majanduste haavatavust USA-st ja euroalalt pärit krediidi- ja nõudlusšokkide suhtes. Uuring näitab, et euroalal on oluline roll mitte ainult šokkide allikana, vaid ka kolmandate riikide šokkide edasikandjana.

Artikkel II, „Euroala rahapoliitika mõju Kesk- ja Ida-Euroopale”, jätkab rahvusvaheliste šokkide ülekandemehhanismide uurimist, keskendudes euroala rahapoliitiliste šokkide mõjule CESEE riikides. Uuritakse pikemat ajaperioodi, mis hõlmab nii tavapärase kui ka mittetraditsioonilise rahapoliitika perioode (1995–2017). Arvestades CESEE regiooni tugevaid majandussidemeid euroalaga on need riigid väga tundlikud euroala rahapoliitika muutuste suhtes. Antud artikkel tutvustab uut kahetasandilist lähenemist, et lisada euroala rahapoliitilisi šokke GVAR-raamistikku, võimaldades konsistentset šokkide tuvastamist nii üksikutes riikides kui ka euroalal tervikuna. Uuring panustab teaduskirjandusse, kuna rakendab uudset metoodikat, mis võimaldab euroalasiseseid erinevusi arvesse võtta. Tulemused näitavad tugevaid piirkondlikke erinevusi euroala rahapoliitilistele šokkidele reageerimisel. CESEE riikides ilmnevad tugevad ülekandemõjud, mille puhul toodangu ja hindade muutused ületavad sageli euroala sees täheldatavaid mõjusid. Ülekandemehhanism toimib nii otseste kanalite kaudu, nagu kaubandus- ja finantssuhted, kui ka kaudsete kanalite kaudu, mis hõlmavad kolmandate riikide mõjusid. Kokkuvõttes juhib see uurimus tähelepanu CESEE majanduste haavatavusele euroala šokkide suhtes, rõhutades vajadust läbipaistvate ja hästi kommunikeeritud poliitikameetmete järele, et vähendada kahjulikke ülekandemõjusid.

Artikkel III, „Netovara jaotus ja rahapoliitika mõju”, laiendab rahapoliitika ülekandemõjude analüüsi, uurides, kuidas netovara erinev jaotumine vanusegruppide lõikes mõjutab rahapoliitika mõjusust Euroopa riikides. Kasutades 2017. aasta HFCS andmeid, uurib artikkel olulisi erinevusi varade kogumise mustrites CESEE ja Lääne-Euroopa riikides. Lääne-Euroopas saavutab jõukuse tase maksimumi vahetult enne pensioniea saabumist, samas kui CESEE riikides koguvad nooremad kohordid vara kiiremini. Artikli panus põhineb eeldusel, et see lahknevus võib olla tingitud põlvkondlikest erinevustest tootlikkuses, mida on mõjutanud CESEE regiooni postkommunistliku üleminekuperioodi ajalooline kontekst. Uuringus rakendatakse täiustatud uuskeinsistlikku (New Keynesian) mudelit koos kattuvate põlvkondade raamistikuga, hõlmates väljapakutud põlvkondade vaheliste tootlikkuse erinevuste hüpoteesi, et neid varade jaotuse mustreid kirjeldada. Mudel näitab, et rahapoliitika on Lääne-Euroopas vähem tõhus, kuna vara koondumine vanemaealistele vähendab selle mõju tarbimisele ja investeeringutele. Vastupidiselt sellele reageerivad CESEE riigid, kus suurem osa varadest kuulub noorematele kohortidele, tugevamini rahapoliitika muudatustele. See tuleneb nooremate indiviidide kõrgemast tundlikkusest intressimäärade suhtes, mis toob kaasa ka suurema üldise mõju tarbimisele ja investeeringutele. Antud uurimus rõhutab demograafiliste ja tootlikkusega seotud tegurite tähtsust riigispetsiifiliste reaktsioonide kujundamisel euroala rahapoliitilistele šokkidele ja avab uusi tahke rahapoliitika mõjude heterogeensuse kohta võrreldes Artiklitega I ja II.

Appendix 1

I

Fadejeva, L., Feldkircher, M., and Reininger, T. (2017). International spillovers from Euro area and US credit and demand shocks: A focus on emerging Europe. *Journal of International Money and Finance*, 70(C):1–25.
DOI 10.1016/j.jimonfin.2016.0

Journal of International Money and Finance 70 (2017) 1–25

Contents lists available at ScienceDirect

Journal of International Money and Finance

journal homepage: www.elsevier.com/locate/jimf

International spillovers from Euro area and US credit and demand shocks: A focus on emerging Europe ☆

Ludmila Fadejeva [a], Martin Feldkircher [b,*], Thomas Reininger [b]

[a] Latvijas Banka, Riga, Latvia
[b] Oesterreichische Nationalbank (OeNB), Vienna, Austria

ARTICLE INFO

Article history:
Available online 10 August 2016

JEL Classification:
C32
F44
E32
O54

Keywords:
Credit shock
Global vector autoregressions
Emerging Europe
Sign restrictions

ABSTRACT

In this paper, we examine the international effects of contractions in loan supply, loan demand and aggregate demand in the euro area and the USA. All three shocks have been at the forefront in spreading stress during the period of the global financial crisis and in particular so to countries that are strongly integrated with the euro area. We find that these shocks decrease international output and total credit to a varying degree. Loan demand and aggregate demand shocks in the euro area trigger significant negative spillovers on output in most other regions. Evidence for global negative output effects of euro area loan supply shocks is fraught with considerable estimation uncertainty. When these three types of shocks emanate from the USA, we find significant negative spillovers on output also for loan supply shocks. In general, international effects on total credit are an order of magnitude larger than those on output, with again more evidence that is significant for US than euro area shocks. Last, and taking a regional stance, our results indicate that economies from emerging Europe are most vulnerable to all shocks considered. Through their strong economic integration with the euro area, these economies are likewise exposed to euro area and US shocks, and spillover effects are often larger than the domestic response in the country of shock-origin.
© 2016 Elsevier Ltd. All rights reserved.

☆ The views expressed in this paper are not necessarily those of the Oesterreichische Nationalbank (OeNB) and Latvijas Banka. We would like to thank Rudolfs Bems, Konstantins Benkovsvkis, Elona Dushku, Sandra Eickmeier, Robert Kunst, participants

http://dx.doi.org/10.1016/j.jimonfin.2016.08.001
0261-5606/© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

When the financial crisis erupted in 2008, the global economy witnessed a collapse in trade followed by a sharp contraction of real activity. In its aftermath, financial and economic conditions were characterized by tightened credit, increasing loan loss provisions and a lack of confidence between banks (Busch et al., 2010). On the one hand it was argued that the decrease in new lending was driven by a sharp reduction in the demand for loans. On the other hand, banks were blamed to have tightened credit standards, being overly reluctant to engage in new lending as a part of cleaning their balance sheets. These effects have certainly contributed to the sharp drop in international real activity witnessed during the period of 2008–2009. However, countries not directly affected by shocks to credit saw their output deteriorate facing adverse aggregate demand shocks for their exports and/or a surge in risk averseness of international investors triggering a kind of "flight to safety" redirection of their investment (Chudik and Fratzscher, 2011). From a policy perspective, the distinction between supply driven and demand driven shocks to credit lending and other macroeconomic shocks, such as adverse aggregate demand, is important since they might call for very different responses of monetary and fiscal policy (Gambetti and Musso, 2012).

In this paper we investigate *spillovers* from euro area and US shocks. Both economies have been at the core of recent episodes of macrofinancial stress, the sovereign debt crisis (the euro area) on the one hand, and the global financial crisis (the USA) on the other hand. We examine three shocks in more detail that have been vital in spreading stress recently, namely adverse loan supply and demand shocks and – more generally – a negative shock to aggregate demand. For that purpose we use a global vector-autoregressive (GVAR) model that was put forward among others in Pesaran et al. (2004), Dees et al. (2007a,b), Garratt et al. (2006), and extend it to feature total credit and countries from Central, Eastern and Southeastern Europe (CESEE), and the Commonwealth of Independent States (CIS). To a different degree, these countries share strong trade and financial linkages – either in the form of direct cross-border loans to the non-financial sector, wholesale funding or intra-group parent bank funding to the banking sector – with the euro area. Including these countries in a study to assess adverse shocks to credit supply in the euro area seems thus essential and provides a new angle on the strength and transmission of financial shocks in general and during the crisis. Finally, our analysis separates loan supply, loan demand and aggregate demand shocks from other macroeconomic shocks by explicitly controlling also for disturbances from aggregate supply and monetary policy. This yields a comprehensive assessment of macroeconomic fluctuations of a broad range of economies with different degrees of financial and trade integration with the world economy.

Our general results are as follows: We find evidence that output and total credit decline in response to the credit-related and aggregate demand shocks. Global negative effects on output are significant for all regions (in Asia partly in the short-term only) following a loan demand or aggregate demand shock in the euro area or the USA. By contrast, negative output effects of loan supply shocks are significant for all regions except for Latin America (in the medium- to long-run) and for Asia if these shocks emanate from the USA, and are fraught with estimation uncertainty if these are euro area shocks. Moreover, regarding total credit, it turns out that more regions are significantly affected by US shocks compared to euro area shocks. Second and taking a regional stance, the high degree of economic integration with the euro area renders CESEE and CIS economies most vulnerable to euro area macrofinancial shocks. Through knock-on effects, mostly via the euro area, both regions are also strongly exposed to US shocks. This is also demonstrated via a historical decomposition analysis which shows that US shocks contributed strongly in explaining deviations from trend growth in output and

of internal seminars at Latvijas Banka, the OeNB, the Joint Vienna Institute, and participants of the 8th SEE Research Workshop of the Albanian National Bank, Tirana, for helpful comments. We are grateful to Kristiana Rozite for the assistance during the internship at the Bank of Latvia. Authors' email addresses: ludmila.fadejeva@bank.lv, martin.feldkircher@oenb.at and thomas.reininger@oenb.at.

* Corresponding author.
E-mail address: martin.feldkircher@oenb.at (M. Feldkircher).

total credit in these regions. Looking at the size of spillover effects on CESEE and CIS economies reveals mostly larger effects than in the country of shock-origin.

The paper is structured as follows: the next section summarizes the relevant literature, while Section 3 introduces the global VAR (GVAR) model, the data and the model specification. Section 4 presents a set of sign restrictions that we employ to the shocks of interest. Section 5 illustrates the results and Section 6 concludes.

2. Related literature

In the aftermath of the crisis, heightened interest in the real effects of negative credit shocks was reflected in a vastly growing empirical literature. One strand of the literature employs survey data. In an early and seminal paper, Lown and Morgan (2006) use the US Federal Reserve loan officer opinion survey and treat credit standards as an endogenous variable in a small vector autoregression (VAR). Lown and Morgan (2006) find that fluctuations in commercial credit standards are highly significant in predicting commercial bank loans, output and investment in the trade sector. Furthermore, US credit standards are unaffected by an (unexpected) increase in the federal funds rate, while lending rates rise in parallel with the policy rate. More recently, Ciccarelli et al. (2010) use detailed answers from the US and unique euro area bank lending surveys to assess the effect of a monetary policy shock on output and inflation via loan supply and demand (credit channel). They find evidence for an operative credit channel implying that an increase in the policy rate deters the availability of credit and in turn impacts output and inflation. While the credit channel tends to amplify the real consequences of monetary policy shocks, Ciccarelli et al. (2010) found evidence that during the recent crisis, a reduction of credit supply to firms contributed to the decline in output growth. Bassett et al. (2014) construct a unique credit supply indicator from the US loan officer opinion survey, which is adjusted for macroeconomic and bank-specific factors that otherwise would affect loan demand. They find that tightening credit supply leads to a substantial decrease in output, a widening in credit spreads and an easing of monetary policy.

A second strand of the literature uses aggregated data and sign restrictions on the impulse response functions to identify loan supply shocks. Busch et al. (2010) focus on the recent dynamics of loans to non-financial corporations in Germany. Based on historical shock decompositions they find that monetary policy was basically neutral in the period of the outbreak of the global financial crisis and its immediate aftermath. With the beginning of 2008, other non-identified shocks overcompensated the detrimental effect of a negative loan supply shock on loan dynamics. Meeks (2012) investigated credit shocks on the US market for high yield corporate bonds and found that shocks to the credit spread cause immediate and prolonged contractions in output. Furthermore, shocks to the credit market had an adverse effect on output in every recession in the USA since 1982. Fornari and Stracca (2012) estimate a panel VAR for 21 advanced economies and assess how shocks emanating from the financial sector impact standard indicators of real activity and financial conditions. Their imposed restrictions on the impulse response functions allow them to isolate this financial shock from an aggregate demand and a monetary policy shock, but fail to attach a more structural interpretation to the financial shock itself. Their results show that financial shocks have a noticeable effect on key macro variables such as output, but that investment reacts most strongly, a fact that is well in line with Peek et al. (2003). Furthermore, cross-country differences seem to play a minor role only. Gambetti and Musso (2012) use a time-varying VAR framework allowing for stochastic volatility and analyze the effect of loan supply shocks on output and loan growth in three major economies, the euro area, the UK and the USA. They find that loan supply shocks have a significant impact on economic activity, inflation and credit markets and that this effect is varying over time. Especially, during periods of economic slowdown, the contribution of the loan supply shock in explaining movements in output and credit growth is larger. Furthermore, the short-term impact of the loan supply shock on output and credit growth seems to have strengthened in the most recent past. Hristov et al. (2012) derive sign restrictions from DSGE models that explicitly allow for a banking sector and feature financial frictions. Based on a panel VAR they find that loan supply shocks in euro area countries are important determinants of growth in loans and real GDP, thereby corroborating the results of Gambetti and Musso (2012). In contrast to Fornari and Stracca (2012), however, the results provided in Hristov et al. (2012) reveal important cross-country differences within the euro area as regards to the timing and the magnitude of the shocks.

While the strands of literature reviewed above differ with respect to the identification of the loan supply shock and the data employed, they share the same focus, which is on the effect of loan supply shocks on the *domestic* economy. There are only a few papers that bring in a *global* angle. Helbling et al. (2011) reveal that credit market shocks shaped the global business cycle during the latest global recession, especially if the shock emanates from the USA. Eickmeier and Ng (2015) extend this further by addressing the question how shocks to credit in four major economies transmit internationally using a global macro model that links single economies by the strength of their bilateral trade and financial ties. In line with Helbling et al. (2011), Eickmeier and Ng (2015) find a pivotal role for the USA in shaping economic conditions in the global economy, while the effect of credit supply shocks emanating from Japan or the euro area are comparably milder. Finally, Eickmeier and Ng (2015) observe a significant flight-to-quality effect which is mirrored in an appreciation of the US dollar vis-a-vis other main currencies.

3. The GVAR model

The empirical literature on GVAR models has been largely influenced by the work of Hashem M. Pesaran and co-authors (Garratt et al., 2006; Pesaran et al., 2004). In a series of papers, these authors examine the effect of US macroeconomic impulses on selected foreign economies employing agnostic, structural and long-run macroeconomic relations to identify the shocks. (Dees et al., 2007a,b; Pesaran et al., 2004). Recent papers have advanced the literature on GVAR modeling in terms of country coverage (Feldkircher, 2015), Bayesian estimation of the local models (Crespo Cuaresma et al., 2016; Dovern et al., 2015), the analysis of house price shocks (Cesa-Bianchi, 2013), credit supply shocks (Eickmeier and Ng, 2015), cost-push shocks (Galesi and Lombardi, 2013), financial stress shocks (Dovern and van Roye, 2014), monetary policy shocks (Feldkircher and Huber, 2016), liquidity shocks during the Great Recession of 2007–2009 (Chudik and Fratzscher, 2011), and for stress-testing of the financial sector (Castrén et al., 2010). For an excellent survey regarding recent applications within the GVAR framework, see Chudik and Pesaran (2016).

The GVAR is a compact representation of the world economy designed to model multilateral dependencies among economies across the globe. In principle, a GVAR model comprises *two layers* via which the model is able to capture cross-country spillovers. In the first layer, separate time series models – one per country – are estimated. In the second layer, the country models are stacked to yield a global model that is able to assess the spatial propagation of a shock as well as the dynamics of the associated responses.

The first layer is composed by country-specific local VAR models, enlarged by a set of weakly exogenous and global variables (VARX* model). Assuming that our global economy consists of $N+1$ countries, we estimate a VARX* of the following form for every country $i=0,\ldots,N$:[1]

$$x_{it} = a_{i0} + a_{i1}t + \Phi_i x_{i,t-1} + \Lambda_{i0}x^*_{it} + \Lambda_{i1}x^*_{i,t-1} + \pi_{i0}d_t + \pi_{i1}d_{t-1} + \epsilon_{it}. \tag{3.1}$$

Here, x_{it} is a $k_i \times 1$ vector of endogenous variables in country i at time $t \in 1,\ldots,T$, Φ_i denotes the $k_i \times k_i$ matrix of parameters associated with the lagged endogenous variables and Λ_{ik} are the coefficient matrices of the k^*_i weakly exogenous variables, of dimension $k_i \times k^*_i$. Furthermore, $\epsilon_{it} \sim N(0, \Sigma_i)$ is the standard vector error term, d_t denotes the vector of *strictly exogenous* variables, which are linked to the vector of exogenous variables through the matrices π_{i0} and π_{i1}, and t is a deterministic trend component. If $\Lambda_{i0}, \Lambda_{i1}, \pi_0$ and π_1 are composed exclusively by zero elements, the specification boils down to that of a standard VAR model (with a deterministic linear trend if $a_{i1} \neq 0$).

[1] For simplicity, we use a first-order VARX* model for the exposition. The generalization to longer lag structures is straightforward.

The weakly exogenous or *foreign* variables, x_{it}^*, are constructed as a weighted average of their cross-country counterparts,

$$x_{it}^* := \sum_{j \neq i}^{N} \omega_{ij} x_{jt}, \tag{3.2}$$

where ω_{ij} denotes the weight corresponding to the pair of country i and country j. The weights ω_{ij} reflect economic and financial ties among economies, which are usually proxied using data on bilateral trade weights.[2] The assumption that the x_{it}^* variables are weakly exogenous at the individual level reflects the belief that most countries are small relative to the world economy.

Following Pesaran et al. (2004), the country-specific models can be rewritten as

$$A_i z_{it} = a_{i0} + a_{i1} t + B_i z_{it-1} + \pi_{i0} d_t + \pi_{i1} d_{t-1} + \epsilon_{it}, \tag{3.3}$$

where $A_i := (I_{k_i}, \quad -\Lambda_{i0})$, $B_i := (\Phi_i, \quad -\Lambda_{i1})$ and $z_{it} = (x_{it}', \quad x_{it}^{*'})'$. By defining a suitable link matrix W_i of dimension $(k_i + k_i^*) \times k$, where $k = \sum_{i=1}^{N} k_i$, we can rewrite z_{it} as $z_{it} = W_i x_t$. x_t denotes the vector that stacks all the endogenous variables of the countries in our sample. Note that this implies that the weakly exogenous variables are endogenous within the system of all equations. Substitution of (3.3) in (3.1) and stacking the different local models leads to the global equation, which is given by

$$\begin{aligned} x_t &= G^{-1} a_0 + G^{-1} a_1 t + G^{-1} H x_{t-1} + G^{-1} \pi_0 d_t + G^{-1} \pi_1 d_{t-1} + G^{-1} \epsilon_t \\ &= b_0 + b_1 t + F x_{t-1} + \Gamma_0 d_t + \Gamma_1 d_{t-1} + e_t, \end{aligned} \tag{3.4}$$

where $G = (A_0 W_0, \cdots, A_N W_W)'$, $H = (B_0 W_0, \cdots, B_N W_W)'$ and a_0, a_1, π_0 and π_1 contain the corresponding stacked vectors containing the parameter vectors of the country-specific specifications. The eigenvalues of the matrix F, which is of prime interest for forecasting and impulse response analysis, have to lie within the unit circle in order to ensure stability of Equation 3.4.

3.1. Estimation and times series properties

Following the bulk of the literature we estimate the single country VARX models in error correction form, which allows for cointegration relationships within and between countries. More specifically, in the empirical part we are going to estimate a VARX*(1, 1) model which is re-written in error correction form as follows:

$$\Delta x_{i,t} = c_{i,0} + \alpha_i \beta_i' ((z_{i,t-1}, d_{t-1}) - \gamma_i (t-1)) + \Lambda_{i,0} \Delta x_{i,t}^* + \Delta d_t + \epsilon_{i,t}. \tag{3.5}$$

Here, α_i denotes the $k_i \times r_i$ adjustment or loading matrix, β_i the $(k_i + k_i^*) \times r_i$ matrix of coefficients attached to the long-run equilibrium and r_i the cointegration rank. In case the variables contained in z_t are cointegrating, the long-run matrix $\alpha_i \beta_i'$ will be rank deficient. We follow the convention made in the literature and assume that the foreign variables are "long-run forcing" for endogenous variables but not vice versa. The single country VARX models are then estimated conditional on the weakly exogenous variables contained in $x_{i,t}^*$ using reduced rank regression. This provides estimates of α_i, β_i, and r_i. The remaining parameters can then be estimated by standard least squares (Dees et al., 2007a; Pesaran et al., 2004).

We have tested each variable for the presence of a unit root by means of an augmented Dickey–Fuller test. Output, price inflation and interest rates are mostly integrated of order 1, which ensures the appropriateness of the econometric framework pursued in this study. The ADF-test results for total credit, on the other hand, indicate integration of order 2. Furthermore, during the particular time period we cover in this study, there tends to be a significant change in total credit growth after 2009 and

[2] See, e.g., Eickmeier and Ng (2015), and Feldkircher and Huber (2016) for an application using a broad set of different weights.

consequently the ratio of output and credit. This (crisis-induced) break in the long-term cointegration relationship renders the country models more unstable. Hence, we augment the cointegration equation by a step dummy from 2009Q1 to 2013Q4 (see Table A.1). This structural break dummy accounts for the above mentioned break in the output to credit relationship and helps to stabilize the model.[3] Cointegration rank is tested by means of a test based on the trace statistic. The test identifies 2–3 relationships that determine the long-run behavior of the economy for most of the countries. The number of cointegration relations in the country models was further reduced by examining the country-specific persistence profiles of the long-run relationships.

3.2. Data and general model specification

Our data set contains quarterly observations for 41 countries and 1 regional aggregate, the euro area (EA)[4]. More specifically we include countries from emerging Asia, the CESEE region including the Baltics, the CIS region, Latin America and other developed economies.[5] Thus our data include emerging economies, advanced economies and the most important oil producers and consumers across the globe.

We include 76 quarterly observations from the period 1995Q1 to 2013Q4. The *domestic* variables that are used in our analysis comprise data on real activity, change in prices, the real exchange rate, and short term interest rates and government bond yields (Dees et al., 2007a,b; Pesaran et al., 2004, 2007, 2009). This data set is extended to feature total credit to the private sector which is based on a new data set provided by the BIS.[6] We further have adjusted for foreign exchange rate movements for countries whose credit markets are characterized by large shares of foreign currency denominated credit.[7] The variables used in the model are briefly described in Table 1. Most of the data are available with wide country coverage, with the exception of government yields. Since local capital markets in emerging economies (in particular in Eastern Europe) are still developing, data on government yields are hardly available for these countries.

The euro area and US country models deviate from the rest of the countries in several instances. First, in line with the literature, the oil price is determined within the US country model. Second, to identify a loan supply shock later on it is essential to include the "price" of total credit besides the aforementioned variables. Consequently we substitute the long-term interest rates with the composite lending rate in the US or euro area model.

Next, we have to specify the weights that link the single country models. In the early literature on GVARs, weakly exogenous variables have been exclusively constructed based on bilateral trade flows (Dees et al., 2007a; Pesaran et al., 2004, 2009). More recent contributions suggest using trade flows to calculate foreign variables related to the real side of the economy (e.g., output and inflation) and financial flows for variables related to the financial side of the economy (e.g., interest rates, total credit). We follow Eickmeier and Ng (2015) and choose weights based on bilateral trade flows to calculate y^*, Dp^* on the one hand, and weights based on bilateral banking sector exposure[8] to construct i_s^*, i_l^*, tc^* on the other hand.

---

[3] To check the overall robustness of our results, we have also tried to exclude the structural break dummy from the country models. In general, the GVAR still satisfies the eigenvalue conditions of stability. However, impulse response functions regarding total credit converged only slowly.

[4] The country composition on which the data on the euro area is based changes with time. While historical time series are based on data of the ten original euro area countries, the most recent data are based on 17 countries. The results of our analysis remain qualitatively unchanged if we use a consistent set of 14 euro area member states throughout the sample period instead of the rolling country composition for the data on the euro area, as the relative economic size of these three countries is quite small.

[5] Emerging Asia (Asia, 9) refers to CN, KR, PH, SG, TH, ID, IN, MY, and TR; CESEE and Baltics (CESEE, 12) refer to CZ, HU, PL, SK, SI, BG, RO, HR, AL, LT, LV, and EE; CIS (4) refers to RU, UA, BY, and GE; Latin America (LATAM, 5) refers to AR, BR, CL, MX, and PE; and rest of the world (RoW, 12) refers to US, EA, UK, CA, AU, JP, NZ, CH, NO, SE, DK, and IS. Abbreviations refer to the two-digit ISO country code.

[6] See http://www.bis.org/statistics/credtopriv.htm for more details.

[7] More specifically, these are Estonia, Latvia, Lithuania, Slovenia, Slovakia, Czech Republic, Poland, Hungary, Bulgaria, Romania, Croatia, Albania, Ukraine, Russia and Turkey.

[8] For more details on how to construct the financial weights see Backé et al. (2013).

Table 1
Data description.

Variable	Description	Min.	Mean	Max.	Coverage
y	Real GDP, average of 2005 = 100. Seasonally adjusted, in logarithms.	3.675	4.545	5.400	100%
Δp	Consumer price inflation. CPI seasonally adjusted, in logarithms.	–0.213	0.018	1.215	100%
e	Nominal exchange rate vis-à-vis the US dollar, deflated by national price levels (CPI).	–5.699	–2.404	5.459	100%
i_S	Typically 3-months-market rates, rates per annum.	–0.001	0.092	4.331	97.6%
i_L	Typically government bond yields, rates per annum.	0.006	0.054	0.638	40.5%
tc	Total credit (domestic and cross-border), seasonally adjusted and in logarithms.	–2.575	4.495	7.786	97.6%
EA_{lr}	Composite lending rate for the Euro area, weights based on volumes of credit outstanding.	0.028	0.053	0.098	–
US_{lr}	Composite lending rate for the USA, weights based on volumes of credit outstanding.	0.032	0.060	0.095	–
$poil$	Price of oil, seasonally adjusted, in logarithms.	2.395	3.710	4.753	–
Trade flows	Bilateral data on exports and imports of goods and services, annual data.	–	–	–	–
Banking exposure	Bilateral outstanding assets and liabilities of banking offices located in BIS reporting countries and Russia. Annual data.	–	–	–	–

Notes: Summary statistics pooled over countries and time. The coverage refers to the cross-country availability per country, in %. The share of foreign currency denominated loans in total loans for CZ, HU, PL, SI, SK, BG, RO, EE, LT, LV, HR, AL, RU, UA and TR is calculated at constant exchange rates as of end June 2013.

Last, and since our data span is rather short, untreated outliers can have a serious impact on the overall stability and the results of the model. For example, some countries witnessed extraordinarily high interest rates at the beginning of the sample period (which returned steadily to "normal" levels) and others were exposed to one-off crisis events (Russia or Argentina, for instance). Outliers have been identified by a residual analysis (roughly as those exceeding 2 standard deviations) of the individual country VECM models. These observations have been smoothed prior to estimating the GVAR, which has the advantage over direct inclusion of country dummies, that outlier effects cannot be carried over to other country models via foreign variables. The exact specification of the country models is provided in the Appendix Table A.1.

4. Identification of structural shocks

The applied literature using GVAR models for counterfactual analysis relies strongly on the concept of generalized impulse response functions to trace out the dispersion of shocks to macroeconomic variables across countries. Generalized impulse response functions, however, fail to attach an economic interpretation to the origins of the shock. In this study we follow Eickmeier and Ng (2015) and go beyond the rather agnostic approach by identifying a negative loan supply shock via restrictions that are imposed on the signs of the impulse response functions directly. This identification, however, applies for the country of shock-origin only (e.g., once the euro area and once the USA).

More formally, we follow Dees et al. (2007b) and identify the shocks locally in the US and the euro area country models. Suppose, the US model is indexed by $i = 0$:

$$x_{0,t} = \psi_{01}x_{0,t-1} + \Lambda_{00}x^*_{0,t} + \Lambda_{01}x^*_{0,t-1} + \epsilon_{0,t}. \tag{4.1}$$

Without loss of generality, we omit the deterministic part of our model. The reduced form of the model in Equation 4.2 is given by

$$Q_0x_{0,t} = \tilde{\psi}_{01}x_{0,t-1} + \tilde{\Lambda}_{00}x^*_{0,t} + \tilde{\Lambda}_{01}x^*_{0,t-1} + \tilde{\epsilon}_{0,t}, \tag{4.2}$$

where $\tilde{\epsilon}_{0,t} \sim \mathcal{N}(0, I_{k_0})$ and $\tilde{\psi}_{01}, \tilde{\Lambda}_{00}$ and $\tilde{\Lambda}_{01}$ denote the parameters to be estimated. The relationship between the reduced form in (4.2) and the structural form in Equation 4.1 can be seen by noting that $\psi_{01} = Q_0^{-1}\tilde{\psi}_{01}, \Lambda_{00} = Q_0^{-1}\tilde{\Lambda}_{00}, \Lambda_{01} = Q_0^{-1}\tilde{\Lambda}_{01}$ and $\epsilon_{0,t} = Q_0^{-1}\tilde{\epsilon}_{0,t}$. Thus finding the structural form of the model boils down to finding Q_0.

In what follows we set $Q_0^{-1} = P_0R_0$ where P_0 is the lower Cholesky factor of $\Sigma_{\epsilon,0}$ and R_0 being an orthonormal $k_0 \times k_0$ matrix.[9] The variance–covariance structure of $\epsilon_{0,t}$ is given by $\Sigma_{\epsilon,0} = P_0^{-1}R_0R_0'P_0^{-1\prime}$. In the present application we find R_0 by relying on sign restrictions. That is, we search for an orthonormal rotation matrices until we find an R_0 that fulfills a given set of restrictions on the impulse response functions.

This implies that conditional on using a suitable rotation matrix R_0, we can back out the structural shocks. To obtain a candidate rotation matrix we draw R_0 using the algorithm outlined in Rubio-Ramírez et al. (2010). We then proceed by constructing a $k \times k$ matrix Q, where the first k_0 rows and columns correspond to Q_0.

Formally, Q looks like

$$Q = \begin{pmatrix} Q_0 & 0 & \cdots & 0 \\ 0 & I_{k_1} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & I_{k_N} \end{pmatrix}. \tag{4.3}$$

The corresponding structural form of the global model looks like:

$$QGx_t = \tilde{F}x_{t-1} + \tilde{\epsilon}_t, \tag{4.4}$$

with $\Sigma_{\tilde{\epsilon}} = G^{-1}\Sigma_\epsilon G^{-1\prime}$ and assuming a block diagonal structure on Σ_ϵ as proposed in Eickmeier and Ng (2015). Note that this is not prohibitive since by premultiplying Σ_ϵ with G^{-1}, $\Sigma_{\tilde{\epsilon}}$ will in general not be block diagonal, allowing for immediate cross-country spillovers. Equation 4.4 is used to obtain structural impulse response functions. In case responses fulfill the set of sign restrictions we keep the candidate rotation matrix until we have collected 50 such matrices. The final results are then based on the matrix that is closest to the median response, as outlined in Fry and Pagan (2011).

To check whether the inclusion of contemporaneous foreign variables in the model helps capture the cross-country correlation, we look at the average pairwise correlation for the first differences of variables and the residual terms of individual country models. The maximum average correlation between first differences of variables is 0.21, and the one between residuals 0.06 correspondingly, therefore the block diagonal structure of error variance–covariance matrix is permissible.

We propose the constraints below to identify the shocks of interest. These are based on modified restrictions proposed by Hristov et al. (2012) and Eickmeier and Ng (2015).

We distinguish five different types of structural shocks affecting the euro area and the USA: (i) monetary policy shock, (ii) aggregate supply shock, (iii) aggregate demand shock, (iv) loan demand, and (v) loan supply shock. Separating these additional shocks as opposed to leaving them as a residual to the analysis should help in pinning down the loan supply shock more clearly, as increasing the number of restrictions enhances identification of the shock of interest (Paustian, 2007).

Each shock is characterized by a different pattern of restrictions (signs) or non-restrictions on how the shock impacts on endogenous variables, namely output, prices, money market rate, loan rate, lending margin (i.e., spread between loan rate and money market rate), and total credit volume. These signs are established a priori on theoretical grounds, for which we refer to recent literature on structural VARs and its reference to DSGE models (Canova and Paustian, 2011; Eickmeier and Ng, 2015; Fratzscher et al., 2009; Gambetti and Musso, 2012; Hristov et al., 2012). These signs relate to the changes (i.e., first differences) of the variables considered in this study such that e.g., a contractionary monetary policy shock would induce a slowdown in output growth (or even a negative output growth rate) rather

[9] Orthonormality implies that R_0 satisfies $R_0R_0' = I_{k_0}$.

than necessarily a decline in output. In this sense our framework imposes rather weak restrictions and lets ample room for the data to speak. Defining these shocks, we followed the principle that they have to distinguish themselves from each other by at least one restriction in order to be mutually exclusive, which is clearly a requirement of the sign restriction approach (Fry and Pagan, 2011).

Restrictions are imposed on impact and on the first quarter, in some cases on the first quarter only. We do not rely on additional longer lag restrictions for defining shocks and discriminating between them. Any restriction on any lag for a specific type of shock would not necessarily help to sufficiently distinguish different types of shocks that have the same restriction on impact in common (Fry and Pagan, 2011). Besides, we note that on-impact responses of a further shock may follow immediately in the next period after a previous shock.

In the following, we briefly summarize the features of the different types of structural shocks, assuming an adverse, i.e., contractionary shock. The *monetary policy shock* is reflected in an increase in the money market rate, transmitted into the lending rate, albeit imperfectly, so that the lending margin decreases. In parallel, output and prices as well as the total credit volume are restricted to decline.

The *aggregate supply shock* is characterized by a decline of output (relative to a base line) and the opposite movement in prices (Hristov et al., 2012). Several authors suggest that the central bank would react by hiking key nominal interest rates (Canova and Paustian, 2011; Fratzscher et al., 2009; Hristov et al., 2012). We refrain from doing so, taking into account varying historical experience and the leeway of central banks to react alternatively by the communication channel to keep inflation expectations firmly anchored. Correspondingly, we do not put a restriction on the loan rate or the lending margin. Concerning total credit volumes, we assume a negative response immediately following the adverse impact on output and costs (prices). This is similar to Gambetti and Musso (2012), Eickmeier and Ng (2015), and Hristov et al. (2012), who suggest a closely related movement of output and loans, partly incorporated as an explicit restriction.

The *aggregate demand shock* consists of a decrease in output and prices while the money market rate decreases. Concerning output, we note that we treat an adverse fiscal policy shock as type of an aggregate demand shock. We acknowledge that for a small and open economy, in which foreign demand is a particularly large component of total final demand, an asymmetric aggregate demand shock could have such a strong depreciating effect on the currency that prices may not decrease and the central bank may be reluctant to cut key policy rates, preventing money market rates from decreasing. However, we stress that our five shocks defined here relate to the euro area and the USA and not to CESEE countries directly. Concerning the loan rate, there are good reasons to argue in favor of a decrease in the loan rate, as the deterioration of investment opportunities will weaken loan demand (and issues of corporate debt securities) and policy rate reductions may be transmitted at least partly. However, we do not impose a restriction on the lending margin. We assume a negative response of loan and, hence, total credit volume, immediately following the adverse impact on output. The decrease in new lending volumes can be driven by the reluctance of banks to lend (given lower collateral value and subdued near-term growth prospects) as well as a reduced demand for credit (as a result of lower income and/or deteriorating sentiment). Hristov et al. (2012) and Gambetti and Musso (2012) do not differentiate aggregate demand from a loan demand shock assuming that the former comprises both effects.

However, as shown in the work based on bank-level data for Chile by Calani et al. (2010), insights into the behavior of economic agents during episodes of "credit shrinkage" suggest differentiating to some extent between aggregate demand and *loan demand* development. For example, rising unemployment and expected lower income may lead to postponing consumption, housing purchases and investment, therefore reducing demand for credit later on, as captured by the above-mentioned aggregate demand shock.[10] While the decrease of loan demand is the dominant result of a weakening of aggregate demand, at least after a short delay, it may be also the initial cause of ensuing dampening of aggregate demand, in particular in response to mounting over-indebtedness and emerging

[10] However, aggregate demand and loan demand can also work in opposite directions. Given weak aggregate demand (outlook), the unavailability of alternative sources of funding or self-insurance against potential future lack of liquidity by agents, may lead to the expansion of demand for bank loans in the short run (Calani et al., 2010). Moreover, during times of weak aggregate demand, mortgage may be viewed as safe investment, pushing-up loan demand temporarily.

Table 2
Sign restrictions.

Shock	y	Δp	i_s	Lending rate	tc	Lending rate – i_s
Monetary policy	$\downarrow$	$\downarrow$	$\uparrow$	–	$\downarrow$	$\downarrow$
Aggregate supply	$\downarrow$, $y > tc$	$\uparrow$	–	–	$\underline{\downarrow}$	–
Aggregate demand	$\downarrow$, $y > tc$	$\downarrow$	$\downarrow$	$\downarrow$	$\underline{\downarrow}$	–
Loan demand	$\underline{\downarrow}$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$, $tc > y$	–
Loan supply	$\underline{\downarrow}$	–	–	$\uparrow$	$\downarrow$, $tc > y$	$\uparrow$

Notes: The restrictions are imposed as $\geq / \leq$ and on the growth rates of the variables in the table. In general, restrictions are imposed on impact and on the first quarter. Underlined arrows reflect an exception to this in the sense that the restriction is imposed on the first quarter only.

difficulties of debt servicing.[11] We distinguish a loan demand shock from an aggregate demand shock by restricting the relative effect of the shocks on real output and total credit on impact. In the case of a loan demand shock, it is assumed that total credit shrinks stronger on-impact than real output, while the opposite is assumed for an aggregate demand shock. Note also that we put no direct restriction on the on-impact response of output to a loan demand shock, as we also have not directly restricted the on-impact response of total credit to an aggregate demand shock.

Finally, the adverse *loan supply shock* consists of an increase in the loan rate and a simultaneous increase in the lending margin (see Eickmeier and Ng, 2015), where we leave it unrestricted whether the money market rate increases less than the loan rate or even decreases. Correspondingly, we put no restriction on the reaction of prices. We find support for this rather cautious approach by the mixed evidence from VAR models with sign restrictions and from DSGE models with financial frictions with respect to the sign restriction on short-term interest rate and on prices (Eickmeier and Ng, 2015; Hristov et al., 2012). Both output and loan and, hence, total credit volume are restricted to decrease. Moreover, we assume that output declines less than the total credit volume, at least on impact, following Eickmeier and Ng (2015).

Table 2 summarizes the sign restrictions for identifying five main types of shocks. Note that these five types of shocks conform to the principle of mutual exclusivity. However, as noted above, real world examples may feature on-impact responses of two structural shocks that follow immediately after each other. Thus, for instance, a loan demand shock in one period may trigger an aggregate demand shock in the next one. Or, a loan supply shock may be followed by an aggregate supply shock.

5. Empirical results

In this section we summarize the domestic and international effects of euro area and US loan supply, loan demand and aggregate demand shocks. We also perform a historical decomposition analysis of the shocks and examine to what extent second-round effects matter.

5.1. Domestic effects

Fig. 1, top panel, shows the cumulative structural impulse responses of the domestic variables to a loan supply shock in the euro area and the USA, respectively. The loan supply and demand shocks are normalized to a 1% fall in total credit on impact, while the shock to aggregate demand is calibrated as a 1% decrease in output. The reaction of money market rates and inflation to the loan supply shock was left unrestricted (see Table 2). While inflation, short-term interest rates and lending rates adjust quickly to the new equilibrium, total credit and output contract only gradually, with the latter more prolonged in the euro area than in the USA. In the long-run, the decrease in total credit is considerably larger than the decrease in output in both the euro area (by about three times) and in the

[11] Vice versa, during the period of plummeted housing prices, loan demand may continue to decline, while aggregate demand already starts to grow again.

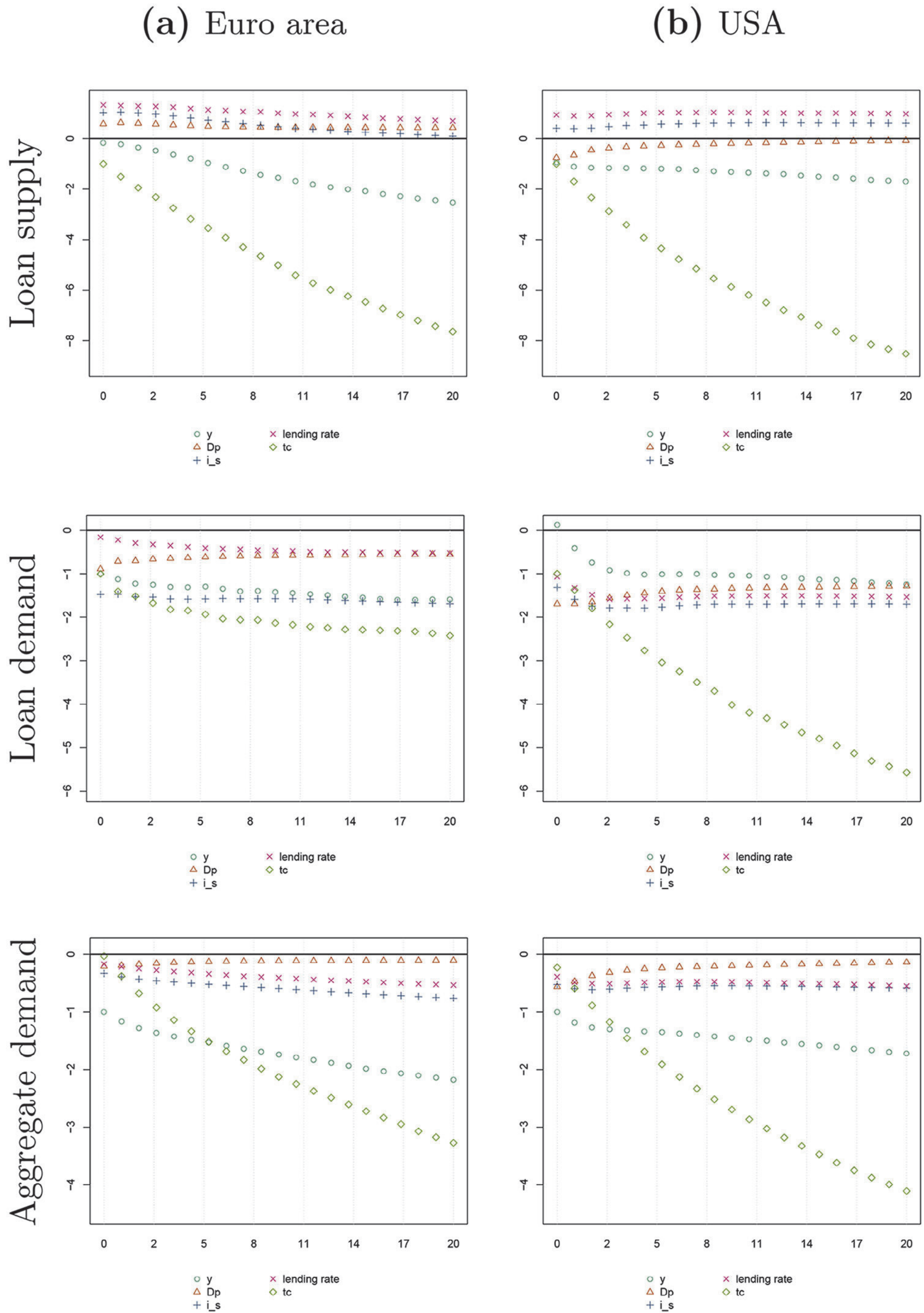


Fig. 1. Domestic response to loan supply, demand and aggregate demand shocks.
Notes: The plots show the domestic responses to loan supply, loan demand, and aggregate demand shocks in the euro area and the USA, respectively. Credit-related shocks are normalized to a fall of total credit by 1% on impact, while the aggregate demand shock is calibrated such that output decreases by 1% initially.

USA (by about five times). The persistent drop in output and total credit is in line with findings of related studies (e.g., Busch et al., 2010). The relative size of the adjustment is also close to the results of previous studies (e.g., Eickmeier and Ng, 2015).

The mid panel of Fig. 1 shows the responses to a loan demand shock. On impact, all variables decrease in both countries, with the exception of output in the USA. Note that the on-impact response of output was left unrestricted in both credit shocks, as we imposed the restriction only with a lag. While in the euro area the initial response of output is about equal in sign and size to that of total credit, the initial responses of these two variables have opposite signs in the USA. In the long run, the decrease in total credit is moderately larger than the decrease of output in the euro area, but substantially larger in the USA (by about 4 times). Last, the bottom panel of Fig. 1 shows the responses to a contractionary aggregate demand shock. In parallel with output, total credit decreases but to a lesser extent. After six (EA) or four (USA) quarters respectively, the decline in total credit surpasses the corresponding decline in output. This may reflect the (delayed) change in the borrowing behavior of firms and households as a result of the aggregate demand shock. Over time, all variables respond gradually to the shock in both the euro area and the USA. In the long-run, the decrease in total credit is larger than the decrease in output in both the euro area (by about 1.5 times) and in the USA (by about 2.5 times).

5.2. International effects of euro area shocks

In this section, we analyze how euro area shocks affect international credit and output. The results are summarized in Figs. 2 and 3 and are based on 200 bootstrap draws using the algorithm described in the manual of Smith and Galesi (2014). We show in dark blue (solid line) the median of the bootstrapped impulse responses along with 50% (light blue shaded area) and 68% (dark blue shaded area) confidence intervals. Regional impulse responses are constructed based on the full set of bootstrapped draws (for all countries in a specific region) as opposed to calculating purchasing power parity weighted averages of country-wise median responses (for a given region).

Looking at responses of real GDP to a negative loan supply shock first, we find that the 1% fall in total credit decreases output in the euro area by about 2.5% in the long-run (top panel of Fig. 2). In turn, output contracts internationally, but to a varying degree. For example, median effects on emerging economies in Asia and Latin America are virtually zero and accompanied by large confidence intervals. By contrast, responses in CESEE and the CIS are much more pronounced. In the long-run, median spillovers are of about the same size as domestic effects in the euro area itself (about −2.5%) but estimation uncertainty is considerable. Results differ for the two types of demand shocks shown in the mid and bottom panels of Fig. 2. Here, effects are significantly negative according to the 68% confidence bounds at least up to 10 quarters throughout all regions considered. More specifically, the loan demand shock triggers a significant decline in output of about 1 to 1.5% in the euro area, other advanced economies, Asia and Latin America, and of about 2 to 2.5% in CESEE and CIS economies in the medium term. Comparing the three shocks, responses are most tightly estimated for the aggregate demand shock yielding significant responses up to and beyond 20 quarters and throughout all regions. Here, the long-run decline of output is slightly more than 2% in the euro area and about half that size in the other regions, with the exception of CESEE and CIS where it is close to 3% and, hence, stronger than in the country of shock-origin.

Fig. 3 shows results for total credit. Long-run median responses to a negative loan supply shock are most pronounced in CESEE countries and, with a delay, in the CIS region, being about 1.5 times larger than in the euro area itself. Estimation uncertainty is more pronounced for responses of CESEE economies, while CIS economies show significant and negative long-run responses according to the 68% confidence bounds. By contrast, other advanced economies as well as emerging economies in Latin America are quite insulated from the shock. In Asia, total credit even increases significantly up to six quarters. This suggests that banks adjust their overall loan portfolio with respect to emerging markets in the medium term. International responses to the two types of demand shocks are very similar in size and shape. The loan demand shock triggers significant contractions in the euro area (up to six quarters), in the CIS (up to 14 quarters) and in Latin America (up to 20 quarters). Effects of the contraction in the euro area aggregate demand generate even longer-lasting spillovers in these regions

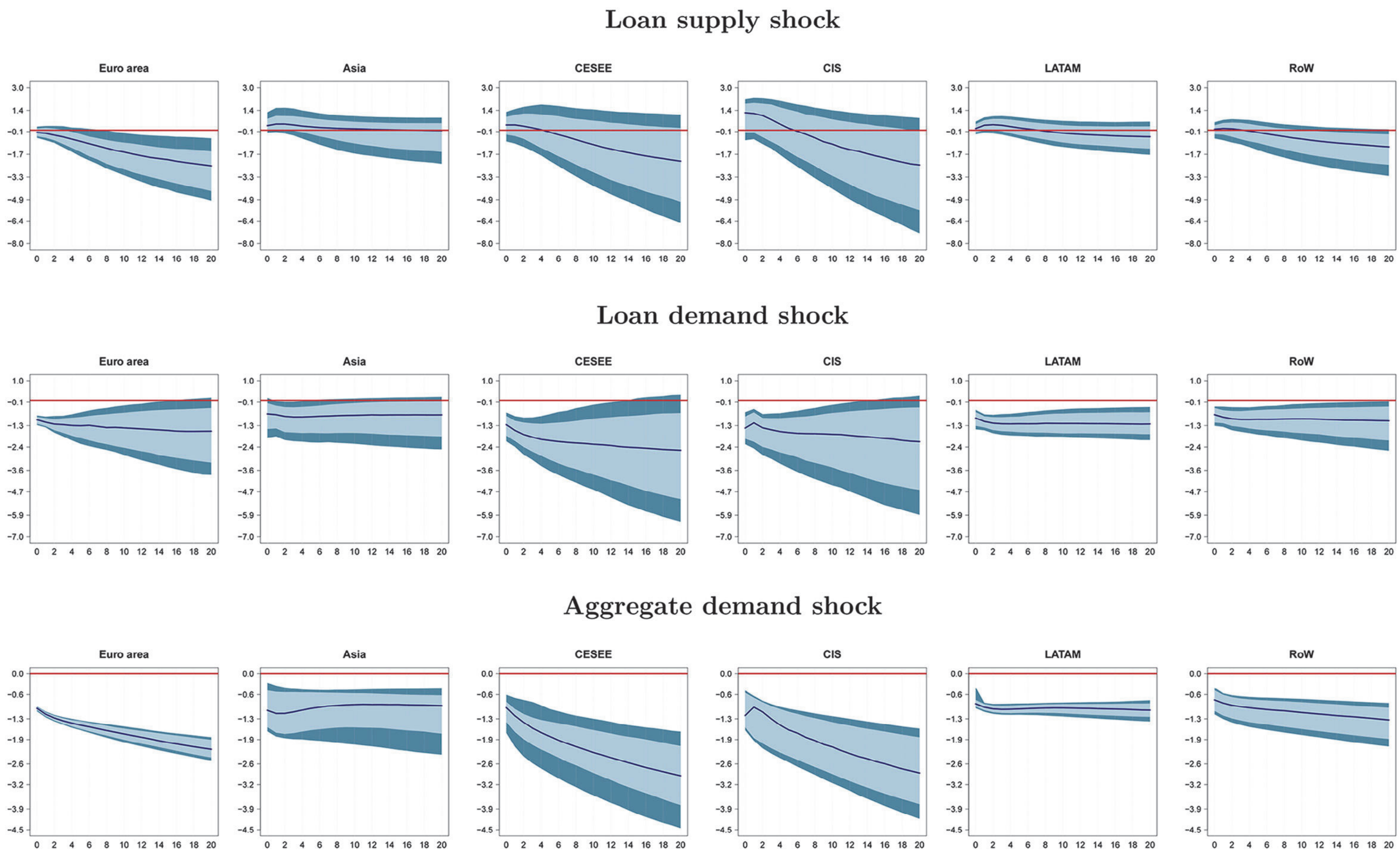


Fig. 2. Responses of real GDP (shock origin: EA).
Notes: The figure shows impulse responses of real GDP to loan supply, loan demand and aggregate demand shocks in the euro area. Median responses in dark blue (solid line), 50% bootstrap confidence bounds light blue shaded area, 68% bounds dark blue shaded area. Responses of advanced economies (RoW) are excluding the euro area for which responses are shown separately. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

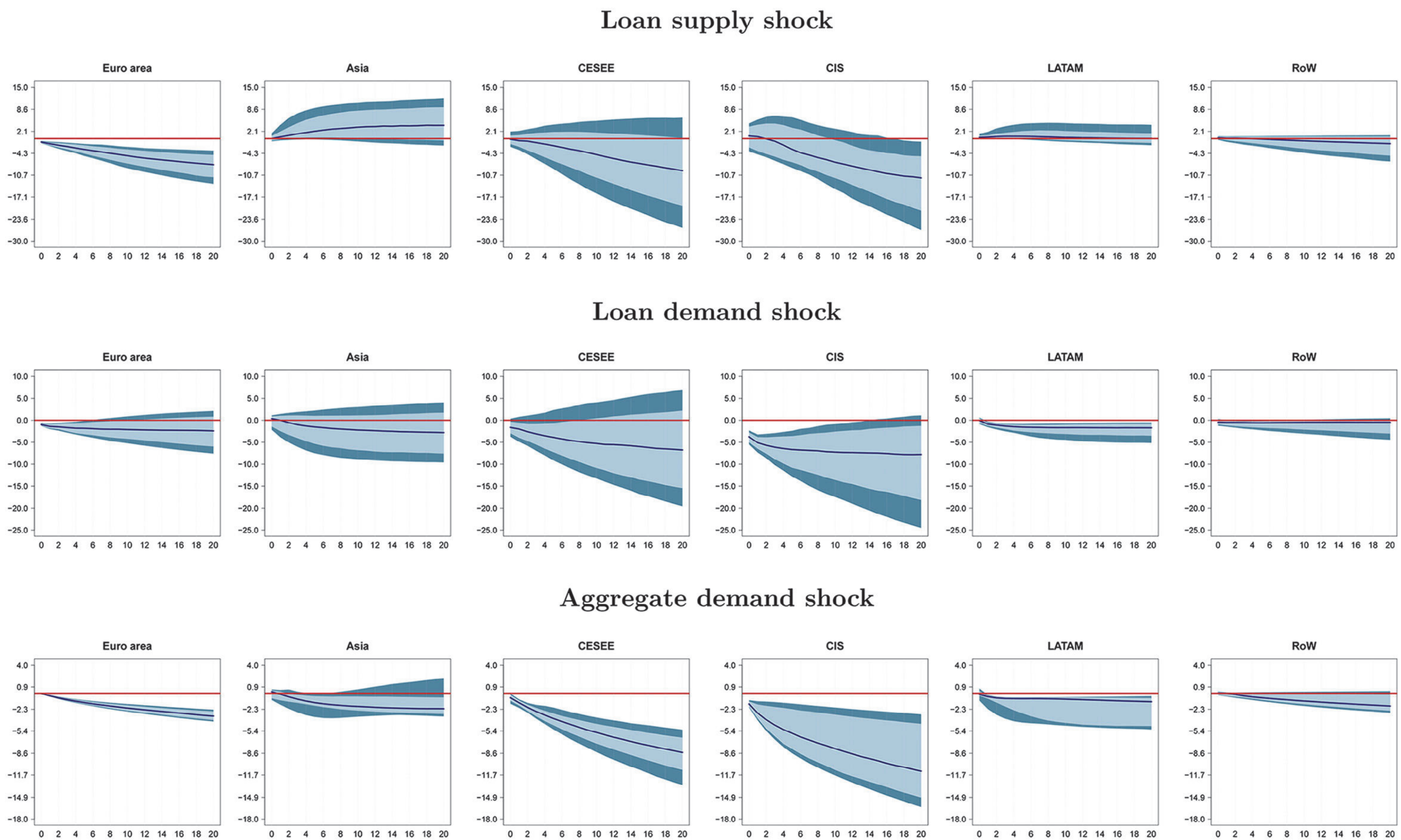


Fig. 3. Responses of total credit (shock origin: EA).

Notes: The figure shows impulse responses of real GDP to loan supply, loan demand and aggregate demand shocks in the euro area. Median responses in dark blue (solid line), 50% bootstrap confidence bounds light blue shaded area, 68% bounds dark blue shaded area. Responses of advanced economies (RoW) are excluding the euro area for which responses are shown separately. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and additionally in CESEE. Looking at the size of the spillovers, contractions in total credit are most pronounced for CESEE and CIS economies. More specifically, in response to both demand shocks, the contraction of total credit is about 2.5 (CESEE) and 3 (CIS) times stronger than in the euro area itself.

Summing up, a negative shock to euro area loan supply triggers contractions in both real output and total credit for all regions but emerging Asia and Latin America. Estimation uncertainty, however, is considerable. By contrast, we find significant negative spillovers on output from both negative loan demand and aggregate demand shocks. This is a general result and holds true for all regions considered (at least up to 10 quarters). International effects on total credit vary more strongly: In response to a negative euro area aggregate demand shock, total credit contracts significantly throughout the regions (up to 20 quarters), re-enforcing the loss in real output. This is only partially so for the loan demand shock, which triggers significant credit contractions only in the euro area itself, the CIS and Latin America (up to 6, 14 and 20 quarters respectively). Similar to the domestic effects, the median decrease in total credit is considerably larger than the median decrease in output in all regions (also if this comparison is limited to significant responses only). In some cases, not even the confidence intervals overlap. To put our results into perspective, we compare the long-run response in the country of shock origin (the euro area) with the long-run spillover effect in each region. These ratios are in general more pronounced for total credit responses than output reactions and – taking a regional perspective – for CESEE and CIS economies.

5.3. Are spillovers from US shocks different?

In this section we complement the analysis of euro area shocks by showing impulse responses for the same set of shocks but originating in the USA. Consequently Figs. 4 and 5 show the international effects of US loan supply, demand and aggregate demand shocks on real GDP and total credit, respectively.

In response to the loan supply shock presented in the top panel of Fig. 4, output contracts significantly in the long-run in all regions but Asia and Latin America. In the latter, real GDP declines significantly only in the short-run, while long-run spillovers are not significant. The shock to US loan demand causes negative significant short-run effects on output in Asia and Latin America (up to six quarters). For the remaining economies effects are significant up to and beyond 20 quarters. In line with results for the euro area shocks, most tightly estimated responses are obtained for the aggregate demand shock. Here output contracts for all regions and significantly so even in the longer term. With respect to the size of the estimated effects, spillovers of all three shocks are very similar to responses in the USA itself. Only in CESEE and the CIS, effects are stronger than in the country of shock-origin (about twice as high).

Responses of total credit are shown in Fig. 5. Loan supply shocks in the USA carry over internationally: Credit declines in other advanced economies and in CESEE (up to and beyond 20 quarters) and the CIS in the medium- to long-run. Similar to the euro area loan supply shock, total credit in Asia increases, however, in the medium- and long-run, and these responses are accompanied by particularly wide confidence bounds. Also for the loan demand shock, responses differ mostly with respect to the persistence and not the direction of the effects. Again, total credit decreases significantly in other advanced economies, CESEE and the CIS in the medium- to long-run, while in Latin America effects are more short-lived (from quarter 2 to quarter 10). Last, responses to the aggregate demand shock are depicted in the bottom panel of Fig. 5. Here, total credit contracts significantly in CESEE, the CIS and Latin America (up to and beyond 20 quarters), while significant short-run effects are visible in Asia (from quarter two to quarter six) and in other advanced economies (from quarter one to quarter eight).

Summing up, we find significant negative responses of real output and total credit to all three shocks and for most regions. A partial exception to this are emerging Asia and Latin America where we found only short-run significant effects in case of loan shocks, namely on output in Asia for loan demand shocks and in Latin America for both loan shocks and on total credit for loan demand shocks in Latin America. Similar to domestic effects and the international effects of euro area shocks, international responses of total credit are of a higher order of magnitude than those of output. Comparing the long-run response in the country of shock origin (the USA) with the long-run spillover effect in each region, the size of long-run effects on output in other advanced economies, Latin America and Asia tends to

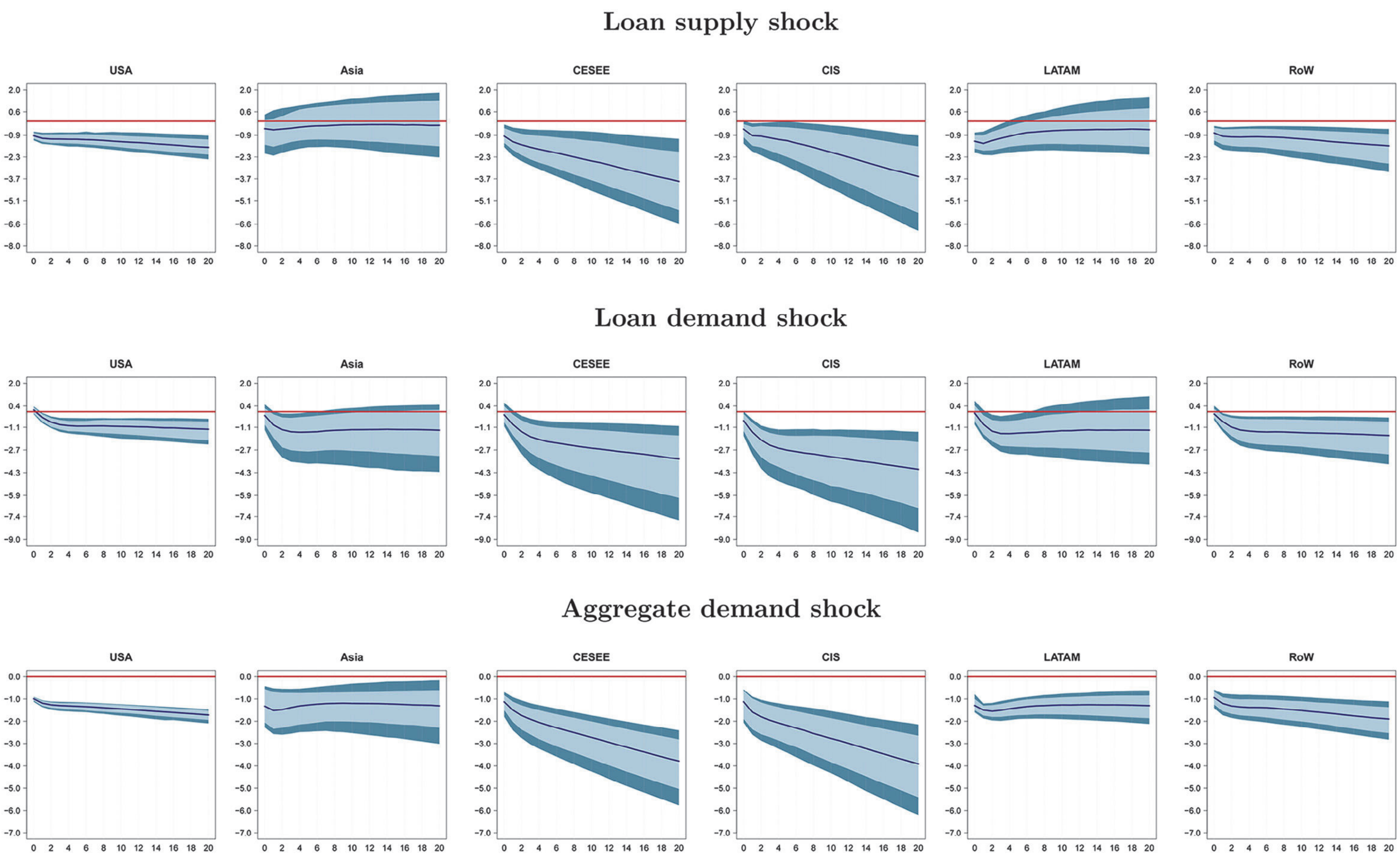


Fig. 4. Responses of real GDP (shock origin: USA).
Notes: The figure shows impulse responses of real GDP to loan supply, loan demand and aggregate demand shocks in the USA. Median responses in dark blue (solid line), 50% bootstrap confidence bounds light blue shaded area, 68% bounds dark blue shaded area. Responses of advanced economies (RoW) are excluding the USA for which responses are shown separately. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

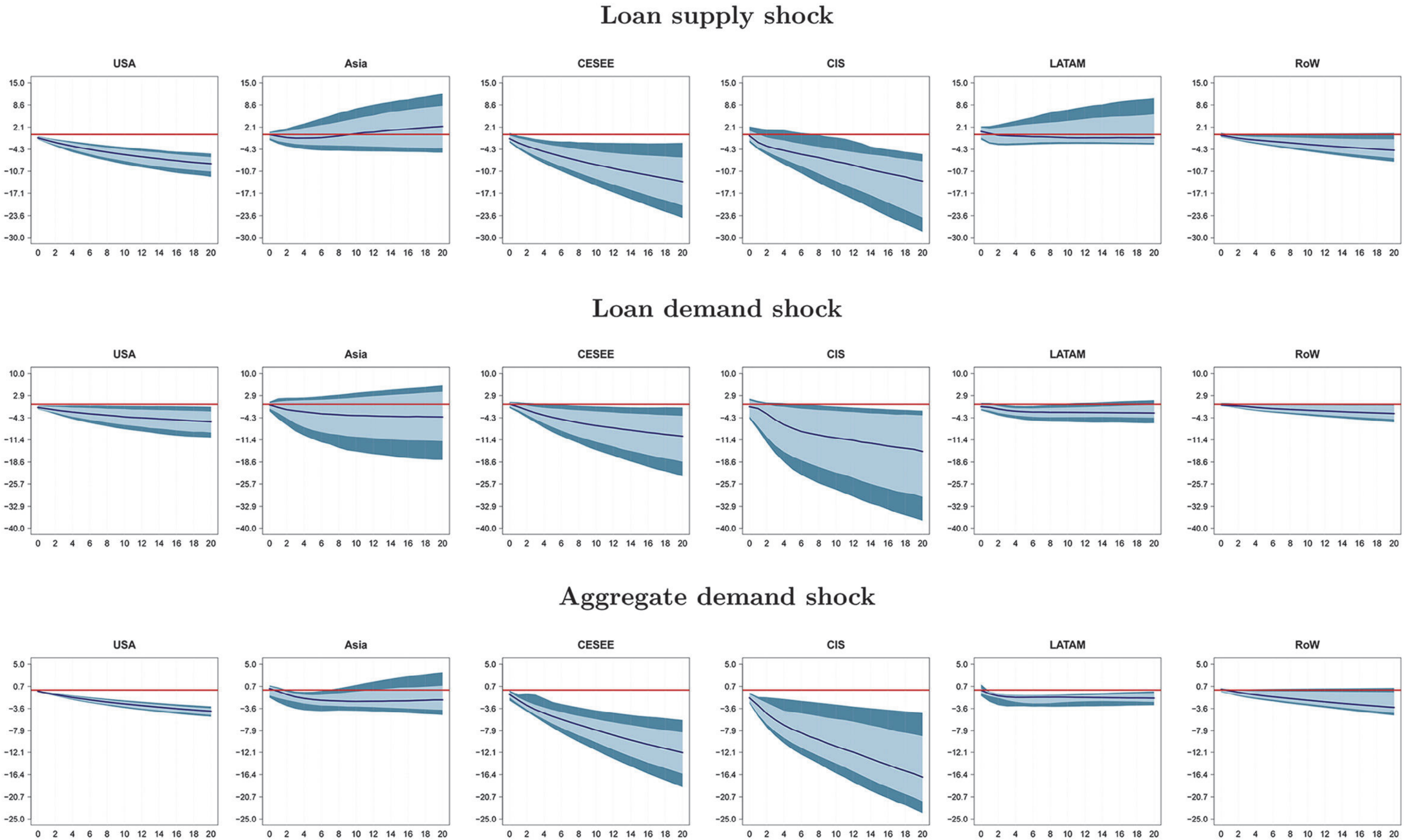


Fig. 5. Responses of total credit (shock origin: USA).

Notes: The figure shows impulse responses of real GDP to loan supply, loan demand and aggregate demand shocks in the USA. Median responses in dark blue (solid line), 50% bootstrap confidence bounds light blue shaded area, 68% bounds dark blue shaded area. Responses of advanced economies (RoW) are excluding the USA for which responses are shown separately. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

be similar to domestic effects in the USA. Total credit declines comparably less in these regions than in the USA. This is different for CESEE and CIS economies. Here, output declines twice as much as in the USA and – depending on the shock – total credit by 2 to 4 times the US contraction.

5.4. Did foreign shocks matter historically for emerging Europe?

In this section we complement the structural impulse response analysis carried out in the previous sections by examining historical decomposition. More specifically, we examine the contribution of shocks originating in the euro area and the USA in explaining deviations from trend growth in CESEE and CIS output and total credit. We focus on these particular regions since impulse response analysis has shown that both regions respond most strongly to foreign shocks. To construct a historical decomposition analysis we follow Luetkepohl (2011) and Burbidge and Harrison (1985). The left (right) panel of Fig. 6 shows the contribution of the three structural shocks originating in the euro area and the USA to CESEE (CIS) real output and total credit.

Results for both regions tend to be very similar and the following general facts emerge from the data. First, the loan supply shock tends to show historically a negative contribution to real GDP and total credit. An exception to this is the period around 2008, when the US Fed cut interest rates aggressively. With the manifestation of the global financial crisis, the contribution of the shock has become increasingly negative. Moreover, US shocks account for a larger share of deviations from trend growth than euro area shocks. This underscores the dominant role of the US economy in shaping the global economy. Contributions of the loan demand shock show a very similar pattern: Contributions of US shocks are higher and mostly negative throughout the sample period. However, the housing boom in the USA (2002 to 2005) seems to have positively contributed to real activity and total credit (see, e.g., Mian and Sufi, 2009, for more details on the rapid mortgage credit expansion in the USA in the early 2000s). Last, aggregate demand shocks contributed mostly negatively to deviations from trend growth and this negative contribution peaked during the global financial crisis. The stronger recovery of the USA compared to the euro area experience is mirrored in positive contributions to both real GDP and total credit in the aftermath of the crisis.

Summing up, we find that the contribution of US shocks tend to exceed the corresponding euro area contribution in explaining deviations from trend growth in output and total credit. Prior to the global financial crisis, the rapid credit expansion in the USA shows a positive contribution to deviations in output and total credit growth in CESEE and CIS economies. With the outbreak of the global financial crisis, this trend has reversed and contributions of credit-related shocks have become increasingly negative. Finally, in the aftermath of the global financial crisis, when the US economy was growing more strongly than the euro area, shocks to US aggregate demand contributed positively to real activity and credit growth in both regions.

5.5. How important are knock-on effects?

Last, we investigate the cross-country angle of the international transmission of the shocks in more depth. More specifically, we examine to what proportion a spillover effect can be traced back to the direct economic and financial linkages between the receiving and the shock-originating country compared to indirect "knock-on" effects via third countries. Depending on the transmission channel of the shock, the relative importance of direct versus indirect effects might change. To this end, we start a series of counterfactual analysis in the spirit of Cesa-Bianchi (2013) by manipulating the weight matrix in the second step of the GVAR layer. That is, for a particular region, we set the bilateral weights to the country of shock-origin to zero,[12] "shutting off" direct spillover effects from the euro area and USA respectively. This is done for each region separately. The resulting responses can be interpreted as the proportion of the spillovers that is caused by indirect effects through other economies besides the country

[12] We do not re-distribute the weights that are set to zero to other economies yielding a weight matrix with row sums smaller than unity. This modification should not have any effects on the overall stability of the model (as opposed of having row sums of the weight matrix exceeding unity).

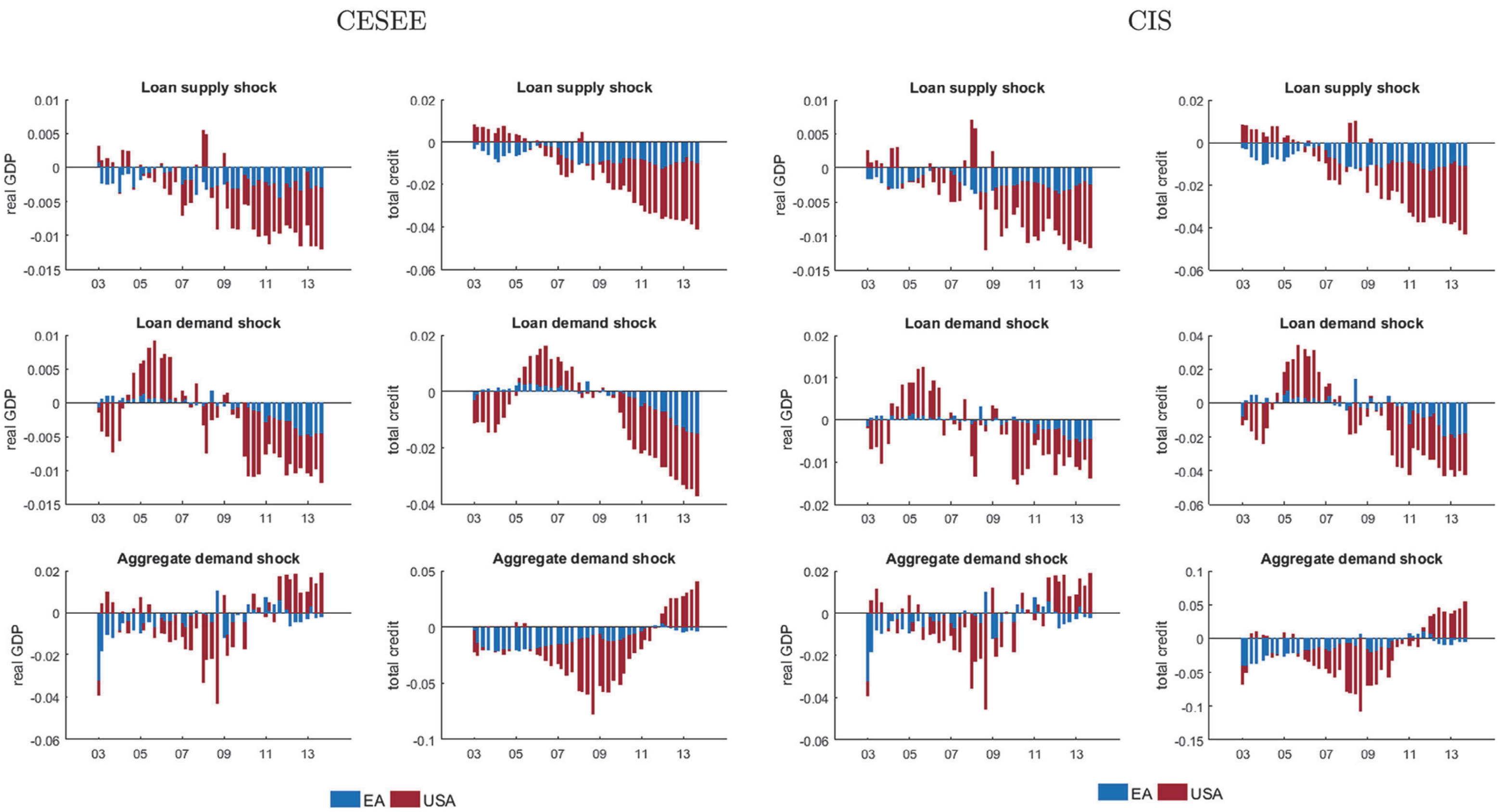


Fig. 6. Historical decomposition of real GDP and total credit in CESEE and the CIS.
Notes: The graphs show simple regional averages of the shocks' contribution in explaining deviations from trend growth (in quarter-on-quarter terms) in real GDP and total credit.

of shock-origin. Figs. 7 and 8 show the ratio of the indirect effect to the total effect (on the x-axis) in % versus the total effect (on the y-axis) after 20 quarters as previously shown in Figs. 2 to 5. The four quadrants of the plot correspond to countries with small total effects and low exposure to indirect effects (top-left), small total effects mainly through knock-on effects (top-right), strong total effects through mainly direct effects (bottom-left) and strong total effects mainly through knock-on effects (bottom-right).[13]

Fig. 7 shows the results for the euro area shocks. The most interesting quadrants are the bottom ones, showing how important second-round effects are for those countries that show most pronounced total responses to the euro area shock. For all three shocks and for both variables, countries that show a strong response brought about by pronounced direct exposure to the euro area are foremost CESEE and CIS economies, and to a lesser extent other advanced European economies such as Denmark and Sweden. Shutting-off the direct transmission channel to the euro area reduces the long-run effect on output and total credit by about 60% to 70% emphasizing the importance of the euro area for these economies. Countries that show pronounced total responses but are to a lesser degree directly exposed to the euro area are the Baltics, Russia and highly open economies such as Malaysia and Singapore (bottom-right quadrant of Fig. 7). The Baltics are among the countries that show the most total pronounced response – effects on other less open economies, such as Poland, or more advanced economies are comparably more modest. The fact that the total effects in the Baltic countries result mainly from indirect effects may point to the role of non-euro area neighboring countries like Sweden, Poland and Russia as shock-transmitters. Within the CIS region, Russia is the most integrated country with the world economy, which is why knock-on effects play a comparably stronger role for the economy than for its peers from the region. Through these links, Russia might serve as a "gatekeeper" relaying global shocks to the region even if the individual CIS countries themselves are only modestly exposed to the country of shock-origin. For most countries that show muted responses, naturally, indirect effects seem to play a stronger role (top-right quadrant of Fig. 7). This implies that most of the modest response is triggered by knock-on effects, while the direct exposure to the euro area plays a minor role for shock transmission. There are only a few countries that show on the one hand a strong exposure to the euro area and on the other hand only modest overall responses.

Next, we assess indirect effects, if the shock originates in the USA, in Fig. 8.

From the discussion in the previous section, we expect strong responses for CESEE and CIS economies. These should be to a lesser extent driven by direct links (to the USA) as responses to the euro area shock. Indeed, we find both CESEE and CIS countries featuring frequently in the bottom right quadrant of the plots in Fig. 8. Countries that are also strongly affected but spillovers are more direct in nature comprise Asian countries, such as Indonesia, Malaysia and Singapore. Other countries for which indirect effects play a minor role comprise important trading partners of the USA, such as the UK, and Asian countries (top left panel). It is worth noting that the total effects of US shocks on Latin American countries are relatively moderate. This may be explained partly by the increased diversification of this region's foreign trade and financing.

Last, we investigate whether indirect effects in general play a more important role for shock transmission to real output compared to total credit. Here, the mean and the median of the ratio of indirect to total effects are about of the same size, regardless from where the shock originates, indicating no different patterns in shock transmission for the two variables under scrutiny.

Summing up, we find in general most pronounced spillover effects on both real GDP and total credit for CESEE and CIS economies. Strong spillovers from euro area shocks can be accounted for by the high degree of economic and financial integration between these regions. Integration with the euro area, however, renders CESEE and CIS economies also more vulnerable to third-country shocks, such as disturbances to US shocks. Similarly, Russia, which is strongly integrated with the global economy mainly via the commodity channel, likely passes on external shocks to other CIS economies.

[13] In a few exceptional cases, when direct effects are very small, the ratio reaches even levels above 100% – this may be explained by the fact that for both total effects and indirect effects the median of 200 bootstrap draws is taken.

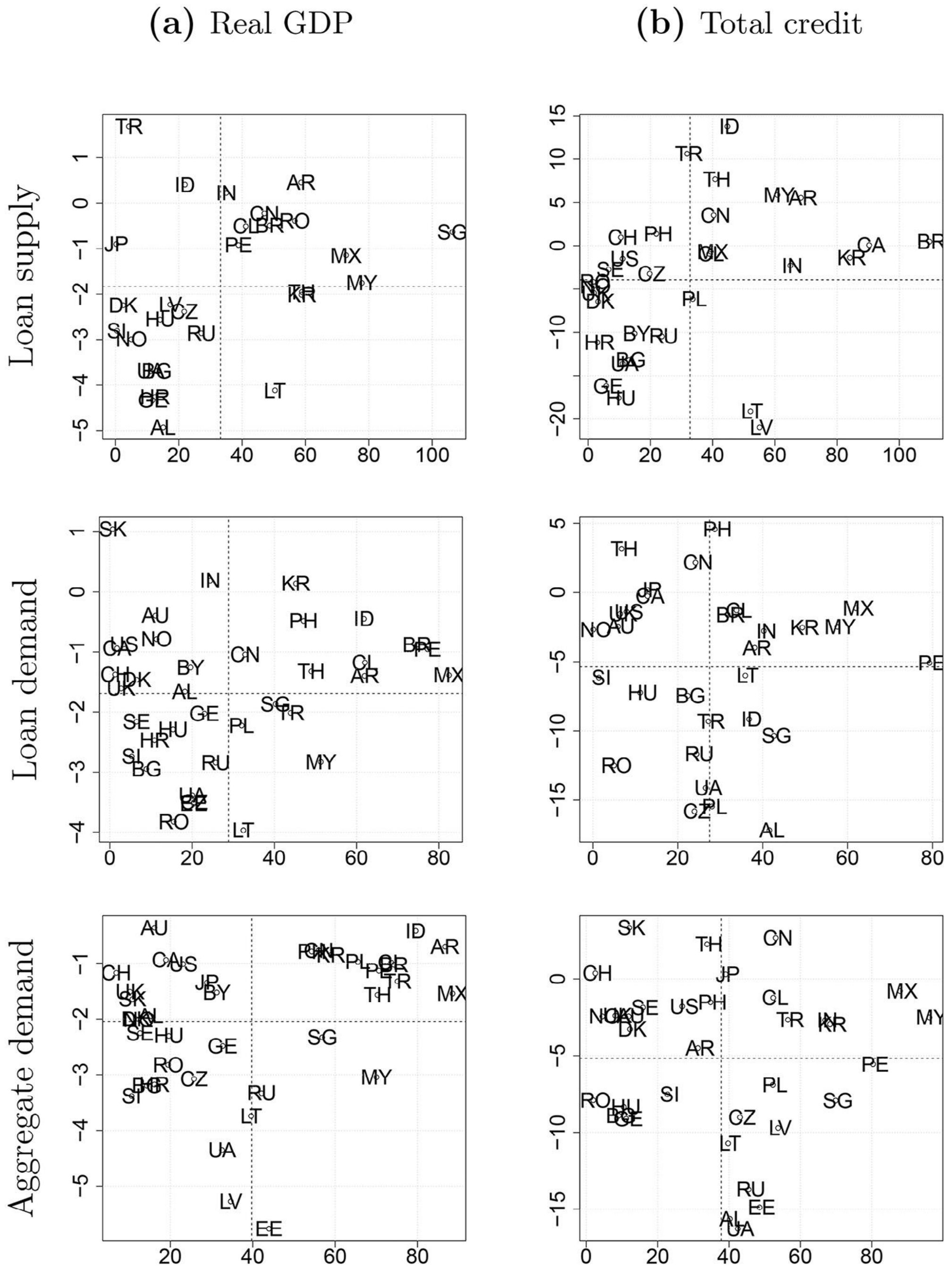


Fig. 7. Ratio of indirect to total effect after $t = 20$ quarters (shock-origin: euro area).
Notes: The scatterplots show the ratio of the indirect to total effect for real GDP and total credit on the x-axis in % and the total effect on the y-axis (as shown in Figs. 2 and 3). The indirect effect is calculated using a weight matrix that sets the trade weights to the country of shock origin (euro area) to zero. Ratios close to zero indicate the importance of direct trade links to the euro area, while large values show that knock-on effects via third countries account for most of the total effect on real GDP and total credit. Responses that switch signs or are larger than 1.5 the interquartile range of the cross-country distribution have been excluded from the plot.

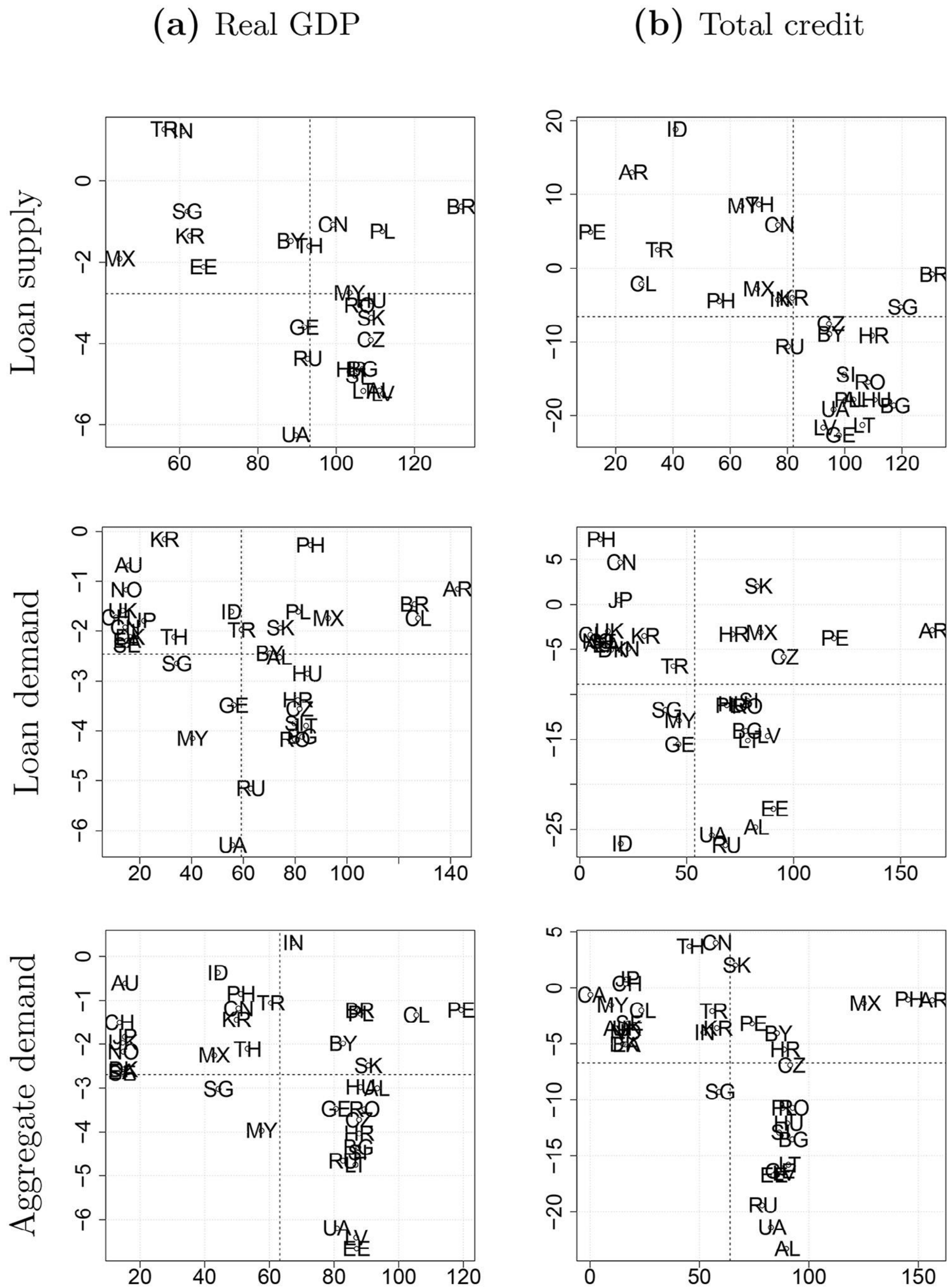


Fig. 8. Ratio of indirect to total effect after $t = 20$ quarters (shock-origin: USA).

Notes: The scatterplots show the ratio of the indirect to total effect for real GDP and total credit on the x-axis in % and the total effect on the y-axis (as shown in Figs. 4 and 5). The indirect effect is calculated using a weight matrix that sets the trade weights to the country of shock origin (USA) to zero. Ratios close to zero indicate the importance of direct trade links to the USA, while large values show that knock-on effects via third countries account for most of the total effect on real GDP and total credit. Responses that switch signs or are larger than 1.5 the interquartile range of the cross-country distribution have been excluded from the plot.

6. Conclusions

In this paper, we use a global VAR model to analyze international spillovers of adverse euro area loan supply and demand shocks. To put our results into perspective and against the backdrop of heightened spillovers during times of financial distress, as witnessed during the global financial crisis, we furthermore analyze the consequences of a negative aggregate demand shock and whether the country of shock-origin is the USA.

Our general results are as follows: First, credit-related shocks trigger a pronounced domestic reaction of total credit which corroborates findings of Gambetti and Musso (2012) and Hristov et al. (2012) for the euro area, and Meeks (2012) and Bassett et al. (2014) for the USA. Domestic credit contractions in the euro area and the USA do only partially cause significant reductions in international output or total credit. More specifically, with respect to the types of shocks considered in this study, global negative effects on output are significant for all regions (in Asia partly in the short-term only) following a loan demand or aggregate demand shock in the euro area or the USA. By contrast, negative output effects of loan supply shocks are significant for all regions except for Latin America (in the medium- to long-run) and for Asia if these shocks emanate from the USA, and are fraught with estimation uncertainty if these are euro area shocks. Second, effects from US shocks induce negative spillovers on total credit with a wider global coverage than the respective euro area shocks. We also find a tendency of US shocks triggering comparably stronger international effects in the short-run. These findings thus generalize results provided in Eickmeier and Ng (2015) and emphasize the importance of the US economy in shaping global economic and financial conditions. Last, similar to domestic effects, international responses on total credit are an order of magnitude larger than those on output, with again more evidence that is significant for US than euro area shocks.

Second and taking a regional stance, real GDP and total credit contractions are most pronounced in the CESEE region (including the Baltic countries) and among CIS economies. The high degree of economic and financial integration with the euro area triggers long-run responses that are even higher than in the euro area itself. These ratios of international to domestic responses (depending on the type of shock and country of shock-origin) range from one to three for real GDP and two to four for total credit. This may be explained partly by structural features, but also by the particularly pronounced boom-bust-cycle during a large part of the time period under study. CESEE and CIS economies also respond significantly to US shocks, which emphasizes the general exposure of these regions to external macrofinancial shocks (Feldkircher, 2015). A more systematic examination of cross-country knock-on effects reveals a significant role for the euro area, not only as a country of shock-origin, but also by passing on third-country shocks, such as US shocks, to the CESEE and CIS economies. In particular the finding that US, but not euro area, loan supply shocks have a significant output effect on CESEE and CIS may be related to the fact that they have both an immediately significant domestic output effect and a significant effect on other advanced economies including the euro area. Moreover, the transmission of euro area loan supply shocks to CESEE and CIS in the period under study may have been dampened by the generally greater stability of parent bank funding than wholesale funding (Lahnsteiner, 2011) – a stability that was enhanced by the Vienna Initiative in 2009–2010 for several CESEE countries.[14] By contrast, US loan supply shocks have a significant impact on the global wholesale funding market and thus both on the refinancing of euro area banks operating in CESEE and CIS and on the direct cross-border financing of banks and companies in these two regions.

Last, foreign shocks played also historically an important role for CESEE and CIS economies in explaining deviations from trend in real GDP and total credit growth. The loan supply shock contributed positively to movements in output and total credit in 2008 when the US Fed slashed interest rates to fight the recession. Contributions of the loan demand shock have been positive during the period from 2004 to 2007, in which mortgage credit in the USA expanded markedly (Mian and Sufi, 2009). With the outbreak of the global financial crisis, the contribution of credit-related shocks turned negative until the end of our sample period. This pattern holds equally true for CESEE and CIS economies. In general contributions of euro area

[14] For more details see http://vienna-initiative.com/.

shocks are smaller than their US counterparts. Contributions of aggregate demand shocks show a somewhat different pattern. Here, contributions are mostly negative and peak during the global financial crisis. In the aftermath of the crisis, shocks to US aggregate demand contribute positively to output and credit growth in both regions, while contributions of euro area shocks are slightly negative. This might mirror the faster recovery in the USA compared to still modest growth in the euro area.

Appendix A

Table A1
Specification of the country models.

Countries	Domestic variables	Foreign variables	DC	CR	Outlying observations
EA	$y, \Delta p, e, tc, i_s, lr/i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	
US	$y, \Delta p, tc, i_s, lr/i_l, poil$	$y^*, \Delta p^*, e^*$	5*	1	
UK	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	
JP	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	e_{98q4}
CN	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	tc_{01q1}, $i_{s,96q1:q2,08q4}$
CZ	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	$tc_{00q3:02q3}$, $i_{s,97q2:98q4}$
HU	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	
PL	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	$e_{08q4:09q1}$, $y_{96q4,98q4}$, $i_{s,97q1:98q2}$
SI	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	$tc_{00q1:q2,01q1:q2,02q1:2}$, $i_{s,96q2}$
SK	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	tc_{97q1}, $y_{98q4,07q4,09q1}$, $i_{s,97q1}$
BG	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	tc_{97q4}, $y_{95q4:q4,99q4}$
RO	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	e_{97q1}, $y_{96q1:q4}$, $i_{s,97q1}$, $\Delta p_{96q3,97q1:q2}$
EE	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	y_{08q4}, $i_{s,97q3:q4,98q4,99q2}$
LT	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	y_{09q1}
LV	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	$tc_{96q4:96q3}$, $i_{s,09q2}$, Δp_{95q4}
HR	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	
AL	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$y_{96q:99q4}$, $i_{s,97q2,98q3}$, $\Delta p_{96q3,97q3}$, $tc_{97q1,00q3,01q3}$
RU	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	$i_{s96q2:q3}$, $\Delta p_{95q4,96q1}$, $tc_{96q3,97q3:99q2}$
UA	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	e_{98q4}, $\Delta p_{95q4,96q1}$, $tc_{98q3:q4}$
BY	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$e_{99q3:q4}$, $\Delta p_{95q4,96q1}$, $i_{s,96q1}$
GE	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	e_{99q1}, tc_{96q1}, $i_{s,96q2,98q4}$
AR	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$e_{95q1:02q4}$, $tc_{01q1:q4}$, $i_{s,01q3:02q3}$
BR	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	2	$i_{s,97q4:98q1,98q4:99q1,99q3:q4}$, y_{95q4}, $e_{95q1:98q4}$
CL	$y, \Delta p, e$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	
MX	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	
PE	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$i_{s,98q3}$
KR	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*$	3	2	$y_{97q1:98q4}$, $i_{s,97q4,98q1}$, $tc_{97q4:98q3}$
PH	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$i_{s,95q3,97q3:q4,00q4}$, $\Delta p_{99q2,00q1}$, tc_{01q4}
SG	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	
TH	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$i_{s,96q1:q2,97q3:99q4}$, $y_{11q4,12q4}$, $e_{95q1:97q2,97q4,98q1,98q4}$
IN	$y, \Delta p, e, tc$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$\Delta p_{98q1,99q1}$
ID	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$i_{s,97q3}$, $y_{95q1:97q4}$, $e_{98q1:98q3}$, tc_{99q2}
MY	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	4	1	$i_{s,97q2,97q4,98q1,98q4,99q2}$, $\Delta p_{08q4,09q1,09q4}$, $e_{95q1:97q3}$
AU	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	1	$i_{s,08q4}$, Δp_{00q3}, e_{08q4}
NZ	$y, \Delta p, e, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$i_{s,08q4}$, Δp_{00q3}, e_{08q5}
TR	$y, \Delta p, e, tc, i_s$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	
CA	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	5*	2	
CH	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	
NO	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$i_{s,98q3:q4,99q1}$
SE	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	
DK	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	Δp_{07q4}
IS	$y, \Delta p, e, tc, i_s, i_l$	$y^*, \Delta p^*, tc^*, i_s^*, i_l^*, poil^{**}$	3	1	$i_{s,01q1,02q1}$, tc_{08q4}

Notes: The table represents the general specification and variable cross-country variable coverage of our GVAR model. Throughout the paper we have used 1 lag for endogenous, weakly exogenous and strictly exogenous variables only. Deterministic components (DC): 3-intercept, 4-intercept and trend 5*-intercept and structural break dummy for the period 2009Q1–2013Q4. CR denotes the cointegration rank. Based on a residual analysis we have smoothed outlying observations provided in the last column of the table.

References

Backé, P., Feldkircher, M., Slačík, T., 2013. Economic spillovers from the Euro area to the CESEE region via the financial channel: a GVAR approach. Focus Eur. Econ. Integr. (4), 50–64.
Bassett, W.F., Chosak, M.B., Driscoll, J.C., Zakrajšek, E., 2014. Changes in bank lending standards and the macroeconomy. J. Monet. Econ. 62 (C), 23–40.
Burbidge, J., Harrison, A., 1985. An historical decomposition of the great depression to determine the role of money. J. Monet. Econ. 16 (1), 45–54.
Busch, U., Scharnagl, M., Scheithauer, J., 2010. Loan supply in Germany during the financial crisis. Discussion Paper Series 1: Economic Studies 05/2010, Deutsche Bundesbank.
Calani, M.C., Garca, P.S., Oda, D.Z., 2010. Supply and demand identification in the credit market. Central Bank of Chile, Working Paper Series (571).
Canova, F., Paustian, M., 2011. Business cycle measurement with some theory. J. Monet. Econ. 58 (4), 345–361.
Castrén, O., Dées, S., Zaher, F., 2010. Stress-testing euro area corporate default probabilities using a global macroeconomic model. J. Financ. Stabil. 6 (2), 64–78.
Cesa-Bianchi, A., 2013. Housing cycles and macroeconomic fluctuations: a global perspective. J. Int. Money. Finance 37 (C), 215–238.
Chudik, A., Fratzscher, M., 2011. Identifying the global transmission of the 2007–2009 financial crisis in a GVAR model. Eur. Econ. Rev. 55 (3), 325–339.
Chudik, A., Pesaran, M.H., 2016. Theory and practice of GVAR modelling. J. Econ. Surv. 30 (1), 165–197.
Ciccarelli, M., Peydró, J.-L., Maddaloni, A., 2010. Trusting the bankers: a new look at the credit channel of monetary policy. Working Paper Series 1228, European Central Bank.
Crespo Cuaresma, J., Feldkircher, M., Huber, F., 2016. Forecasting with global vector autoregressive models: a bayesian approach. J. Appl. Econometr. forthcoming.
Dees, S., Holly, S., Pesaran, H.M., Smith, V.L., 2007a. Long run macroeconomic relations in the global economy. Economics 1 (3), 1–20.
Dees, S., di Mauro, F., Pesaran, H.M., Smith, L.V., 2007b. Exploring the international linkages of the euro area: a global VAR analysis. J. Appl. Econometr. 22 (1), 1–38.
Dovern, J., van Roye, B., 2014. International transmission and business-cycle effects of financial stress. J. Financ. Stabil. 13, 1–17.
Dovern, J., Feldkircher, M., Huber, F., 2015. Does joint modelling of the world economy pay off? Evaluating global forecasts from a Bayesian GVAR. Working Papers 200, Oesterreichische Nationalbank (Austrian Central Bank).
Eickmeier, S., Ng, T., 2015. How do credit supply shocks propagate internationally? A GVAR approach. Eur. Econ. Rev. 74 (C), 128–145.
Feldkircher, M., 2015. A global macro model for emerging Europe. J. Comp. Econ. 43 (3), 706–726.
Feldkircher, M., Huber, F., 2016. The international transmission of US shocks – evidence from Bayesian global vector autoregressions. Eur. Econ. Rev. 81, 167–188. Model Uncertainty in Economics.
Fornari, F., Stracca, L., 2012. What does a financial shock do? First international evidence. Econ. Policy 27 (71), 407–445.
Fratzscher, M., Saborowski, C., Straub, R., 2009. Monetary policy shocks and portfolio choice. Working Paper Series 1122, European Central Bank.
Fry, R., Pagan, A., 2011. Sign restrictions in structural vector autoregressions: a critical review. J. Econ. Lit. 49 (4), 938–960.
Galesi, A., Lombardi, M.J., 2013. External shocks and international inflation linkages. In: di Mauro, F., Hashem Pesaran, M. (Eds.), The GVAR Handbook: Structure and Applications of a Macro Model of the Global Economy for Policy Analysis. Oxford University Press, Oxford, pp. 255–270. (chapter).
Gambetti, L., Musso, A., 2012. Loan supply shocks and the business cycle. Technical Report 1469, ECB Working Paper Series.
Garratt, A., Lee, K., Pesaran, M.H., Shin, Y., 2006. Global and National Macroeconometric Modelling: A Long-Run Structural Approach. Oxford University Press, Oxford.
Helbling, T., Huidrom, R., Kose, M.A., Otrok, C., 2011. Do credit shocks matter? A global perspective. Eur. Econ. Rev. 55 (3), 340–353.
Hristov, N., Hülsewig, O., Wollmershäuser, T., 2012. Loan supply shocks during the financial crisis: evidence for the euro area. J. Int. Money. Finance 31 (3), 569–592.
Lahnsteiner, M., 2011. The refinancing structure of banks in selected CESEE countries. Focus Eur. Econ. Integr. Q1/11, 44–69.
Lown, C., Morgan, D.P., 2006. The credit cycle and the business cycle: new findings using the loan officer opinion survey. J. Money Credit Bank. 38 (6), 1575–1597.
Luetkepohl, H., 2011. Vector autoregressive models. Economics Working Papers ECO2011/30, European University Institute.
Meeks, R., 2012. Do credit market shocks drive output fluctuations? Evidence from corporate spreads and defaults. J. Econ. Dyn. Control 36 (4), 568–584.
Mian, A., Sufi, A., 2009. The consequences of mortgage credit expansion: evidence from the U.S. mortgage default crisis. Q. J. Econ. 124 (4), 1449–1496.
Paustian, M., 2007. Assessing sign restrictions. B. E. J. Macroecon. 7 (1), 1–33.
Peek, J., Rosengren, E.S., Tootell, G.M.B., 2003. Identifying the macroeconomic effect of loan supply shocks. J. Money Credit Bank. 35 (6), 931–946.
Pesaran, M.H., Schuermann, T., Weiner, S.M., 2004. Modeling regional interdependencies using a global error-correcting macroeconometric model. J. Bus. Econ. Stat. 22, 129–162. American Statistical Association.
Pesaran, M.H., Schuermann, T., Smith, L.V., 2007. What if the UK or Sweden had joined the euro in 1999? An empirical evaluation using a Global VAR. Int. J. Financ. Econ. 12 (1), 55–87.
Pesaran, M.H., Schuermann, T., Smith, L.V., 2009. Forecasting economic and financial variables with global VARs. Int. J. Forecast. 25 (4), 642–675.
Rubio-Ramírez, J.F., Waggoner, D.F., Zha, T., 2010. Structural vector autoregressions: theory of identification and algorithms for inference. Rev. Econ. Stud. 77 (2), 665–696.
Smith, L.V., Galesi, A., 2014. GVAR toolbox 2.0. Technical Report, Toolbox <https://sites.google.com/site/gvarmodelling/home> (accessed 19.08.16.).

Appendix 2

II

Benecká, S., Fadejeva, L., and Feldkircher, M. (2020). The impact of Euro area monetary policy on Central and Eastern Europe. *Journal of Policy Modeling*, 42(6):1310–1333. DOI 10.1016/j.jpolmod.2020.05

Available online at www.sciencedirect.com

ScienceDirect

Journal of Policy Modeling 42 (2020) 1310–1333

Journal of Policy Modeling

www.elsevier.com/locate/jpm

The impact of euro Area monetary policy on Central and Eastern Europe

Soňa Benecká[a], Ludmila Fadejeva[b,*], Martin Feldkircher[c]

[a] Czech National Bank, Czech Republic
[b] Latvijas Banka Proofs, Latvijas Banka, 2a.Kr.Valdemara Street, Riga, LV-1050, Latvia
[c] Oesterreichische Nationalbank, Austria

Received 22 December 2019; received in revised form 7 April 2020; accepted 22 May 2020
Available online 29 June 2020

Abstract

This paper investigates the effects of a euro area monetary policy shock on Central, Eastern, and South-eastern Europe (CESEE). We use shadow rates as a proxy for the monetary policy stance and propose a novel way of treating euro area countries in a multi-country framework. More specifically, our approach allows to place sign restrictions on both euro area aggregate and single member states' quantities. This procedure fully takes cross-country heterogeneity within the euro area into account and leads to shocks that are economically consistent between both layers of aggregation. Our results show that prices and output fall in response to the euro area monetary tightening, both within the euro area and the CESEE region but to a varying degree. The revealed cross-country heterogeneity in the size of the effects emphasizes the usefulness and importance of our empirical approach.
© 2020 Published by Elsevier Inc. on behalf of The Society for Policy Modeling.

JEL classification: C32; F44; E32; O54

Keywords: Euro area monetary policy; Global vector autoregression, spillovers

* Corresponding author.
E-mail addresses: sona.benecka@cnb.cz (S. Benecká), ludmila.fadejeva@bank.lv (L. Fadejeva), martin.feldkircher@oenb.at (M. Feldkircher).

https://doi.org/10.1016/j.jpolmod.2020.05.004
0161-8938/© 2020 Published by Elsevier Inc. on behalf of The Society for Policy Modeling.

1. Introduction

In the wake of the 2008/09 global financial crisis, major central banks cut their policy rates to stimulate economic growth and consumer price inflation. As the room for conventional monetary policy quickly eroded, other non-standard/unconventional forms of monetary policy were implemented. It is obvious that monetary easing in advanced economies has the potential to affect the economies in neighboring countries. Indeed, there has been a broad discussion about the possible negative effects of the unconventional monetary policy of the ECB and the Fed on small open economies after the introduction of such measures. Monetary policy easing in the advanced economies may have stimulated significant capital inflows and exchange rate appreciation, thereby threatening external competitiveness. In addition, some of these flows could have fueled credit and asset price booms, amplifying financial fragilities. Cheap external funding also has an impact on exposures to foreign currency-denominated debt on domestic balance sheets. These effects can also spill-back to the country of origin, which can lead major central banks to augment their policy functions to include global variables or other factors that account for potential feedback loops.

Empirically, these issues can be addressed in a multi-country model that is able to take into account the economic links between the countries of interest. As such, the global vector autoregressive (GVAR) model proposed by Hashem M. Pesaran and co-authors (Garrat, Lee, Pesaran, & Shin, 2006; Pesaran, Schuermann, & Weiner, 2004) has been widely used in the literature (Chudik & Pesaran, 2016). It provides a coherent way to model contemporaneously a set of countries taking into account their interactions through trade and financial linkages. The early literature using multi-country models and euro area monetary policy made the simplifying assumption of complete homogeneity of effects on euro area countries using aggregate data (see e.g., Dees, di Mauro, Pesaran, & Smith, 2007). Several recent studies have pointed out that both conventional and unconventional monetary policy affects euro area countries differently, though. For example, Cavallo and Ribba (2015) and Dominguez-Torres and Hierro (2020) use a near VAR and find that effects vary significantly between different monetary clusters within the euro area. Dominguez-Torres and Hierro (2020) also note that differences arise depending on the type of instruments used, with more common effects for the period of quantitative easing and more heterogeneity prior to 2008. Huchet (2003) attribute the different response of euro area countries to common monetary policy shock to asymmetric responses to tightening and loosening. Georgiadis (2015) and Burriel and Galesi (2018) use the GVAR methodology and provide evidence for cross-country heterogeneity of responses to conventional (Georgiadis, 2015) and unconventional (Burriel & Galesi, 2018) monetary policy effects. Cross-country heterogeneity in their studies can be partially explained by differences in financial structures, labour market rigidities and industry specialization.

In this paper we propose a novel way of dealing with common monetary policy in a multi-country framework. We employ a GVAR model with two hierarchies of dis-aggregation for euro area countries. On the aggregated level, we select variables that are common to all euro are countries, namely a measure of monetary policy and the euro dollar exchange rate. To account for potential heterogeneity of the monetary policy effects we include macroeconomic data for each euro area member separately. We then propose a way that uses sign restrictions on both the common and the euro area specific variables and yield shocks that are consistent between both levels of aggregation. Using these euro area consistent shocks, we test for the existence of spillovers to neighboring countries, especially to those from the CESEE region. We also examine whether these consistent shocks transmit either through direct (trade and financial) links to the euro area, or (trade and financial) exposure to third countries. Our results point to considerable regional heterogeneity both within the euro area and between neighboring countries. For the euro area, our analysis reveals clusters of countries that go beyond a simple core-periphery distinction. For CESEE economies, we find significant and negative output and price effects, with the latter being comparably weaker. This might be related to higher import prices after a depreciation of local currencies against the euro. Also, short-term interest rates in CESEE tend to fall implying that domestic policy makers try to compensate the spillover driven short-fall in output and prices.

The paper is structured as follows: the next section briefly reviews the relevant literature, section 3 introduces the global VAR model, the data and the model specification; section 4 presents a set of sign restrictions that we employ to separate aggregate supply shocks from aggregate demand shocks and the shock of interest - a shadow rate/monetary policy shock; section 5 illustrates the results and section 6 concludes.

2. Literature review: Monetary policy in the euro area and beyond

Since the global financial crisis, the bulk of the literature focuses on the quantification of the domestic effects of unconventional euro area monetary policy. These studies often use some sort of time series econometrics and differ in the way they capture unconventional monetary policy. Gambacorta, Hofmann, and Peersman (2014) and Boeckx, Dossche, and Peersman (2017) look at an exogenous increase in the ECB's balance sheet. Gambacorta et al. (2014) estimate a structural panel VAR for eight advanced euro area countries and find that a positive shock to the ECB's balance sheet raises economic activity and – to a lesser degree – prices in the euro area. Boeckx et al. (2017) using a structural VAR framework find that an expansionary balance sheet shock stimulates bank lending, reduces interest rate spreads, leads to a depreciation of the euro, and more generally has a positive impact on economic activity and inflation. Burriel and Galesi (2018) use a GVAR framework and a similar identification strategy as in Boeckx et al. (2017). In their analysis, an exogenous increase in the ECB's total assets triggers a significant rise in aggregate output and inflation and a depreciation of the effective exchange rate. A few studies look at spillovers from unconventional measures to emerging Europe.[1] Feldkircher, Gruber, and Huber (2020) specifically look at the effects of quantitative easing in the euro area measured as a flattening of the yield curve. They find that a decrease in the euro area term spread has persistent and positive effects on industrial production in the euro area itself and in neighboring economies and that the transmission works through both an exchange rate and a financial channel. Babecka Kucharcukova, Claeys, and Vasicek (2016) construct a synthetic monetary conditions index by using a dynamic factor model. In a second step they utilize the monetary condition index in a monetary VAR and show that effects are strong on euro area prices, while impacts on output are muted. Bluwstein and Canova (2016) use a Bayesian mixed-frequency structural VAR model and find positive effects on prices and output. The effects tend to be larger in countries with more advanced financial systems and a larger share of domestic banks. Moder (2019) employs two-country vector autoregressions to assess spillovers to Southeastern Europe, drawing on a an identification scheme which is similar to that of Boeckx et al. (2017) and Burriel and Galesi (2018). She finds significant positive price effects for all countries and output effects for half of the countries covered. Horváth and Voslá()̌rová (2016) use a panel vector autoregressive framework

[1] For recent assessments of spillovers from euro area conventional monetary policy shocks to CESEE, see Potjagailo (2017) and Cavallo and Ribba (2020).

to examine the reaction of macroeconomic variables in CESEE economies to both a shock to the shadow rate as a measure of unconventional policy (Wu & Xia, 2016) and an exogenous increase in central banks' assets. They find strong effects on output, while spillovers to prices are rather weak. Last, Hájek and Horváth (2018) examine spillovers from US and euro area shadow rate shocks. They find generally weaker spillovers to Southeastern EU economies compared to their peers from Central and Eastern Europe. Also, euro area monetary policy shocks turn out to cause stronger spillovers to CESEE relative to a US-based shock.

3. The GVAR model

The GVAR is a compact representation of the world economy designed to model multilateral dependencies among economies across the globe. In general, a GVAR model comprises *two layers* via which the model is able to capture cross-country spillovers. In the first layer, separate time series models – one per country – are estimated. In the second layer, the country models are stacked using bilateral weights that proxy economic ties between countries (e.g., trade weights). The resulting global representation of the model then can be used to assess the spatial propagation of a shock as well as the dynamics of the associated responses.

In our application, the first layer is composed of country-specific vector autoregressive (VAR) models, enlarged by a set of weakly exogenous variables (VARX model). Assuming that our global economy consists of N countries, we estimate a VARX of the following form for every country $i = 1, \ldots, N$:[2]

$$x_{it} = a_{i0} + \Phi_i x_{i,t-1} + \Lambda_{i0} x^*_{it} + \Lambda_{i1} x^*_{i,t-1} + \varepsilon_{it}. \tag{3.1}$$

Here, a_{i0} is a vector of intercepts, x_{it} is a $k_i \times 1$ vector of endogenous variables in country i at time $t \in 1, \ldots, T$, Φ_i denotes the $k_i \times k_i$ matrix of parameters associated with the lagged endogenous variables, and Λ_{ik} are the coefficient matrices of the k^*_i weakly exogenous variables, of dimension $k_i \times k^*_i$. Furthermore, $\varepsilon_{it} \sim N(0, \Sigma_i)$ is the standard vector error term.

The weakly exogenous or *foreign* variables, x^*_{it}, are constructed as a weighted average of their cross-country counterparts,

$$x^*_{it} := \sum_{j \neq i}^{N} \omega_{ij} x_{jt}, \tag{3.2}$$

where ω_{ij} denotes the weight corresponding to the pair of country i and country j. The weights ω_{ij} reflect economic and financial ties between economies, which are usually proxied using data on bilateral trade flows.[3] The assumption that the x^*_{it} variables are weakly exogenous at the individual level reflects the belief that most countries are small relative to the world economy.

There are different ways to introduce euro area country-specific and region-specific information within the GVAR framework. Georgiadis (2015) and Feldkircher et al. (2020), for example, use a mixed cross-section GVAR to account for the common monetary policy in the euro area. This implies to enlarge the set of countries by a further country model that determines euro area

[2] For simplicity, we use a first-order VARX model for the exposition. The generalization to longer lag structures is straightforward.

[3] See, for example, Eickmeier and Ng (2015) and Feldkircher and Huber (2016) for an application using a broad set of trade and financial weights.

monetary policy based on feedback of macro-data from the single member states. A monetary policy shock using sign restrictions can then be implemented by placing restrictions on statistics such as the average of the behavior of macroeconomic variables of the euro area single countries. Burriel and Galesi (2018) propose modeling euro area monetary policy using the mixed cross section approach in combination with common variables. The latter refer to euro area monetary policy variables. Importantly, in their framework, the common variable reacts contemporaneously to aggregated euro area variables such as output and prices.

In this paper, we draw on the work of Burriel and Galesi (2018) modeling euro area monetary policy through common variables and adequately placed sign restrictions on macroeconomic quantities of euro area single countries. The resulting shock will be consistent between the aggregated and disaggregated level. More specifically, we assume that the euro area policy rate (proxied by a shadow rate) and the exchange rate against the US dollar are c̆ommonv̆ariables for the euro area single countries and determined in a separate country model. The common variables are assumed to be driven by weighted euro area country-specific variables such as output, prices and long-term interest rates and enter the euro area country-specific VARX models contemporaneously and with lags.

To do so, we need some additional notation. Let us denote by i' the set of country specific models, and by i'' the common variable (regional) model with $i = \left(i', i''\right)$. The set of country-specific models can be divided further into euro area ($i^{'}_{EA}$) and non-euro area country models ($i^{'}_{Non-EA}$), where $i^{'}_{EA} = 1, .., N_{EA}$ and $i^{'}_{Non-EA} = 1, \ldots, N_{Non-EA}$.

Then, the euro area *common variables* follow the process

$$x_{i'',t} = a_{i''0} + \Phi_{i''} x_{i^{''},t-1} + \Lambda_{i''0} \hat{x}_{i',t} + \Lambda_{i''1} \hat{x}_{i',t-1} + \varepsilon_{i'',t} \tag{3.3}$$

where $x_{i'',t}$ denotes the $r \times 1$ vector of common euro area variables and $\hat{x}_{i',t}$ the aggregated euro area macroeconomic variables constructed using the euro area PPP-GDP weights $\hat{W}_{EA}$: $\hat{x}_{i',t} = \hat{W}_{EA} x_{i^{'}_{EA},t}$.

Following Chudik and Pesaran (2013) we further include oil prices as a *dominant unit* in our model

$$\iota_t = \mu_0 + \Phi_1 \iota_{t-1} + \Lambda_{\iota 1} \tilde{x}_{t-1} + \eta_t, \tag{3.4}$$

where ι is a dominant unit variable, and $\tilde{x}$ is a set of world feedback variables $\tilde{x}_t = \tilde{W} x_t$ constructed using the purchasing power parity (PPP)-GDP weights of all countries. The difference between a dominant unit and a common variable is given by the assumption about the timing of the effect: the dominant unit – such as oil prices – is assumed to react with a lag to aggregate developments in the world variables $\tilde{x}_{i,t}$. By contrast, common variables in the euro area are allowed to react immediately to movements in euro area member states' variables. This is justified by noting that relating the measure of the monetary policy stance to macroeconomic developments is equivalent with modeling the reaction function of the ECB and it is well-known that movements in the macroeconomic environment are contained in the information set of the national bank.

For a typical, non-dominant country model (3.1) the VARX specification looks like

$$A_i z_{it} = a_{i0} + B_i z_{it-1} + \Psi_0 \iota_t + \Psi_1 \iota_{t-1} + \varepsilon_{it},\ \varepsilon_{it} \sim \left(0,\ \Sigma_{i,\varepsilon}\right) \tag{3.5}$$

where $A_i := \left(I_{k_i},\ -\Lambda_{i0}\right)$, $B_i := (\Phi_i,\ \Lambda_{i1})$, and $z_{it} = \left(x_{it},\ x^{*}_{it}\right)$. By defining a suitable link matrix W_i of dimension $\left(k_i + k^{*}_i\right) \times k$, where $k = \sum_{i=1}^{N} k_i$, we can rewrite z_{it} as $z_{it} = W_i x_{it}$. The vector x_{it} contains all endogenous variables of the countries in our sample, both country specific models denoted with i' and common variable models denoted with i''. Note that this implies that the weakly exogenous variables are endogenous within the system of all equations. Substituting (3.5) in (3.1) and stacking the different local models leads to the global equation, which is given by

$$x_{it} = G^{-1}a_{i0} + G^{-1}Hx_{i,t-1} + G^{-1}\Psi_0\iota_t + G^{-1}\Psi_1\iota_{t-1} + G^{-1}\varepsilon_{it}, \tag{3.6}$$

where $G = (A_0W_0, \cdots, A_NW_W)'$, $H = (B_0W_0, \cdots, B_NW_W)'$, and a_{i0} contain the corresponding stacked vectors containing the parameter vectors of the country-specific specifications..

Assuming that the innovations ε_{it} and η_t are uncorrelated and defining the vectors $y_t = (x_{it}, \iota_t)$, $x_{it} = (x_{i't}, x_{i''t})$, equations (3.3), (3.4), (3.6) can be written as

$$y_t = H_0^{-1}h_0 + H_0^{-1}H_1y_{t-1} + H_0^{-1}\zeta_t = b_0 + \Gamma y_{t-1} + e_t \tag{3.7}$$

where

$$H_0 = \begin{bmatrix} G_0 & -\Psi_0 \\ 0 & I \end{bmatrix}, H_1 = \begin{bmatrix} H_1 & \Psi_1 \\ \Lambda_{\iota 1} & \Phi_1 \end{bmatrix}, h_0 = \begin{bmatrix} a_{i0} \\ \mu_0 \end{bmatrix}, \zeta_t = \begin{bmatrix} \varepsilon_{it} \\ \eta_t \end{bmatrix}.$$

To ensure stability of the model, the eigenvalues of the matrix $\Gamma = H_0^{-1}H_1$, which is of prime interest for forecasting and impulse response analysis, have to lie within the unit circle.

3.1. Data and weights specification

Our data set contains quarterly observations for 37 countries, including the 12 euro area countries that adopted the common currency prior to 2007 and 10 CESEE and Baltic countries. Together, we have 17 euro area member states. Table 1 presents the country coverage.

The sample features 64 quarterly observations and spans the period from 2001Q1 to 2016Q4. The *variables* used in our analysis comprise data on real activity (y), consumer prices (p), the real exchange rate (e), short-term interest rates (i_S) and long-term government bond yields (i_L), and oil prices ($poil$) (Pesaran, Schuermann, & Smith, 2009; Dees, di Mauro et al., 2007, b, Pesaran et al., 2004; Pesaran, Schuermann, & Smith, 2007). The variables used in the model are briefly described in Table 2. Most of the data are available with wide country coverage, with the exception of government bond yields. Since local capital markets in emerging economies (in particular in Eastern Europe) were still developing at the beginning of our sample period, data on long-term interest rates are hardly available for these countries.

Regarding monetary policy, we use *shadow interest rate* instead of short-term interest rates in the euro area, Japan, the United Kingdom and the USA (EA_{ls}, JP_{ls}, UK_{ls} and US_{ls}). In these economies, nominal interest rates reached the zero lower bound during our sample period and hence shadow interest rates are a better means of measuring the overall monetary policy stance.

Table 1
Country coverage.

Advanced Economies [adv] (3):	US, UK, JP
Euro Area 12 [euro] (12):	AT, BE, DE, ES, FI, FR, GR, IE, IT, LU, NL, PT
CESEE and Baltics [cee] (10):	CZ, HU, PL, SK, SI, BG, RO, LT, LV, EE
Other Emerging [emer] (8):	RU, BR, MX, KR, IN, ID, CN, TR
Other Advanced [oadv] (7):	AU, CA, SE, DK

Notes: Abbreviations refer to the two-digit ISO country code.

Table 2
Data description, 2001Q1-2016Q4.

Variable	Description	Min.	Mean	Max.	Coverage
y	Real GDP, average of 2005 = 100. Seasonally adjusted, in logarithms.	4.19	4.66	5.54	100%
p	Consumer price. CPI seasonally adjusted, in logarithms.	3.63	4.70	5.54	100%
e	Nominal exchange rate vis-à-vis the US dollar, deflated by national price levels (CPI).	−5.57	−2.17	5.11	100%
iS	Typically3-month-marketrates, rates per annum.	−0.02	0.01	0.16	100%
iL	Typically government bond yields, rates per annum.	−0.00	0.01	0.06	65%
EA_{ls}	Shadow rate for the euro area	−0.018	0.002	0.011	–
US_{ls}	Shadow rate for the United States	−0.013	0.001	0.013	–
UK_{ls}	Shadow rate for the United Kingdom	−0.016	0.004	0.014	–
JP_{ls}	Shadow rate for Japan	−0.012	−0.004	0.001	–
CZ_{ls}	Shadow rate for the Czech Republic	−0.017	0.018	0.056	–
BG_{ls}	Shadow rate for Bulgaria	−0.023	0.016	0.054	–
poil	Price of oil, seasonally adjusted, in logarithms.	2.96	4.10	4.80	–
Trade Flows	Bilateral data on exports and imports of goods and services, annual data.	–	–	–	–
Banking Exposure	Bilateral outstanding assets and liabilities of banking offices located in BIS reporting countries and Russia. Annual data.	–	–	–	–

Notes: Summary statistics pooled over countries and time. The coverage refers to the cross-country availability per country, in %.

According to the original Scholes idea, a shadow rate stands for the hypothetical rate that would occur if the zero lower bound was not binding. In normal times, the shadow rate is very close to the actual policy rate, while it can become negative if the central bank provides an additional stimulus. This way, shadow rates allow for a continuous evaluation of the monetary policy stance during periods of both conventional and unconventional monetary policy stimulus.

There exist several versions of shadow interest rates depending on the econometric technique used to estimate them (see Comunale & Striaukas, 2017, for an excellent overview of further measures of unconventional monetary policy). The most widely used ones are from Krippner (2013) and Wu and Xia (2016). Other versions of euro area shadow interest rates are developed by Ajevskis (2016) in the Latvijas Banka and Babecka Kucharcukova et al. (2016) in the Česká Národní Banka.

Several methods based on yield curve modeling or factor analysis have been developed to estimate shadow short-term rates in a zero lower bound environment, giving slightly different paths (see Fig. 1).

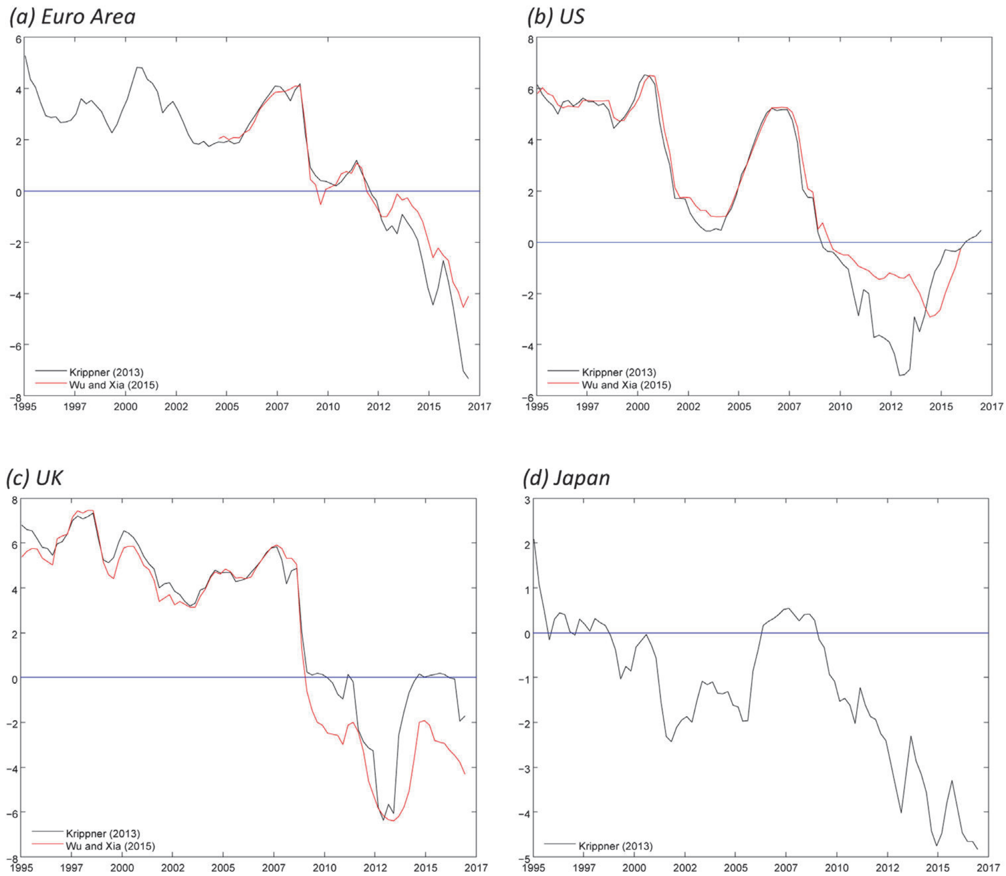


Fig. 1. Shadow rate estimates for the euro area, the US, the UK and Japan.

In this paper, we use the shadow rate of Krippner (2013) for the euro area, the United States, the United Kingdom, and Japan. As a robustness check, we compare the results employing shadow rates from Wu and Xia (2016). Several CESEE and Baltic countries introduced the euro towards the middle or end of the period analyzed in this paper (SK – 2007, SI – 2009, EE – 2011, LV – 2014, LT – 2015). In order to account for euro area monetary policy effects on these countries, we adjust their short-term rates time series with the dynamics of the euro area interest shadow rate with the introduction of the euro. In 2015–2016, some CESEE countries, such as the Czech Republic and Bulgaria, also implemented unconventional monetary policies, mirrored in negative values of yield curves and deposit facility rates. To account for this, we also calculate shadow rates for these economies applying the method described in Ajevskis (2016). The shadow rates are provided in Fig. 2. Including shadow rates for the CESEE economies where applicable ensures a proper assessment of the transmission of the euro area monetary policy shock to the region.

Next, we have to specify *weights* that link the single country models. These should proxy the (economic) connectivity between the countries. In the early literature on GVARs, weakly exogenous variables were constructed exclusively based on bilateral trade flows (2009, Dees, Holly, Pesaran, & Smith, 2007; Pesaran et al., 2004).

To get a first impression about the trade connectivity between the CESEE and the countries of the euro area, Fig. 3 shows weights based on bilateral, annual trade flows, averaged over the sample

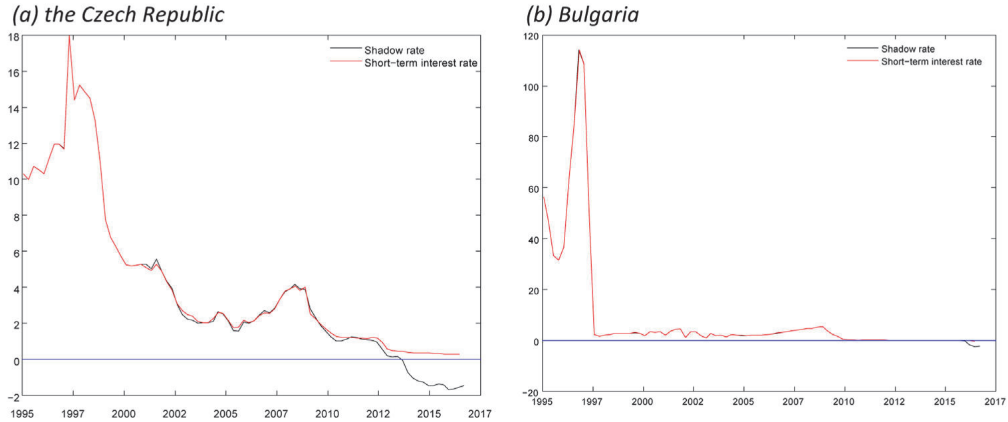


Fig. 2. Shadow rate estimates for the Czech Republic and Bulgaria.
Notes: Estimated using the method presented in Ajevskis (2016).

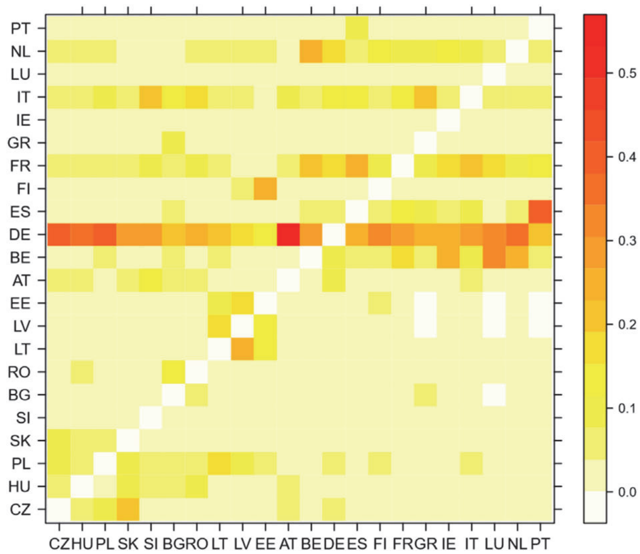


Fig. 3. Distribution of trade weights for euro area and CESEE economies.
Notes: The plot shows weights based on bilateral trade flows, averaged over the sample period.

period. The plot reveals Germany as the country with the strongest trade ties with the CESEE region, probably through production links in the automobile sector. Other CESEE economies trade strongly with Finland (Estonia), or Italy (Bulgaria, Slovenia). Hence, the euro area – CESEE trade structure differs considerably across countries. Comparing shocks from models that use euro area aggregate data (in which big countries such as Germany dominate) from those using single country data could thus lead to potentially very different results for receiving countries such as Bulgaria, Estonia or Slovenia. Also, through second-round effects and different trade links of single euro area member states with the rest of the world, using aggregate data might lead to very different dynamics and ultimately results. Similarly, the strong intra-CESEE trade is evident from the plot. Hence, a framework that yields consistent responses and allows for potential heterogeneity with in the euro area seems of ample importance to get reliable estimates of spillover effects.

More recent GVAR contributions suggest using various weights. For example, Eickmeier and Ng (2015) propose using trade flows to calculate foreign variables related to the real side of the economy (e.g., output and inflation) and financial flows for variables related to the financial side of the economy (e.g., interest rates and total credit). An alternative strand of the literature focuses on statistical as opposed to observed measures of connectivity. As such, Diebold and Yilmaz (2009) and Diebold and Yilmaz (2014) propose using forecast error variance decompositions for a VAR model to gauge the connectivity between the variables of interest. Most recent applications span analyses of the connectivity between (the returns of) international asset classes, banking networks and firm networks (see Chan-Lau, 2017).[4] We follow the GVAR literature though and choose time-varying weights based on bilateral trade flows to calculate y^*, p^* and financial weights based on bilateral banking sector exposure[5] to construct i_s^* and i_l^*. This approach is in line with Eickmeier and Ng (2015).

In order to include euro area aggregated variables (output, prices, and long-term interest rates) in the euro area VARX model, the weights should be set to zero for all countries except single euro area member states (see Table 3). The euro area VARX model then includes the aggregated long-term rate of non-EA countries as a foreign variable and we consequently leave these weights unrestricted. Since the euro area exchange rate is defined in the euro area model, we include it in the euro area single country models as a foreign variable with a weight equal to one.

We check for weak exogeneity of foreign variables and present. Only some of the foreign variables in the euro area country models do not satisfy the weak exogeneity assumption. For example, in the German model foreign output and interest rates and in the Netherlands model the foreign exchange rate do not satisfy the assumption. Also, foreign output and interest rates in the VARX for China do not pass the weak exogeneity test. This reflects the country's dominant role in the world economy.

We also tested each variable for the presence of a unit root by means of an augmented Dickey Fuller test. Output, prices and interest rates are mostly integrated of order 1, which ensures the appropriateness of the econometric framework pursued in this study. All results are available from the authors upon request.

4. Identification of structural shocks in the euro area

The traditional way of identifying a shock in the GVAR framework follows Dees, Holly et al. (2007). They propose identifying the shock locally (in a specific country model) and assess spillovers by using structural generalized impulse response functions (for applications, see Dees, Holly et al., 2007; Eickmeier & Ng, 2015; Chen, Lombardi, Ross, & Zhu, 2017; Feldkircher & Huber, 2016; Fadejeva, Feldkircher, & Reininger, 2017, among others.). This procedure implies that the shocks are orthogonal within the country of interest and correlated across countries.

A particular problem arises when using data on euro area member states in which case the common monetary policy has to be modelled. Burriel and Galesi (2018) use a combination of zero and sign restrictions and Feldkircher et al. (2020) and place these on the average responses across 19 euro area economies. In this paper we offer a different solution. We propose a way to identify shocks simultaneously for both individual and aggregated variables in a group of countries

[4] A recent paper Elhorst, Gross, and Tereanu (2018) presents an interesting bridge between GVAR and spatial econometrics, introducing a measure of spillovers using cross-section connectivity (weight) matrices and impulse responses.

[5] For more details on how to construct the financial weights, see Backé, Feldkircher, and Slacík (2013).

Table 3
Weights Used to Construct Foreign Variables.

y, p (trade weights)	EA	US	..	AT	..	PT
EA	0	0	0	0	0	0
US	0	0	x	x	x	x
..	0	x	0	x	x	x
AT (euro area countries)	x	x	x	0	x	x
..	x	x	x	x	0	x
PT	x	x	x	x	x	0
$\sum$	1	1	1	1	1	1
i_l (financial weights)	EA	US	..	AT	..	PT
EA	0	0	0	0	0	0
US	0	0	x	x	x	x
..	0	x	0	x	x	x
AT (euro area countries)	x	x	x	0	x	x
..	x	x	x	x	0	x
PT	x	x	x	x	x	0
$\sum$	1	1	1	1	1	1
i_s (financial weights)	EA	US	..	AT	..	PT
EA	0	x	x	x	x	x
US	x	0	x	x	x	x
..	x	x	0	x	x	x
AT (euro area countries)	0	0	0	0	0	0
..	0	0	0	0	0	0
PT	0	0	0	0	0	0
$\sum$	1	1	1	1	1	1
e (trade weights)	EA	US	..	AT	..	PT
EA	0	x	x	1	1	1
.	x	x	0	0	0	0
	0	0	0	0	0	0
..	0	0	0	0	0	0
PT	0	0	0	0	0	0
$\sum$	1	1	1	1	1	1

Notes: x – values between zero and one.

with common variables through a two-step procedure, which allows us to preserve the economic interpretation of the shock on the individual country level.

To identify the euro area monetary policy shock, we need to back out the endogeneous part of (7), which refers to euro area individual country models ($i^{`}_{EA}$) and the euro area common variables (i''). This part can be written in matrix notation as

$$\begin{bmatrix} I & -G_{i''} & -\Psi_0 \\ -\Lambda_{i'0}\hat{W}_{EA} & I & 0 \end{bmatrix} \begin{bmatrix} x_{i^{`}_{EA},t} \\ x_{i'',t} \\ \iota_t \end{bmatrix} = \begin{bmatrix} a_{i^{`}_{EA}0} \\ a_{i''0} \end{bmatrix}$$

$$+ \begin{bmatrix} H_{i^{`}_{EA}} & H_{i''} & \Psi_1 \\ \Lambda_{i^{`}_{EA}1}\hat{W}_{EA} & \Phi_{i''} & 0 \end{bmatrix} \begin{bmatrix} x_{i^{`}_{EA},t-1} \\ x_{i'',t-1} \\ \iota_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{i^{`}_{EA},t} \\ \varepsilon_{i'',t} \end{bmatrix}. \tag{4.8}$$

To obtain the structural form of the model in (4.8), we need to orthogonalize the error term. One way of doing this is to use the lower Cholesky factor P of the variance-covariance matrix of $\omega_t = \left(\varepsilon_{i^{'}_{EA},t}, \varepsilon_{i'',t}\right)$, $\Sigma_\omega = PP'$. To use sign restrictions for identification, we further have to find a suitable $(r+k) \times (r+k)$ orthonormal[6] rotation matrix R, that ensures the fulfillment of the restrictions placed on the impulse response functions. Recall that r is the number of variables in the common variable (regional) model i'', and k the maximum number of variables in euro are individual country models $i^{'}_{EA}$. Finally, the mapping from reduced to structural errors is achieved by pre-multiplying the reduced form errors with $Q = PR$.

To preserve individual euro area country information, while keeping the size of the rotation matrix compact, we propose to apply several steps: First, we collect the orthogonal impulse responses of the euro area countries by using the Cholesky factor P (from 4.8). Second, we draw a rotation matrix R. (see 4.9) with dimensions equal to the number of unique variables in the individual euro area countries plus the number of common euro area variables $(r+k) \times (r+k)$, where the matrix dimensions represent variables and shocks.

$$\begin{bmatrix} \begin{bmatrix} a_{i'11} & \dots & a_{i'1(k+r)} \\ \vdots & \vdots & \vdots \\ a_{i'k1} & \dots & a_{i'k(k+r)} \end{bmatrix} \\ \begin{bmatrix} a_{i'(k+1)1} & \dots & a_{i'(k+1)(k+r)} \\ \vdots & \vdots & \vdots \\ a_{i'(k+r)1} & \dots & a_{i'(k+r)(k+r)} \end{bmatrix} \end{bmatrix} \begin{matrix} -> \tilde{R}k \times (r+k) \\ \\ -> \tilde{\tilde{R}}r \times (r+k) \end{matrix} \quad , \hat{W}_{EA} = \begin{bmatrix} 1/\hat{W}_1 \\ 1/\hat{W}_2 \\ \dots \\ 1/\hat{W}_{N_{EA}} \end{bmatrix} \tag{4.9}$$

Third, we expand the part of rotation matrix which corresponds to individual EA country models ($\tilde{R}$) along the variable dimension using country weights (GDP-PPP euro area weights) $\tilde{R} \otimes \hat{W}_{EA} = \tilde{R}_W$ and combine the obtained matrix with the part corresponding to the common variables, $R_0 = (\approx R, \tilde{R}_W)$. A simplified example of such rotation matrix expansion is presented in Table 4.[7] Importantly, the expanded rotation matrix R_0 is a pseudo inverse matrix $R_0 R_0^+ = I$, thus orthogonality of the structural error terms is preserved.

Fourth, we apply the rotation matrix obtained to the orthogonal impulse responses and collect country impulse responses to shocks. This is done by constructing a global matrix Q, where the

[6] Orthonormality implies that R satisfies $RR' = I$.

[7] To save space we show only three shocks, potentially, however, the number of shocks is equal to $r + k$.

Table 4
Orthogonal rotation matrix for the euro area country group *Rotation matrix expanded* (Example).

	AD shock	MP shock	AS shock		AD shock	MP shock	AS shock
Shadow r	r11	r12	r13	Shadow r	r11	r12	r13
EUR/USD	r21	r22	r23	EUR/USD	r21	r22	r23
EA* y	r31	r32	r33	AT y	r31/W(AT)	r32/W(AT)	r33/W(AT)
EA* dp	r41	r42	r43	BE y	r31/W(BE)	r32/W(BE)	r33/W(BE)
EA* ltir	r51	r42	r53		...	...	...
				AT dp	r41/W(AT)	r42/W(AT)	r43/W(AT)
				BE dp	r41/W(BE)	r42/W(BE)	r43/W(BE)
					...	...	...
				AT ltir	r51/W(AT)	r52/W(AT)	r53/W(AT)
				BE ltir	r51/W(BE)	r52/W(BE)	r53/W(BE)
					...	...	...
				PT ltir	r51/W(PT)	r52/W(PT)	r53/W(PT)

$Q_0 = PR_0$ forms corresponding rows and columns. Pre-multiplying Eq. (3.7) with Q yields the structural form of the global model:

$$Q^{-1}y_t = Q^{-1}\Gamma y_{t-1} + \tilde{e}_t, \; Q = \begin{pmatrix} Q_0 & 0 & \cdots & 0 \\ 0 & I & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & I \end{pmatrix}. \tag{4.10}$$

Finally, we aggregate the collected impulse responses with weights and check if the sign restrictions (regional or country-specific) are satisfied.

Note that using the approach outlined above involves sampling a rotation matrix R_0 of size $\left(r + k_{i^{\cdot}_{EA}} * N_{i^{\cdot}_{EA}}\right) \times (r + k)$ which is much smaller than compared to the full-size euro area rotation matrix $\left(r + k_{i^{\cdot}_{EA}} * N_{i^{\cdot}_{EA}}\right) \times \left(r + k_{i^{\cdot}_{EA}} * N_{i^{\cdot}_{EA}}\right)$. Also, our approach implies that coefficients of the rotation matrix for the same variables in different euro area countries will be of the same sign, which allows for a consistent economic interpretation.

To obtain a candidate rotation matrix we draw R_0 using the algorithm outlined in Rubio-Ramírez, Waggoner, and Zha (2010). Since there is a multitude of R that satisfies the restrictions, Fry and Pagan (2011) suggest to base the inference on the rotation matrix that gives the impulse responses closest to the median impulse responses obtained from the whole set of R.

We propose the following constraints to separate monetary policy disturbances from the other macroeconomic shocks. Table 5 summarizes the sign restrictions for identifying three main types of shocks – monetary policy, aggregate demand, and aggregate supply. Separating two additional shocks as opposed to leaving them as a residual in the analysis, should help pin down the monetary policy shock more clearly, as increasing the number of restrictions enhances the identification of the shock of interest (Paustian, 2007).

The sign restrictions are defined for two blocks of variables: first, for euro area common variables – i.e., the shadow rate and the exchange rate – and second, for *aggregates* of the euro area country-specific variables – output, prices, and the long-term interest rate. In this way, we allow for heterogeneity in the aggregate effect of the euro area countries as a whole. Sign restrictions

Table 5
Sign restrictions.

Shock	y	p	i_s *(shadow)*	i_l	e
Monetary Policy	↓	$\underline{\downarrow}$	↑	–	–
Aggregate Supply	↓	↑	↑	–	↑
Aggregate Demand	↓	↓	↓	–	–

Notes: The restrictions are imposed on impact and in the first quarters. The underlined arrow indicates an exception to this in the sense that the restriction is imposed in the second and third quarters.

are imposed on impact and in the following quarter for all variables with the exception of the price reaction to the monetary policy shock. Allowing for price rigidities, we restrict the response of prices to the monetary policy shock to be negative in the second and third quarters only.

In choosing the identification of the monetary policy shock we followed the widely used assumption, that a monetary policy tightening will on aggregate reduce price growth, although not necessarily immediately (Chen et al., 2017; Feldkircher & Huber, 2016; Georgiadis, 2015; Uhlig, 2005). The effect on real GDP, however, is more ambiguous. Uhlig (2005) has shown that it can be either slightly positive or negative. We restrict the overall effect of euro area real GDP to be negative, while allowing for heterogeneity in the aggregate effect of the euro area countries by not restricting country-specific effects.

5. Empirical results

In this section we present responses to a +25 bp increase in the euro area's shadow rate. We first show the domestic responses for the euro area countries, before we proceed to examining the international effects. The last paragraph of this section includes some robustness checks.

5.1. Domestic effects

Domestic responses of euro area countries are shown in Fig. 5, with the orange, solid line denoting the median effects along with the 16th and 84th percentiles (orange, dashed) of 400 bootstrapped replications. For comparison, we also show the area spanned by the 16th and 84th percentiles (blue shaded area) for the aggregated euro area response, where we use purchasing power parity (PPP) weights to aggregate responses of the single euro area countries.[8]

The top panel of the plot shows a significant, negative response of euro area output, with a peak effect of about −0.4%. In Austria, Finland, France, Italy, Spain and the Netherlands, output also responds negatively, but peak effects are much smaller and above the euro area aggregate. By contrast, responses in Germany (peak effect of about −0.6%) and Ireland (peak effect of about 1.0%) are particularly strong. Positive but insignificant effects are estimated for Greece. The relative strength and the size of the overall effect are very similar to the estimates provided in Boeckx et al. (2017) and Burriel and Galesi (2018), who assess monetary policy using an exogenous increase in the ECB's balance sheet. In the bottom panel of Fig. 5, we see that consumer prices respond negatively but responses are not as precisely estimated as those of real GDP. On average, a 25 bp increase in the shadow rate leads to an decrease in the price level of 0.15%.

[8] PPP weights are from the IMF's World Economic Outlook data base and averaged over the sample period.

As before, the aggregate response might mask regional heterogeneity which results in overall insignificant responses. In fact, countries that show stronger negative responses than the euro area aggregate include euro area core countries such as Belgium, Germany on the one hand and euro area periphery countries such as Greece and Ireland on the other hand. Consumer prices increase in the Netherlands. Taken at face value, our results reveal a considerable degree of heterogeneity in the euro area. Also, a simple distinction between core and periphery countries is not sufficient to adequately capture cross-country heterogeneity within the euro area. This result is in line with Dominguez-Torres and Hierro (2020) who show that clusters change with the time period of the sample. Our results generalize this finding by demonstrating that the composition of clusters can also change depending on the variables under scrutiny suggesting hence that different transmission channels are operative.

5.2. *International effects*

In this section, we examine international effects that arise from the euro area monetary tightening. To get a first impression of the results, we examine regional impulse response functions, aggregated by PPP weights. The regions in Fig. 6 correspond to the ones listed in Table 1.

Briefly, the results show that international output and prices fall, but not significantly so on the aggregate level. Interestingly, short-term interest rates tend to decrease, and even significantly so in advanced economies (which include the USA). A similar pattern can be observed for long-term rates. The rational behind that might be that domestic policy tries to compensate the output loss by lowering policy rates. As mentioned above, regional aggregates serve only to get a crude, first impression of the overall results and significant responses might get washed out by aggregation.

We now turn to country-specific responses of CESEE countries, depicted in Figs. 7 and 8. As a result of euro area monetary tightening, output declines in all CESEE countries but effects vary in size and precision. For example, countries that react stronger than the regional CESEE aggregate comprise the Czech Republic, Slovenia and the Baltic States. In the Baltics, the peak effect is about −0.6%, whereas in the Czech Republic and Slovenia, output declines by 0.4 to 0.5%. The least, but still significant, drop in output occurs in Poland, which might be explained by the relatively closed Polish economy. The bottom panel of Fig. 7 shows responses to prices. Here, out of the ten CESEE economies, four show a significant and negative response of domestic prices. These comprise Bulgaria, the Czech Republic, Estonia and Hungary. In the latter the response is particularly pronounced (−0.3%). Relative to output, price effects tend to be less precisely estimated and are smaller in magnitudes. This finding is in line with a broad bulk of the literature (Bluwstein & Canova, 2016; Horváth & Voslářová, 2016; Potjagailo, 2017) and can be related to exchange rate movements. In fact, if local currencies depreciate, imports from the euro area get significantly more expensive for CESEE economies putting upward pressure on domestic prices.

Next, we examine the responses of short-term interest rates and exchange rates, provided in the upper panel of Fig. 8. Here, we see two clusters of CESEE countries. The first cluster comprises countries that have already adopted the euro. Naturally, short-term interest rates in these countries are positively correlated with the euro area shadow interest rate – at least in the short run. Only Latvia seems an exception to this. The remaining CESEE economies react with a decrease in the policy rate. This might reflect the domestic reaction of the policy maker in order to compensate for the loss in output or negative pressure on domestic prices. Responses are significant in four out of the ten CESEE economies. The response of exchange rates against the US dollar show a diverse picture. Here, we find significant appreciations of domestic currencies only in Romania and some euro countries (Slovakia and Slovenia).

Summing up, we find significant and negative spillovers to output and prices in CESEE. While the effects for the regional aggregate are not precisely estimated, country-specific responses are for particular countries. The same holds true for the reactions of short-term interest rates and exchange rates. This result suggests that a certain degree of heterogeneity prevails in the region which has to be addressed in econometric analysis. The same applies to euro area countries. Here responses, also vary considerably and certain clusters of countries emerge, depending on the variable under scrutiny. This might imply that monetary policy transmission differs across euro area countries.

5.3. Alternative specifications

In this section, we briefly examine the sensitivity of our results to several, alternative specifications. First, we modify the euro area model by introducing euro area common variables in the dominant unit block (see (3.4)). Dominant unit endogenous variables enter the euro area country equations only. Aggregated foreign variables in the dominant unit model are formed from euro area real GDP, prices, and long-term rates, while spillovers are allowed from the shadow rates in advanced countries (the US, the UK, and Japan). The exchange rate, in addition to the above-mentioned variables, assumes the feedback effect from the other exchange rates worldwide. The price of oil remains a global variable, but is now endogenously modelled inside the US country model. This exercise results in a slightly stronger reaction of both real GDP and prices in CESEE countries.

As another robustness check we try an alternative specification of the shadow rate, namely, that proposed by Wu and Xia (2016). As shown in Fig. 1 their estimates of shadow rates for the euro area are quite similar to the ones provided by Krippner (2013). Not surprisingly then, our overall results are qualitatively unchanged when using the shadow rates of Wu and Xia (2016).

5.4. How important are second-round effects?

In this section, we answer the question to which extent overall spillovers are driven by the reactions of third countries. To that end, we examine what proportion of a spillover effect can be traced back to the direct economic and financial linkages between the receiving country and the shocks-originating country compared to indirect k̈nock-onëffects via third countries. Technically, we follow Cesa-Bianchi (2013); Fadejeva et al. (2017) and manipulate the weight matrix in the second step of the GVAR layer. That is, we set the bilateral weights of CESEE and euro area countries to zero[9], s̈hutting offẗhe direct transmission of spillover effects from the euro area. The resulting responses can be interpreted as the proportion of the spillover that is caused by indirect effects through other economies besides the euro area countries.

Fig. 4 shows the ratio of the indirect effect to the total effect (on the x-axis) versus the total effect (on the y-axis) after 20 quarters. For the Baltic countries, in line with results presented by Burriel and Galesi (2018), knock-on effects through third countries account for most of the total effect on their real GDP (and less so in the case of prices). The Czech Republic, Poland and

[9] We do not re-distribute the weights that are set to zero to other economies yielding a weight matrix with row sums smaller than unity. This modification should not have any effect on the overall stability of the model (as opposed to having row sums of the weight matrix exceeding unity).

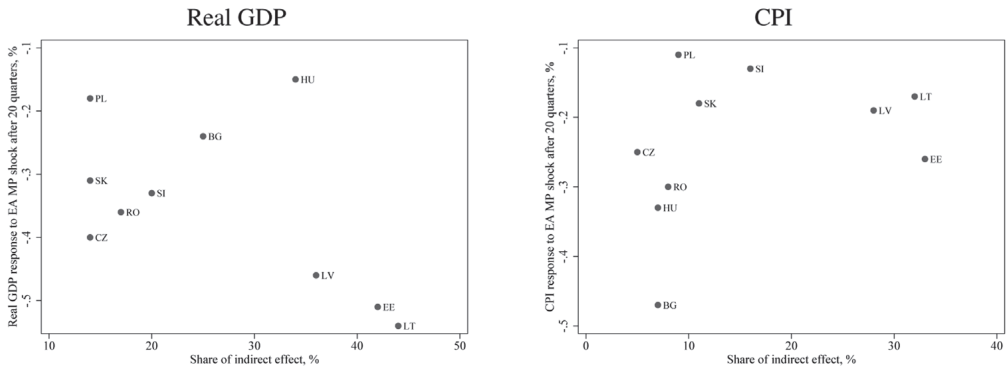


Fig. 4. Ratio of the indirect to the total effect of the euro area monetary policy shock (normalized to a 25 bp EA shadow rate increase) after 20 quarters.

Notes: The scatter plots show the ratio of the indirect to total effect for real GDP and CPI on the x-axis and the total effect on the y-axis. The indirect effect is calculated using a CESEE-EA weight matrix that sets the weights to zero. Ratios close to zero indicate the importance of direct links from the euro area (EA12) countries, while large values show that knock-on effects via third countries account for most of the total effect on real GDP and CPI.

Slovakia, on the other hand, receive the highest share of the monetary policy effects directly from links to the euro area.

6. Conclusions

In this paper, we evaluate the effect of euro area monetary policy on output and prices, with a special focus on individual euro area and CESEE countries. As an overall measure of the monetary policy stance, we rely on shadow rates for the euro area, other advanced economies, and CESEE countries in which the policy rate hit the zero lower bound.

We propose a new way of modeling euro area countries and their joint monetary policy in a GVAR framework. On the aggregate level, we single out variables that are common to euro area countries, namely the interest rate and the exchange rate. On the individual level, euro area member states' macroeconomic variables are determined in country-specific models. Feedback and interaction between these two layers of aggregation is established by letting the common variables enter the individual country models as foreign variables, and the aggregated euro area variables (real GDP, prices, and long-term rates) enter the equations for common variables with contemporaneous and lagged effects. Using this setting, we then identify a euro area monetary policy shock with sign restrictions where the rotation matrix is adjusted to ensure consistency between the aggregate and euro area country specific level. Hence our method yields an economically consistent euro area monetary policy shock, which is important for guiding policy-making. It is also important for spillover analysis, since CESEE countries feature distinct trade and financial links with single euro area member states and having a non-consistent euro area shock could in turn lead to misleading effects on neighboring countries.

Using this approach, we find a considerable degree of effects in the euro area. Some countries, like Greece and Ireland, considerably deviate from responses of the remaining euro area countries. A core-periphery distinction, however, might be too simplistic. Rather, depending on the variable under scrutiny, different clusters of countries emerge that behave in a more similar way. For example, countries in which prices decline more strongly than the euro area aggregate include euro area core countries such as Belgium and Germany on the one hand and euro area periphery

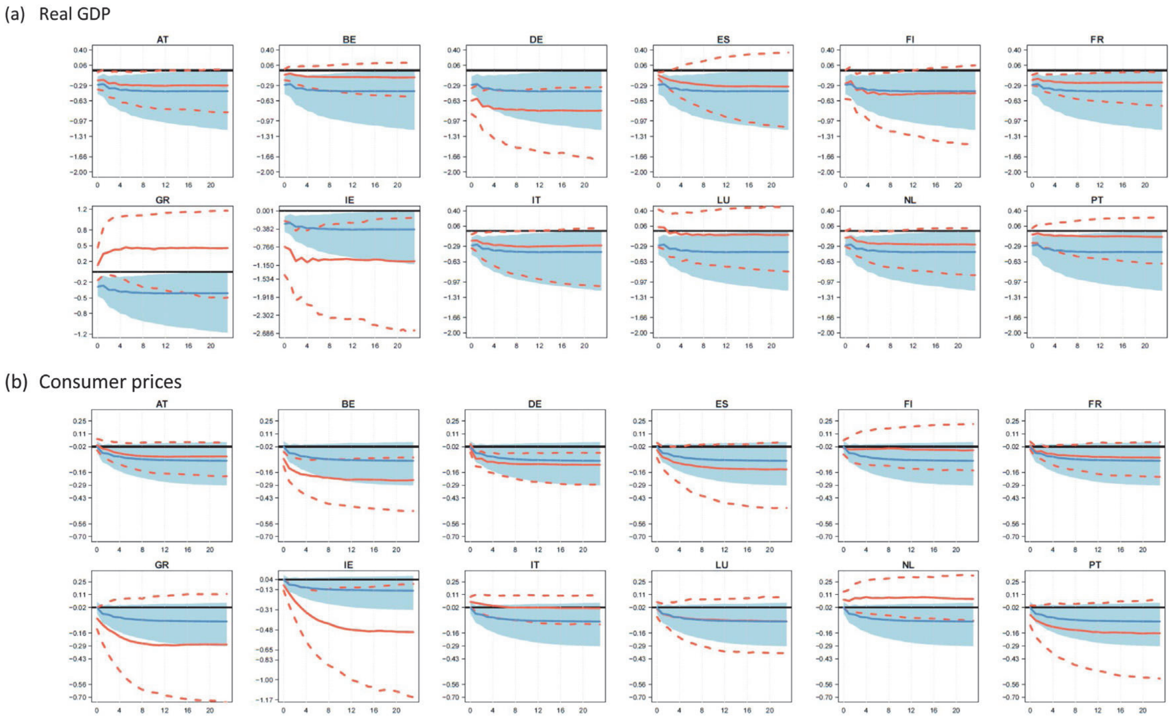


Fig. 5. Responses of euro area countries to a +25 bp euro area shadow rate increase.

Notes: The figure displays country-specific median impulse responses (red solid line) and the 68% confidence bands (red dashed lines). Euro area aggregated responses are in blue (solid line, median, blue area 68% confidence band) and computed using PPP weights. All results based on 400 bootstrap replications.

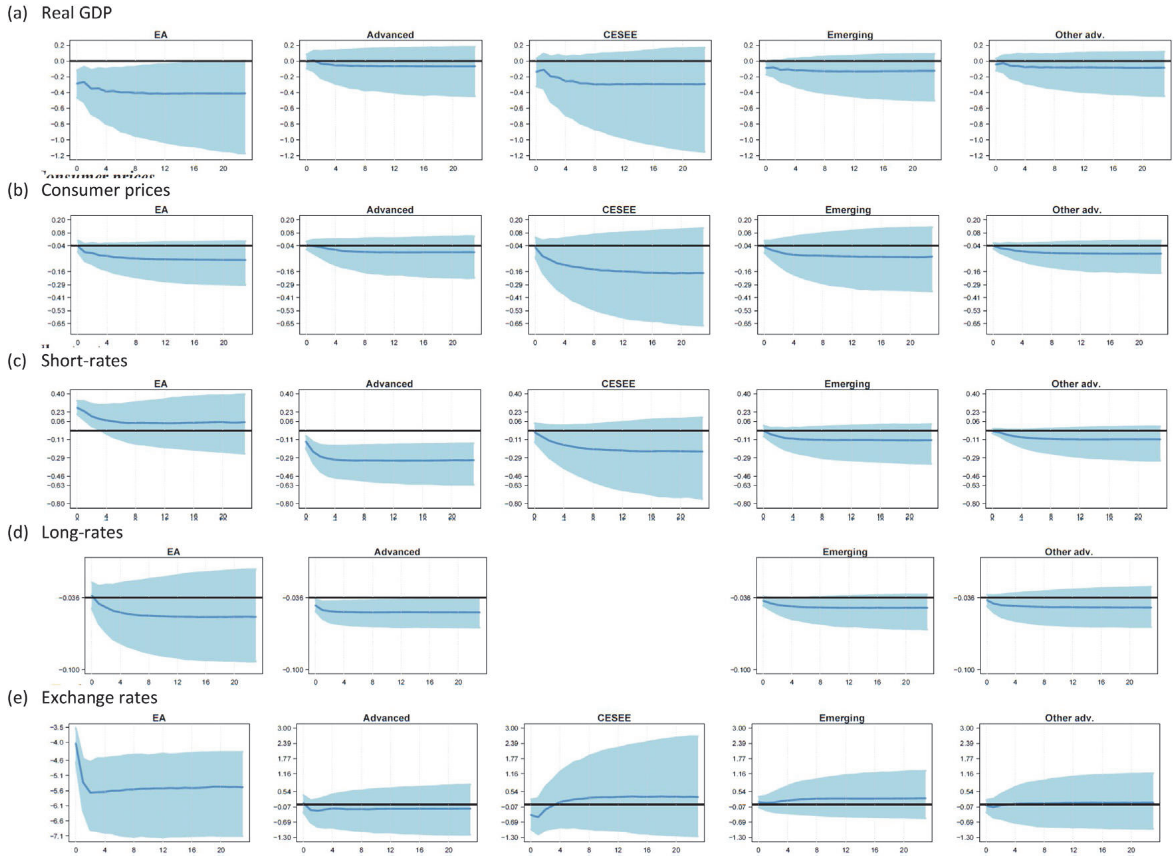


Fig. 6. Regional responses to a +25 bp euro area shadow rate increase.
Notes: Regionally aggregated responses in blue (solid line, median, blue area 68% confidence band), computed using PPP weights. All results based on 400 bootstrap replications.

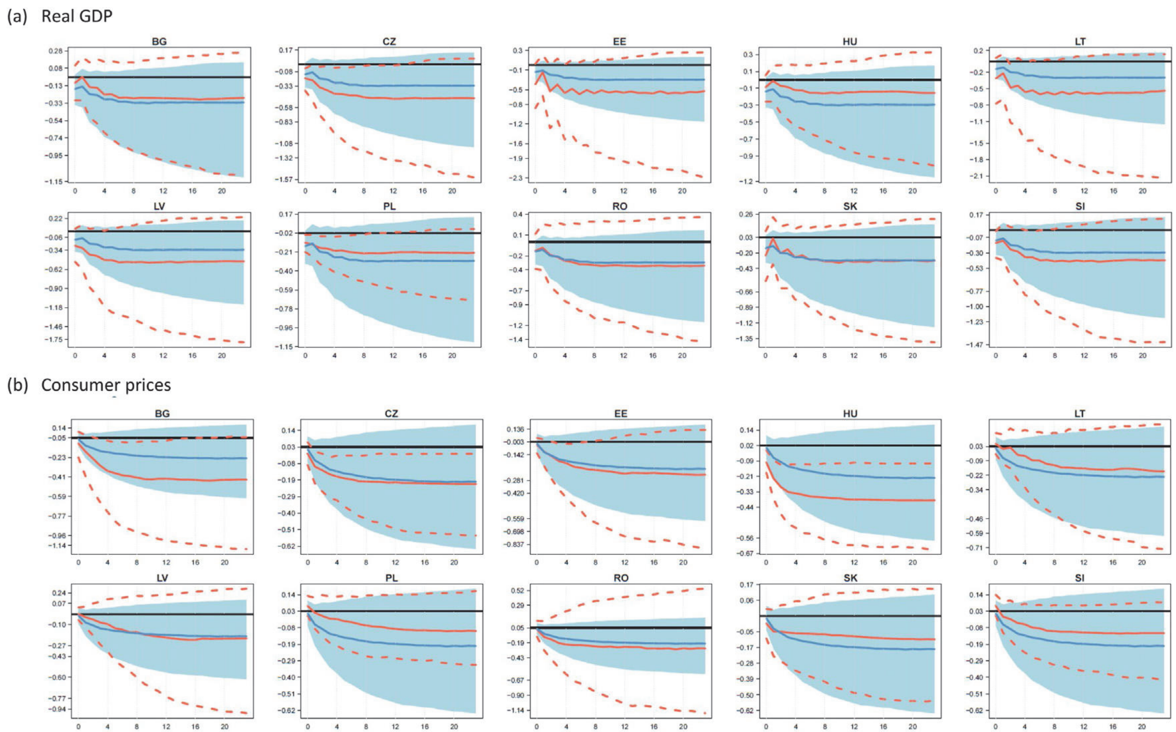


Fig. 7. Responses of GDP and CPI in CESEE countries to a +25 bp euro area shadow rate increase.

Notes: The figure displays country-specific median impulse responses (red solid line) and the 68% confidence bands (red dashed lines). Regionally aggregated responses are in blue (solid line, median, blue area 68% confidence band) and computed using PPP weights. All results based on 400 bootstrap replications

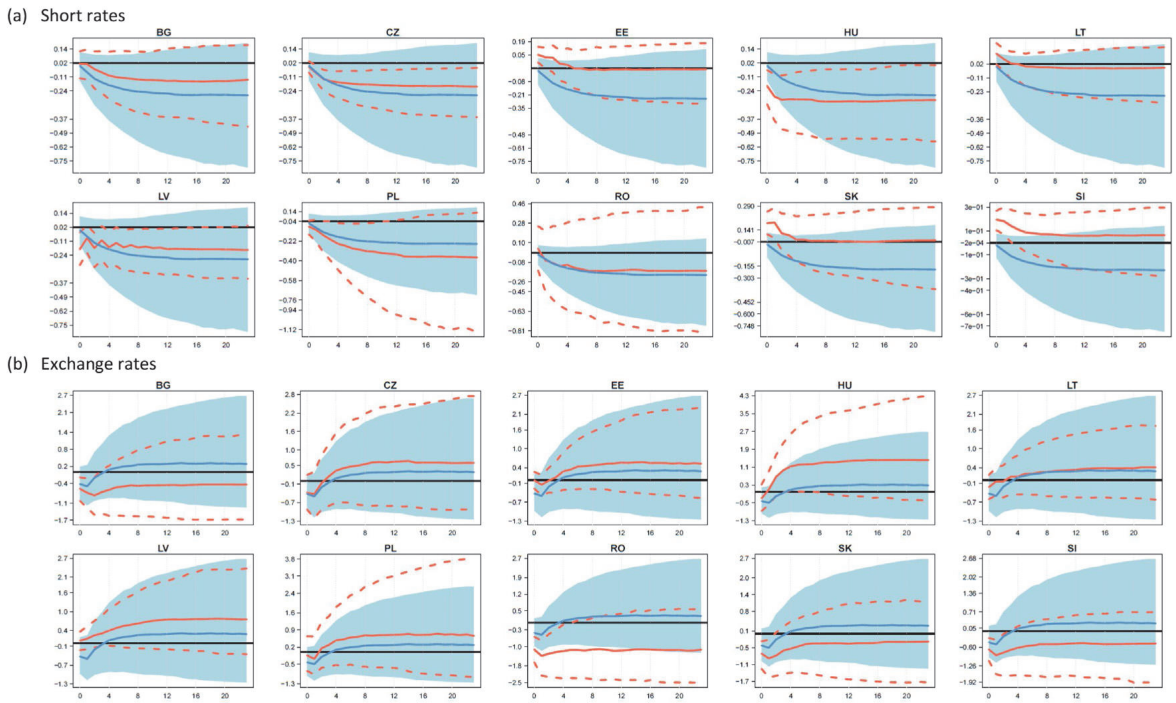


Fig. 8. Responses of short-rates and exchange rates in CESEE countries to a +25 bp euro area shadow rate increase.
Notes: The figure displays country-specific median impulse responses (red solid line) and the 68% confidence bands (red dashed lines). Regionally aggregated responses are in blue (solid line, median, blue area 68% confidence band) and computed using PPP weights. All results based on 400 bootstrap replications.

countries such as Greece and Ireland on the other hand. Our results hence generalize findings by Dominguez-Torres and Hierro (2020) demonstrating that the composition of clusters can also change depending on the variables under scrutiny suggesting that different transmission channels are operative in the euro area.

Effects spill over to other countries, such as the CESEE region. More specifically, we find significant and negative output and price effects in CESEE. Also here we find a considerable degree of heterogeneity of country responses. While regionally aggregated figures point to not precisely estimated effects, country specific responses for particular countries are significantly estimated. We find weaker effects of prices relative to those on output, which is in line with the bulk of the literature (Bluwstein & Canova, 2016; Horváth & Voslářová, 2016; Potjagailo, 2017). This finding might be explained by the high import content of the CESEE countries: if the euro appreciates, imports from the euro area get more expensive putting upward pressure on domestic price levels. We also find that short-term interest rates tend to fall internationally, which might be explained by the domestic policy maker trying to compensate the fall in output and prices.

Spillover effects obtained by our analysis contain both the direct and indirect spillover and effects through third-countries. These total spillover effects are more interesting from the perspective of a policy-maker in a receiving country since they also contain the reactions of neighboring countries. A decomposition of the spillovers reveals that effects of a euro area monetary policy shock on the Baltic countries can be accounted to a large degree by second-round effects through other non-euro area countries. The Czech Republic and Poland, on the other hand, tend to be affected directly through their high degree of integration with the euro area.

Some important policy implications emerge from our analysis. First, sending countries face the trade-off of meeting domestic objectives while avoiding large adverse international spillovers which might cause negative spillbacks. To do so, multi-country models that allow for richer monetary policy reaction functions can provide useful guidance. On top of that, adverse monetary policy spillovers could be contained through transparency and clear communication of policy intentions in central banks in sending countries. Second, receiving economies, cannot totally shield their economy from spillovers since effects might also transpire through third-countries and international production and trade structures cannot be swiftly adjusted. Hence, requiring sound fundamentals in the receiving economy might mitigate - to some extent - spillover effects, but only to a certain extent.

Acknowledgments

This work was supported by Czech National Bank Research Project No. B2/2015. The authors would like to thank Sabah Cavallo, Michal Franta, Petr Král, Jan Hájek, Alessandro Galesi, and CNB seminar participants for comments. All errors and omissions are ours. The views expressed in this paper are those of the authors and do not necessarily represent those of the Czech National Bank, Latvijas Banka, or Oesterreichische Nationalbank.

References

Ajevskis, V. (2016). *A term structure of interest rates model with zero lower bound and the European central bank's non-standard monetary policy measures. Working Papers 2016/02, Latvijas Banka*.

Babecka Kucharcukova, O., Claeys, P., & Vasicek, B. (2016). Spillover of the ECB's monetary policy outside the euro area: How different is conventional from unconventional policy? *Journal of Policy Modeling*, *38*(2), 199–225.

Backé, P., Feldkircher, M., & Slacík, T. (2013). Economic spillovers from the euro area to theˇ CESEE region via the financial channel: A GVAR approach. *Focus on European Economic Integration*, *4*, 50–64.

Bluwstein, K., & Canova, F. (2016). Beggar-thy-neighbor? The international effects of ECB unconventional monetary policy measures. *International Journal of Central Banking*, *12*(3), 69–120.

Boeckx, J., Dossche, M., & Peersman, G. (2017). Effectiveness and transmission of the ECB's balance sheet policies. *International Journal of Central Banking*, *13*(1), 297–333.

Burriel, P., & Galesi, A. (2018). Uncovering the heterogeneous effects of ECB unconventional monetary policies across euro area countries. *European Economic Review*, *101*, 201–229.

Cavallo, A., & Ribba, A. (2015). Common macroeconomic shocks and business cycle fluctuations in euro area countries. *International Review of Economics & Finance*, *38*, 377–392.

Cavallo, A., & Ribba, A. (2020). Measuring the effects of oil price and euro-area shocks on CEECS business cycles. *Journal of Policy Modeling*, *40*, 74–96.

Cesa-Bianchi, A. (2013). Housing cycles and macroeconomic fluctuations: A global perspective. *Journal of International Money and Finance*, *37*(C), 215–238.

Chan-Lau, J. (2017). *Variance decomposition networks: Potential pitfalls and a simple solution. Working paper WP/17/107, International Monetary Fund*.

Chen, Q., Lombardi, M., Ross, A., & Zhu, F. (2017). *Global impact of us and euro area unconventional monetary policies: A comparison. Working Papers 610, Bank of International Settlements; working Papers*.

Chudik, A., & Pesaran, H. M. (2016). Theory and practice of GVAR modeling. *Journal of Economic Surveys*, *30*, 165–197.

Chudik, A., & Pesaran, M. H. (2013). Econometric analysis of high dimensional vars featuring a dominant unit. *Econometric Reviews*, *32*(5-6), 592–649.

Comunale, M., & Striaukas, J. (2017). *Unconventional monetary policy: Interest rates and low inflation. A review of literature and methods. DP 2017/26, Center for Operations Research and Econometrics, Université Catholique de Louvain*.

Dees, S., di Mauro, F., Pesaran, H. M., & Smith, L. V. (2007). Exploring the international linkages of the euro area: A global var analysis. *Journal of Applied Econometrics*, *22*(1).

Dees, S., Holly, S., Pesaran, H. M., & Smith, V. L. (2007). Long run macroeconomic relations in the global economy. *Economics - The Open-Access, Open-Assessment E-Journal*, *1*(3), 1–20.

Diebold, F. X., & Yilmaz, K. (2009). Measuring financial asset return and volatility spillovers, with application to global equity markets. *The Economic Journal*, *119*.

Diebold, F. X., & Yilmaz, K. (2014). On the network topology of variance decompositions: Measuring the connectedness of financial firms. *Journal of Econometrics*, *182*.

Dominguez-Torres, H., & Hierro, L. A. (2020). Are there monetary clusters in the eurozone? The impact of ecb policy. *Journal of Policy Modeling*, forthcoming.

Eickmeier, S., & Ng, T. (2015). How do credit supply shocks propagate internationally? A gvar approach. *European Economic Review*, *74*, 128–145. Issue C.

Elhorst, J. P., Gross, M., Tereanu, E., et al. (2018). *Spillovers in space and time: Where spatial econometrics and global var models meet. Technical report*.

Fadejeva, L., Feldkircher, M., & Reininger, T. (2017). International spillovers from euro area and us credit and demand shocks: A focus on emerging Europe. *Journal of International Money and Finance*, *70*, 1–25.

Feldkircher, M., & Huber, F. (2016). The international transmission of us shocks – Evidence from bayesian global vector autoregressions. *European Economic Review*, *81*(C), 167–188.

Feldkircher, M., Gruber, T., & Huber, F. (2020). International effects of a compression of euro area yield curves. *Journal of Banking & Finance*, *113*, 11–14.

Fry, R., & Pagan, A. (2011). Sign restrictions in structural vector autoregressions: A critical review. *Journal of Economic Literature*, *49*(4), 938–960.

Gambacorta, L., Hofmann, B., & Peersman, G. (2014). The effectiveness of unconventional monetary policy at the zero lower bound: A cross-country analysis. *Journal of Money, Credit, and Banking*, *46*(4), 615–642.

Garrat, A., Lee, K., Pesaran, M. H., & Shin, Y. (2006). *Global and national macroeconometric modelling: A long-run structural approach*. Oxford University Press.

Georgiadis, G. (2015). Examining asymmetries in the transmission of monetary policy in the euro area: Evidence from a mixed cross-section global var model. *European Economic Review*, *75*(C), 195–215.

Hájek, J., & Horváth, R. (2018). International spillovers of (un)conventional monetary policy: The effect of the ECB and us fed on non-euro EU countries. *Economic Systems*, forthcoming.

Horváth, R., & Voslářová, K. (2016). International spillovers of ECB's unconventional monetary policy: The effect on central Europe. *Applied Economics*, *0*, 1–13.

Huchet, M. (2003). Does single monetary policy have asymmetric real effects in emu. *Journal of Policy Modeling*, *25*, 151–178.

Krippner, L. (2013). Measuring the stance of monetary policy in zero lower bound environments. *Economics Letters*, *118*(1), 135–138.

Moder, I. (2019). Spillovers from the ECB's non-standard monetary policy measures on Southeastern Europe. *International Journal of Central Banking*, *15*(4), 127–163.

Paustian, M. (2007). Assessing sign restrictions. *The B.E. Journal of Macroeconomics*, *7*(1), 1–33.

Pesaran, M. H., Schuermann, T., & Smith, L. V. (2007). What if the UK or Sweden had joined the euro in 1999? An empirical evaluation using a global var. *International Journal of Finance & Economics*, *12*(1), 55–87.

Pesaran, M. H., Schuermann, T., & Smith, L. V. (2009). Forecasting economic and financial variables with global vars. *International Journal of Forecasting*, *25*(4), 642–675.

Pesaran, M. H., Schuermann, T., & Weiner, S. M. (2004). Modeling regional interdependencies using a global error-correcting macroeconometric model. *Journal of Business and Economic Statistics, American Statistical Association*, *22*, 129–162.

Potjagailo, G. (2017). Spillover effects from euro area monetary policy across Europe: A factor augmented var approach. *Journal of International Money and Finance*, *72*(C), 127–147.

Rubio-Ramírez, J. F., Waggoner, D. F., & Zha, T. (2010). Structural vector autoregressions: Theory of identification and algorithms for inference. *The Review of Economic Studies*, *77*(2), 665–696.

Uhlig, H. (2005). What are the effects of monetary policy on output? Results from an agnostic identification procedure. *Journal of Monetary Economics*, *52*(2), 381–419.

Wu, J. C., & Xia, F. D. (2016). Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit, and Banking*, *48*(2-3), 253–291.

Appendix 3

III

Fadejeva, L. and Kantur, Z. (2023). Wealth distribution and monetary policy. *Economic Modelling*, 125(C): 106336. DOI 10.1016/j.econmod.2023.10

Economic Modelling 125 (2023) 106336

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.journals.elsevier.com/economic-modelling

Wealth distribution and monetary policy ☆

Ludmila Fadejeva [a], Zeynep Kantur [b,*]

[a] Monetary Policy Department, Latvijas Banka, Riga, Latvia
[b] Department of Economics, Başkent University, Ankara, Turkey

ARTICLE INFO

JEL classification:
E32
E52
J11

Keywords:
Productivity-gap
Wealth distribution
Demographics
Overlapping generations model
New Keynesian model
Monetary policy

ABSTRACT

Net wealth is distributed differently across various age cohorts in European countries. The net wealth distribution pattern in Western EU countries conforms to the life cycle hypothesis, whereas net wealth accumulation peaks at earlier ages in Eastern European countries. This study investigates the underlying reasons for these differences in net wealth distribution and evaluates how they affect monetary policy transmission. To this end, we develop a modified New Keynesian model with a multiperiod overlapping generations demand side to account for demographic and productivity-gap factors, analyzing their interactions with monetary policy within a general equilibrium setting. Using the Household Finance and Consumption Survey database, we calibrate the model for two sets of European countries and replicate the shape of net wealth distribution. Our findings suggest that the shape of net wealth distribution by age significantly determines monetary policy effectiveness and should be considered when designing and implementing monetary policy.

1. Introduction

The distribution of net wealth varies among the age cohorts of European countries. In Western EU countries, such as Austria, Belgium, the Republic of Cyprus, Germany, Spain, Finland, France, Greece, Ireland, Italy, Luxembourg, Malta, the Netherlands, and Portugal, individuals at retirement age hold the majority of net wealth. This is consistent with the life-cycle theory developed by Modigliani and Brumberg (1954). However, in Eastern EU countries, including Hungary, Latvia, Estonia, Poland, Slovenia, and Slovakia, net wealth distribution has shifted toward younger age groups. Fig. 1 illustrates the ratio of net wealth to the mean value of total net wealth in a country by age cohort.

This paper analyzes the potential impact of variations in the shape of net wealth distribution by age on monetary policy effectiveness. In doing so, the underlying reasons for age-related differences in wealth distribution must be determined. Thus, the paper has a twofold objective. First, it examines plausible explanations for observed variations in net wealth distribution by age in the relevant countries. Second, it constructs a comprehensive theoretical framework incorporating these factors to assess the effects of monetary policy shocks.

Several factors could account for cross-country variations in the distribution of net wealth by age, including demographic characteristics; social; cultural; and historical backgrounds, household preferences, and institutional disparities. Extensive research by scholars such as Jappelli (1999) and Kapteyn et al. (2005) reveals that the principal determinants of wealth distribution by age are productivity variations across cohorts and the social security policies of individual countries. Specifically, these studies highlight how the disparities in productivity growth generate differences in permanent incomes across generations, thereby affecting the accumulation of wealth by individuals. In addition, these studies underscore the role of time in wealth accumulation, as the year of birth can significantly influence an individual's wealth trajectory. Moreover, the observed differences in historical contexts and age profiles between the two sets of countries further contribute to the overall variation in net wealth distribution.

Until the end of the 20th century, the countries of Eastern Europe were participants in a centrally planned economic system. Following the system's collapse, disparities in productivity among cohorts have become apparent. Specifically, older workers encounter implicit barriers when processing new resources stemming from the new system, which in turn hinders productivity. Thus, younger individuals earn higher labor income than their older counterparts. This phenomenon is known as "generational heterogeneity" in productivity. The higher

☆ We are very grateful to anonymous referees and the co-editor, Angus C. Chu, for their excellent comments and suggestions to improve the quality of this paper. We would also like to thank the participants and, in particular, the discussants of the 4th CESEEnet Research Workshop (Andrea Colabella), 2nd Baltic Economic Association Conference (Elliot Aurissergues), 7th Luxembourg Workshop on Household Finance and Consumption (Amer Tabakovic), 3rd Annual ESCB Research Cluster Workshop on Monetary Economics (Paola Di Casola), and 6th Conference on Household Finance and Consumption for comments and suggestions. All errors and omissions are ours. The views expressed in this paper are those of the authors and do not necessarily represent those of Latvijas Banka.

* Corresponding author.
E-mail addresses: ludmila.fadejeva@bank.lv (L. Fadejeva), zeynepkantur@gmail.com (Z. Kantur).

https://doi.org/10.1016/j.econmod.2023.106336
Received 18 October 2022; Received in revised form 25 April 2023; Accepted 26 April 2023
Available online 6 May 2023
0264-9993/© 2023 Elsevier B.V. All rights reserved.

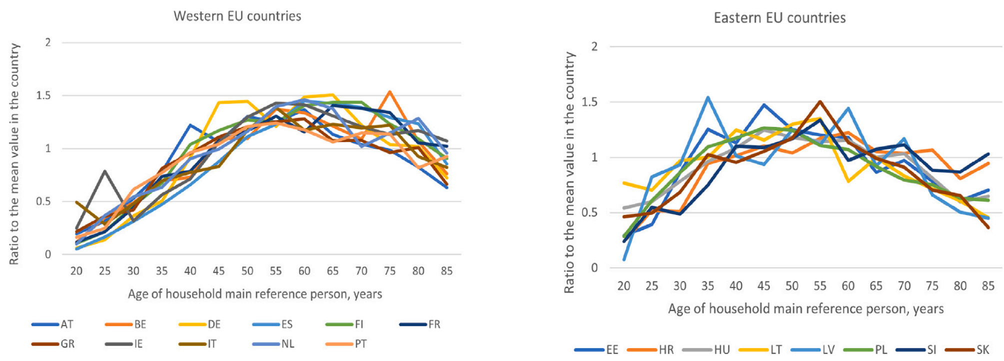


Fig. 1. Ratio of net wealth to country mean by age cohort.
Source: Authors' estimations using Household Finance and Consumption Survey Wave 3 data obtained during 2016–2017.

wage income that young workers receive at the outset of their careers results in accelerated wealth accumulation. Conversely, in Western European countries, there is little evidence of a productivity gap between generations, and net wealth accumulation reaches its peak at retirement age. The sections that follow present evidence in support of our hypothesis regarding the existence of "generational heterogeneity" in productivity levels.

The distribution of net wealth is influenced by several factors, including a country's demographics. In Western Europe, a considerable proportion of the population comprises retired individuals rather than those actively contributing to the workforce, resulting in higher old-age dependency (OAD) ratios. As a consequence, the majority of the accumulated net wealth in these countries is held by the elderly population. In contrast, Eastern European countries have experienced lower OAD ratios over the past three decades, leading to a trend where the bulk of the net wealth distribution is tilted toward the younger individuals.

We know that the productivity gap between generations in Eastern EU countries will eventually disappear, and the OAD will increase as it has in Western EU countries. Therefore, the wealth distribution in Eastern and Western EU countries will likely resemble each other in the long term. However, currently, there are differences in net wealth distribution due to demographic differences and the productivity gap between generations.[1] Our goal is to analyze how disparities in wealth distribution influence the impact of monetary policy using a snapshot of the current situation.

In this paper, we study how the monetary policy effectiveness differs in the two groups of countries due to the differences in net wealth distribution at both age and aggregate levels. To do so, we develop a life-cycle New Keynesian model, which merges multiperiod overlapping generations (OLG) and dynamic new Keynesian (DNK) frameworks. Our approach considers the unique features of the Eastern and Western EU economies that affect the distribution of net wealth, leading to variations in monetary policy outcomes.

The main findings of the paper unveil significant insights into the relationship between net wealth distribution and monetary policy's effectiveness on output and inflation. At the aggregate level, the paper reveals that as the net wealth distribution shifts toward older age groups, the effectiveness of monetary policy diminishes due to the reduced interest rate sensitivity of the population. However, at an individual level, the study suggests that the monetary policy is more effective for younger individuals in the Eastern EU economies. The analysis further emphasizes that generational heterogeneity plays a pivotal role in shaping the net wealth distribution, which, in turn, influences the outcomes at both individual and aggregate levels. The paper also extends the work of prior literature by demonstrating that the natural interest rate decreases steadily not only as the OAD ratio surges but also as the productivity gap between generations diminishes, causing a skewed distribution of net wealth toward the elderly population. (Kantur, 2013; Carvalho et al., 2016; Kara and von Thadden, 2016; Wong, 2016; Bielecki et al., 2018). Lastly, the paper underscores that the different responses of Eastern EU and Western EU countries to monetary policy shocks can partly be attributed to variations in the age-based net wealth distribution.

2. Related literature

This paper pertains to various aspects of the monetary policy literature. To begin with, previous studies such as Kantur (2013), Wong (2016), Bielecki et al. (2018), Berg et al. (2019), Leahy and Thapar (2019), and Bielecki et al. (2021) have investigated the heterogeneous impact of monetary policy on different age cohorts. Notably, Wong (2016) and Berg et al. (2019) have emphasized the dissimilarities in consumption patterns among distinct age groups, demonstrating that monetary policy effectiveness is more significant for younger agents. Other studies, such as Leahy and Thapar (2019) and Selezneva et al. (2015), have examined the same question from different vantage points, suggesting that middle-aged households benefit most from expansionary monetary policy due to their high debt burden. This observation aligns with the research of Calza et al. (2013) and Cloyne et al. (2018), with both papers concluding that households with mortgages are more responsive to monetary policy, particularly when interest rates are flexible.

Our paper relates to two recent and noteworthy works, Bielecki et al. (2021) and Braun and Ikeda (2021), respectively. Bielecki et al. (2021) delves into the redistributive effects of monetary policy, considering life-cycle motives within a more elaborate asset structure framework than that used in our paper. Their focus centers on assessing the impact of monetary policy on housing, real, and nominal financial assets across various age groups. The paper shows that the primary drivers of redistribution are nominal assets and labor income, with real financial assets and housing having a relatively smaller impact. In addition, monetary policy easing leads to a redistribution of welfare

[1] In the model section, we assume that only these two factors account for the difference in wealth distribution between country groups. The majority of Eastern and Western EU countries are in the euro area. Therefore, for the simplicity of model comparison, we ignore that historical differences in countries' monetary policies may contribute to the current pattern of wealth distribution. Another factor that can affect the shape of wealth distribution, such as different degrees of elasticity of substitution in different regions, is explored in the working paper version of this article.

from older to younger generations. In contrast, Braun and Ikeda (2021) addresses the same question by endogenizing the portfolio decisions of households and demonstrates that consumption responses differ by age, with all households choosing to invest less in illiquid assets during periods of tight monetary policy. While our paper employs a simpler asset structure than the aforementioned works, our primary objective is to evaluate the influence of the shape of net wealth distribution on the effectiveness of monetary policy. Specifically, we examine how the productivity gap across generations and demographics of a country contribute to the shape of net wealth distribution and how this shape impacts the monetary policy effectiveness. We achieve this by using a simplified modeling structure that allows us to capture the observed shape of net wealth distribution and analyze its impact on the effectiveness of monetary policy.

Moreover, our contribution delves into the existing body of literature on the effectiveness of monetary policies in European countries. A comprehensive examination of pertinent studies, including the works of Feldkircher and Huber (2016), Fadejeva et al. (2017), Burriel and Galesi (2018), and Hajek and Horvath (2018), reveals that the impact of policy rate changes in Central and Eastern European countries surpasses that of their Western counterparts. In this paper, we elucidate the factors that account for the observed disparities in response among these countries, mainly by analyzing the shape of the net wealth distribution. Our findings indicate that a net wealth distribution skewed toward younger age groups due to a productivity gap between cohorts may elucidate, at least in part, the stronger volatility of responses witnessed in Eastern than in Western European countries.

The remainder of the paper is organized as follows: Section 3 presents evidence of the characteristics that influence net wealth distribution. Section 4 develops the model, incorporating the multiperiod OLG model into the basic New Keynesian framework. Section 5 outlines the calibration for the quantitative exercise. Section 6 analyzes the impact of the monetary shock on economies with different demographic structures and productivity levels. Finally, Section 7 concludes.

3. Empirical evidence

This section presents empirical evidence on the factors that shape net wealth distribution across different age groups. Specifically, we examine how demographic profiles and intergenerational productivity gaps within countries influence wealth distribution patterns.

We observe a significant difference between the age distribution and historical backgrounds of these two groups of countries. Eurostat statistics show that the OAD ratio, the proportion of the population aged 65+ compared with those aged 20–64, has increased steadily in the 28 EU countries over the last 38 years. It has risen from around 20% in 1970 to 33% in 2018. (See Fig. C.1(a) in Appendix C.) Furthermore, we observe that Eastern EU countries have a younger population than Western EU countries. This indicates that the former has a higher population growth rate. Kantur (2013) suggests that in economies with lower population growth rates, the effectiveness of monetary policy is lower due to the decreasing interest rate sensitivity of the entire economy. Thus, it raises concerns about the impact of population aging on the effectiveness of monetary policy in the EU.

The Eastern EU countries were part of a centrally planned economic system until the end of the 20th century. The collapse of the old system led to generational discrepancies in labor productivity in these countries. Lovász and Rigó (2013) conducted a related study on this issue, which proves the existence of an old–young productivity gap using linked employer–employee data for Hungary for 1986 to 2008. Like other Eastern European countries, Hungary underwent a rapid economic transition during this period. Therefore, access to new technologies and resources for workers of various age groups could vary, resulting in different wage levels. According to the study's findings, older skilled workers in Hungary became relatively less productive than young workers from 1992 to 1995.

In this paper, we use the term *generational heterogeneity* to refer to the situation where younger workers exhibit higher productivity levels than older workers at a given point in time. We hypothesize that this phenomenon should result in higher labor income for younger workers in Eastern European countries. To test our hypothesis, we analyzed EU-SILC microdata from 2005 to 2017.[2]

Fig. 2 displays wage–age profiles for 25 EU countries, highlighting interesting differences between Eastern and Western EU countries.[3] In Western EU countries, the ratio of individual to mean wage generally increases gradually, reaching the mean level after age 40, except for the UK, which shows a more hump-shaped profile similar to the United States (see Lagakos et al., 2018). Conversely, in Eastern EU countries, such as Latvia, Lithuania, and Estonia, age–wage profiles are more hump-shaped, indicating that young workers earn at the country-mean wage level. Conversely, older workers earn less than the mean wage. It is essential to note that Fig. 2 only describes the cross-sectional aspect of the wage–age profile and does not necessarily imply that an individual worker's lifetime wage schedule in Eastern EU countries follows the hump-shaped profile throughout their career.

Additionally, official statistics indicate a noteworthy contrast in the average annual real labor productivity growth per person between Eastern and Western EU countries. Over the past 18 years, Eastern EU countries experienced a 3% annual increase in real labor productivity, while Western EU countries only saw a 1% increase (see Fig. C.1(b)). Assuming *generational heterogeneity* between cohorts, the age–wage productivity profiles of Western EU countries should exhibit flatter shapes than those of Eastern EU countries, as demonstrated by the wage–age profile illustrated in Fig. 2.

4. The model

This section presents a framework combining the standard New Keynesian model and the T-period OLG model. Our model incorporates two significant factors that affect the shape of the distribution of net wealth across different age groups: (1) productivity growth between generations and (2) demographic characteristics.[4]

4.1. Households

All households are born as workers. In the first R period of their lifetime, they earn wage income by supplying labor and deciding how much to consume and save. Households can save in two types of assets: one-period nominally riskless discount bonds yielding a nominal return and equity shares of firms, which are infinite-lived assets.[5] After working for R periods, all households retire. During the $T-R$ retirement period, they stop supplying labor but continue to be financially active – savings in bonds and equity – and consume from their wealth. At the end of their lifetime, they consume everything and die. We assume that households do not leave bequests to their offspring. A representative household j who was born at time t and belongs to generation t chooses

[2] European Union Statistics on Income and Living Conditions.

[3] The wage levels are standardized across sectors for each country and year. Each data point in the age category represents a weighted average of the ratio between an individual's wage and the mean wage for the country/year calculated over the 2005–2017 period. A ratio of one indicates that the individual's wage is equivalent to the mean wage of the country in the specific age category.

[4] See Appendices A and B for the derivation of the model.

[5] This study explains the effect of net wealth distribution resulting from the above-motivated factors on the transmission of monetary policy. Therefore, we have abstracted the model from a mortgage market. As studied by Garriga et al. (2021), the mortgage market requires a more complex borrowing/lending scheme with different asset maturities. We prefer to abstract our model from this kind of trade-off.

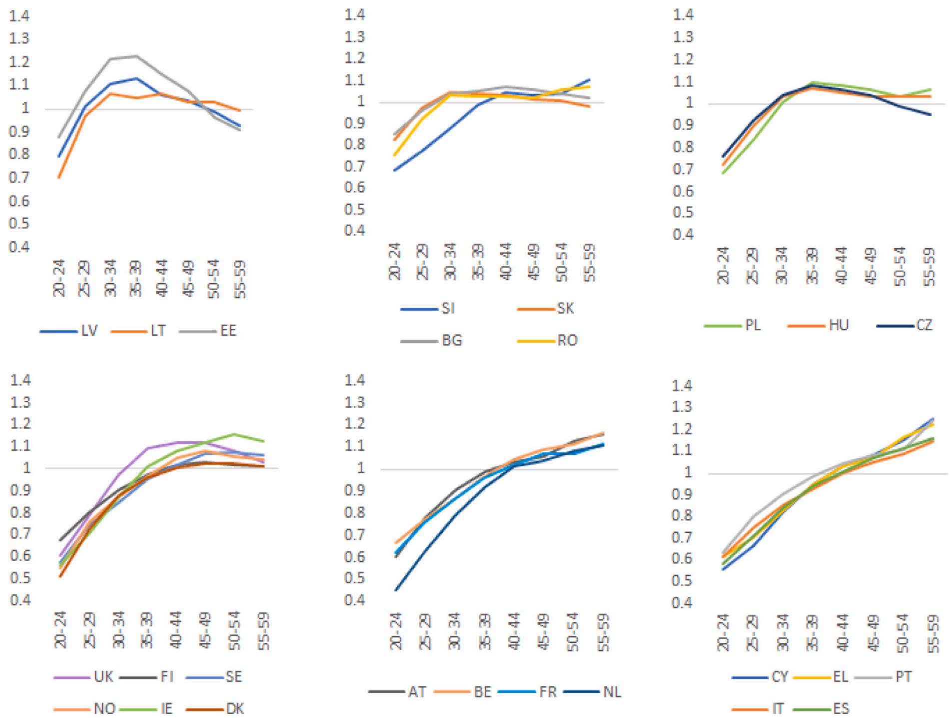


Fig. 2. Wage ratios by cohort and country.
Note: For each age category and country, the figure displays the ratio between the (full-time) wage level of the particular age group and the mean (full-time) wage level of the country. Wages are normalized for each sector, year and country. A ratio of 1 represents the average wage level in the country.
Source: EU-SILC microdata, Eurostat. Data periods: 2005–2017 for Bulgaria and 2007–2017 for Romania.

consumption and labor supply plans to maximize expected lifetime utility:[6]

$$V_t^j = \sum_{k=1}^{R} \beta^{k-1} E_{t+k} \left(\frac{C_{t+k-1}^k(j)^{1-\sigma}}{1-\sigma} - \frac{N_{t+k-1}^k(j)^{1+\psi}}{1+\psi} \right) + \sum_{k'=R+1}^{T} \beta^{k'-1} E_{t+k'} \left(\frac{C_{t+k'}^{k'}(j)^{1-\sigma}}{1-\sigma} \right)$$

where β is the individual's time discount factor, and the parameters σ and ψ represent the inverse of the intertemporal elasticity of substitution and Frisch elasticity of labor supply, respectively. C^k and N^k are the consumption and labor supply of household j at the age of k.[7] The household j earns wage income $WZN^k(j)$ until period R, where Z is an index for the productivity of household j that is constant over its lifetime.[8] The period-budget constraints that the representative household j faces are

$$P_t C_t^1(j) + B_t^1(j) + P_t \int_0^1 Q_t(i) S_t^1(j,s) di = W_t Z_t N_t^1(j)$$

$$P_{t+1} C_{t+1}^2(j) + B_{t+1}^2(j) + P_{t+1} \int_0^1 Q_{t+1}(s) S_{t+1}^2(j,s) di = W_{t+1} Z_t N_{t+1}^2(j) + B_t^1(j)(1+i_t) + P_{t+1} \int_0^1 \left(Div_{t+1}(s) + Q_{t+1}(s) \right) S_t^1(j,s) di$$

$$\vdots$$

$$P_{t+T} C_{t+T}^T(j) = B_{t+T-1}^{T-1}(j)(1+i_{t+T-1}) + P_{t+T} \int_0^1 \left(Div_{t+T}(i) + Q_{t+T}(i) \right) S_{t+T-1}^{T-1}(i,j) di$$

where $B^n(j)$ represents nominal bond holdings of household j, and i refers to the nominal interest rate. P is the price of consumption goods. r denotes the real interest rate. $Div(s)$ and $Q(s)$ represent real dividends paid by the monopolistic competitive firm s and the share price of the firm s, respectively. $S_t(j,s)$ shows the number of shares of firm s held by household j.[9] The intertemporal budget constraint of representative household j is

$$\sum_{k=0}^{T-1} \frac{C_{t+k}^{k+1}}{\prod_{j=0}^{k}(1+r_{t+j-1})} = Z_t \sum_{k=0}^{R-1} \frac{W_{t+k}}{P_{t+k}} \frac{N_{t+k}^{k+1}}{\prod_{j=0}^{k}(1+r_{t+j-1})}. \tag{1}$$

[6] Owing to the abundance of indexing letters present in the model, a prudent decision was made to abstain from introducing another index to track the generations. Hence, an agent who was born at time t belongs to the generation t.

[7] We introduce index k to keep track of age-specific consumption and labor supply.

[8] We assume that a representative agent born at time t belongs to generation t and has a constant productivity level over his/her lifetime denoted by Z_t. However, a representative agent of the next generation born at time $t+1$ has a productivity level denoted by Z_{t+1}, which may differ from Z_t. The productivity levels of each generation grow at a constant rate of g.

[9] Differently from the standard DNK model, we have an equity market in this setup, which enables us to combine the short-lived agents to infinite living firms. Firm ownership is transferred through the equity market—that is, when agents buy firm stocks and become owners of them.

4.2. Production side

The basic New Keynesian framework, as proposed by Clarida et al. (1999), models the production side of the economy. This framework considers two types of firms: consumption (final) and intermediate goods producers. Imperfect competition exists in the intermediate goods market, assuming each firm produces a differentiated good. Price-setting behavior follows a staggered approach, following Calvo (1983), where every period, a random fraction of firms optimally set prices.

4.2.1. Consumption (final) good producers

There is a continuum of intermediate goods indexed by $s \in [0,1]$, which are transformed into homogeneous consumption goods according to the constant returns-to-scale production function:

$$Y_t = \left[\int_0^1 Y_t(s)^{\frac{\epsilon-1}{\epsilon}} ds\right]^{\frac{\epsilon}{\epsilon-1}}$$

where $Y_t(s)$ is the quantity of intermediate good s and $\epsilon > 1$ denotes the price elasticity of demand. The consumption goods sector is subject to perfect competition, which determines the demand function for representative intermediate good s:

$$Y_t(s) = \left(\frac{P_t(s)}{P_t}\right)^{-\epsilon} Y_t$$

where $P_t(s)$ and P_t denote the price of good s and the average price level, respectively. The CES structure of technology in the final goods sector, P_t, is given by

$$P_t = \left(\int_0^1 P_t(s)^{1-\epsilon} ds\right)^{\frac{1}{1-\epsilon}}.$$

4.2.2. Intermediate good firms

Each intermediate firm produces a differentiated good s. All the firms have an identical technology, represented by the following production function at time t:

$$Y_t(s) = \sum_{k=1}^{R} Z_{t-k+1} N_t^k(s) \tag{2}$$

where $Y_t(s)$ and $N_t^k(s)$, respectively, denote the output of firm s and the hours worked demanded by firm s from the age group k at time t. The labor market is competitive, i.e., the nominal wage rate W is taken as given in the production of good s. Intermediate firms are owned by the equity holders and are managed to maximize the profit to the current owners. Through the final goods sector, intermediate firm s faces a downward-sloping demand curve. At time t real profits (dividends) are:

$$Div_t(s) = Y_t(s) - \frac{W_t}{P_t}\sum_{k=1}^{R} Z_{t-k+1} N_t^k(s).$$

Following Calvo (1983), nominal price rigidity is modeled by allowing random intervals between price changes. At each period, a firm adjusts its price with a constant probability $(1-\theta)$ and keeps its price fixed with probability θ.

4.3. The central bank

The monetary policy authority follows a standard Taylor (1993)-type feedback rule:

$$i_t = \rho\, i_{t-1} + (1-\rho)[\phi_\pi(\pi_t) + \phi_y(\hat{y}_t)] + v_t$$

where ϕ_π and ϕ_y are feedback parameters, π_t is the deviation of the rate of inflation from zero-inflation steady state, and $\hat{y}_t$ is the deviation of the level of productivity-adjusted output from its steady-state value. Parameter ρ denotes the degree of policy inertia. The exogenous component of the monetary policy is denoted by v_t and follows an AR(1) process:

$$v_t = \rho_v v_{t-1} + \epsilon_t^v$$

where ϵ_t^v denotes the monetary policy shock and $\rho_v \in [0,1)$ shows the persistence of the shock.

4.4. Demographics

There exist T cohorts at a given time. For each period t, a new cohort is born into the economy, and the existing cohorts become one period older. We assume a constant population growth rate of n. The number of retired agents at time $t+k$ is

$$N_{t+k}^r = (1+n)^k \sum_{i=0}^{T-R-1} (1+n)^i$$

The number of workers at time $t+k$ is

$$N_{t+k}^w = (1+n)^k \sum_{i=T-R}^{T-1} (1+n)^i$$

Finally, it is useful to define an indicator for aging, the OAD ratio. It is the ratio of retired to employed agents in period t:

$$OAD_t = \frac{N_t^r}{N_t^w}.$$

4.5. Market clearing and equilibrium conditions

Variables are normalized by the youngest agents' productivity level Z and the number of workers at a given period N^w. The goods market-clearing condition requires that

$$\mathcal{Y}_t = \sum_{k=1}^{T} C_t^k \tag{3}$$

where $\mathcal{Y}_t$ and C_t^k refer to the productivity-adjusted per worker output level and productivity-adjusted per worker consumption level of the age group k. Labor market clearing implies

$$N_t = \sum_{k=1}^{R} \frac{N_t^k(s)}{(1+g)^{k-1}} = \mathcal{Y}_t \int_0^1 \left(\frac{P_t(s)}{P_t}\right)^{-\epsilon} ds \tag{4}$$

where the term $\left(\int_0^1 \left(\frac{P_t(s)}{P_t}\right)^{-\epsilon} ds\right)$ is the measure of price dispersion across firms. At equilibrium, agents do not trade bonds among themselves; therefore, total bond holdings are $\sum_{k=1}^{T-1} B_t^k = B_t = 0$. The aggregate stock outstanding equity for each intermediate goods-producing firm must equal the corresponding amount of issued shares normalized to 1 $\forall s \in [0,1]$. Hence, the market-clearing condition for shares at time t requires $\sum_{j=1}^{T-1} S_t(j,s) = 1$.

Finally, productivity-adjusted real dividend payments by the intermediate firms and real stock price index are given:

$$Div_t = \int_0^1 Div_t(s)ds \qquad Q_t = \int_0^1 Q_t(s)ds. \tag{5}$$

Next, we derive the log-linearized equilibrium conditions.

4.6. Log-linearized dynamics

The system of equations is log-linearized around the zero-inflation steady state. We use lower case letters to show the log of the variable and a hat to indicate the percentage deviation from its steady-state value. The household side equations are as follows:

Labor supply decision of the representative agent:

$$\hat{w}_t - \hat{p}_t = \psi \hat{n}_t^k + \sigma \hat{c}_t^k \quad k \in \{1, R\}. \tag{6}$$

where $\hat{c}_t^k = log(C_t^k/(C^{k*}Z_tN_t^w))$ denotes the log deviation of consumption of age group k from its value along the *balanced growth path* (BGP).

Euler equation:

$$\hat{c}_t^k = E_t\{\hat{c}_{t+1}^{k+1}\} - \frac{1}{\sigma}[\hat{i}_t - E_t\{\hat{\pi}_{t+1}\}] \quad k \in \{1, T-1\}. \tag{7}$$

Eq. (6) refers to the labor supply decision of a household at the age of k at time t. Eq. (7) is the log-linearized Euler equation of a household at the age of k at time t.[10]

The OLG–IS equation is:

$$\hat{y}_t = \sum_{k=1}^{T} \frac{C_k^*}{y^*}\hat{c}_t^k \tag{8}$$

where $\hat{y}_t$ denotes the log deviation of productivity-adjusted per worker output from its value along the BGP. The OLG–IS equation depends not only on the current period's interest rate and expected inflation but also on the historical interest rate, expected inflation rates, and realized inflation. Since at time t there are T different types of generations who optimize their choices according to the available information. Younger agents at time t decide their consumption using the current period's information. However, the oldest agent of period t has chosen its consumption level in the previous periods using the information available in earlier periods. Therefore, a richer dynamic system is achieved than the standard DNK–IS equation. The slope of the OLG-IS equation depends on the weight distributions of consumption levels by age group. The distribution of weights depends on the population growth rate, n, and the productivity growth rate between generations, g.

Finally, Eqs. (9) and (10) show the log-linear form of stock-price and dividend equations:

$$\hat{q}_t = \Omega[(\frac{div^*}{q^*}\widehat{div}_{t+1} + \hat{q}_{t+1}] - (\hat{i}_t - E_t\{\pi_{t+1}\})) \tag{9}$$

$$\widehat{div}_t = \frac{\mathcal{Y}^*}{div^*}\hat{y}_t - \frac{W^*N^*}{P^*div^*}(\hat{w}_t - \hat{p}_t + \hat{n}_t) \tag{10}$$

where $\Omega = \frac{(1+g)(1+n)}{(1+i^*)}$.

The log-linearized equations of the firm side of the model are the production function and the forward-looking Phillips equation.[11]

$$\hat{y}_t = \hat{n}_t \tag{11}$$

$$\pi_t = \tilde{\beta}\tilde{\Lambda}E_t\{\pi_{t+1}\} + \tilde{\kappa}\widehat{mc}_t \tag{12}$$

where $\widehat{mc}_t = \hat{w}_t - \hat{p}_t$ is the deviation in the real marginal cost from its steady state. $\tilde{\beta} = \beta((1+n)(1+g))^{-\sigma}$ is the population and productivity-adjusted discount factor. $\tilde{\Lambda} = \left(C_t^{k+1}/C_t^k\right)^{-\sigma}$ is the steady state of the (gross) growth rate of consumption. We can express inflation as the discounted sum of current and expected future deviations of marginal costs from steady state by solving the above equation forward. $\tilde{\kappa} = \frac{(1-\theta)(1-\theta\phi)}{\theta}$ shows the responsiveness of inflation to marginal cost.

Due to the OLG setup on the demand side, we obtain an unconventional Phillips equation. Unlike the standard Phillips equation, the weights of the expected inflation and marginal cost depend on productivity and the population growth rate. The finite lifetime of agents leads society to value the expected inflation less than the standard DNK framework. However, as the population ages (and/or productivity growth rate increases), both coefficients, $\phi = \tilde{\beta}\tilde{\Lambda}$ and $\tilde{\kappa}$ converge to the values of the standard infinite-lived problem.

Equilibrium is characterized by Eqs. (6)–(12) and (1), as well as describing monetary policy.

4.7. Balanced growth path

To obtain the values of labor supply N_k^* $k \in \{1, R\}$, consumption C_k^* $k \in \{1, T\}$ and interest rate i^* on BGP, we solve a system of equations that consists of $T-1$ steady state Euler equations, R steady state intratemporal labor-consumption equations, the intertemporal budget constraint, and the market-clearing condition for a given set of parameters σ, ψ, β, ϵ as well as population and productivity growth rates n and g.

$$C_{k-1}^{*-\sigma} = \beta((1+n)(1+g))^{-\sigma}C_k^{*-\sigma}(1+i^*) \qquad k \in \{2, T\}$$

$$C_k^{*-\sigma}\frac{1/\mathcal{M}}{(1+g)^{k-1}} = N_k^{*\psi}\left(\frac{\sum_{i=0}^{R-1}(1+n)^i}{(1+n)}\right)^{\sigma+\psi} \qquad k \in (1, R)$$

$$\sum_{k=1}^{T} C_k^*\left(\frac{(1+n)(1+g)}{1+i^*}\right)^{k-1} = \frac{1}{\mathcal{M}}\sum_{k=1}^{R} N_k^*\left(\frac{1+n}{1+i^*}\right)^{k-1}$$

$$\sum_{k=1}^{T} C_k^* = \sum_{k=1}^{R}\frac{N_k^*}{(1+g)^{k-1}}$$

On the BGP, the stochastic discount factor is also constant since the consumption growth rate is constant.

$$\Lambda = \frac{1}{1+i^*} = \beta[(1+n)(1+g)]^{-\sigma}\left(\frac{C_{k+1}^*}{C_k^*}\right)^{-\sigma}$$

The above relation shows that as the population and productivity growth rate increases, the steady-state interest rate rises, other parameters being equal. This relationship can be reconciled with the empirical finding of Papetti (2021), which states that the decline in effective labor due to aging and longer life expectancy results in a lower natural rate of interest rate. Fig. 3 illustrates the relation between productivity and population growth rate with the value of steady-state interest rate on the BGP.

Using steady-state values for consumption C^*, hours worked N^*, and interest rate i^*, we calculate the value of (productivity-adjusted) stock prices, q^*, and dividends, div^*, on the BGP.

$$div^* = (1 - 1/\mathcal{M})\sum_{k=1}^{T} C_k^*$$

$$q^* = \frac{(1+n)(1+g)}{i^* - n - n\,g - g}div^*$$

Moreover, by using the above steady states and period-budget constraints, we calculate wealth accumulation by an agent over a lifetime. In our analysis, the wealth of an individual is the summation of the riskless bond and equity holdings of an agent and represented as $A_k^* = B_k^* + q^*S_k^*$.

$$A_1^* = \left(\frac{1}{\mathcal{M}}N_1^* - C_1^*\right)$$

$$A_k^* = \left(\frac{1}{\mathcal{M}}\frac{N_k^*}{(1+g)^{k-1}} - C_k^* + \frac{(1+i^*)}{(1+g)(1+n)}A_{k-1}^*\right) \quad k \in (2, R)$$

$$A_k^* = \left(-C_k^* + \frac{(1+i^*)}{(1+g)(1+n)}A_{k-1}^*\right) \qquad k \in (R+1, T-1)$$

Values of A^* represent the distribution of the lifetime wealth of an individual on the BGP. They also show the distribution of wealth by age group.

5. Calibration

This section provides an overview of the parameterization used for the quantitative analysis. The model has been calibrated to an annual

[10] Differently from the standard New Keynesian model with a representative agent, the household's Euler equation and the goods market condition are not sufficient to derive the dynamic IS equation. The derivation of IS equation needs further work by aggregating the individual consumption functions obtained by combining the Euler equation and intertemporal budget constraint of the agent.

[11] See Appendix B for the detailed derivation of the supply-side equations and the Phillips relation.

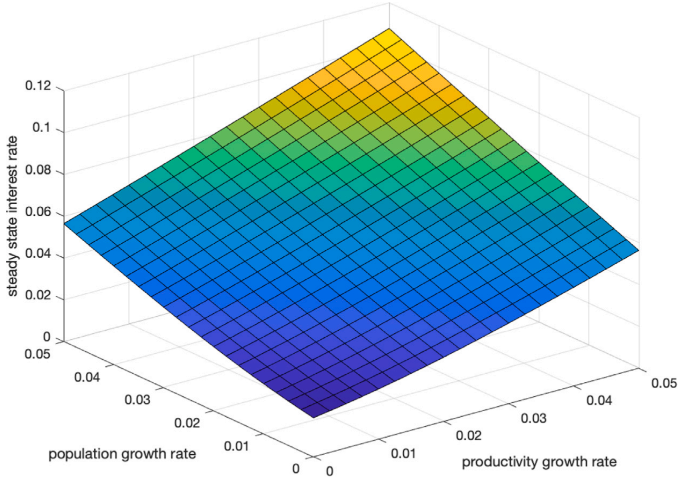


Fig. 3. The relation between steady-state interest rate and productivity and population growth rates on the balanced growth path. ($\sigma = 1$, $\psi = 1$, $\beta = 0.98$).

Table 1
Parameter values.
Source: Authors' estimations for different model specifications.

	Model(1)	Model(2)	Model(3)	Model(4)	Model(5)	Model(6)
σ	1	1	1	1	1	1
ψ	1	1	1	1	1	1
n	0.0	0.0	0.0	0.0025	0.0025	0.0025
g	0.0	0.01	0.02	0.0	0.01	0.02
ϵ	11	11	11	11	11	11
μ	1.1	1.1	1.1	1.1	1.1	1.1
β	0.98	0.98	0.98	0.98	0.98	0.98
ϕ	0.982	0.986	0.990	0.983	0.987	0.990
κ	0.088	0.087	0.086	0.088	0.086	0.086
$\tilde{\beta}$	0.980	0.970	0.961	0.978	0.968	0.958
OAD	30.0	30.0	30.0	27.6	27.6	27.6

Note: T=65, R=50.

Table 2
Consumption and labor growth rates with model calibration results, %.
Source: Authors' estimations for different model specifications and HFCS wave 3 data.

	Western EU	Eastern EU	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
$N_R^*/N_{R-1}^* - 1$	0.2	−0.3	−1.0	−0.2	−0.7	−1.4	−0.3	−1.5
$C_T^*/C_{T-1}^* - 1$	−0.2	−0.7	−1.0	−0.3	−0.7	−1.0	−0.3	−0.6

Note: Total consumption and gross income are estimated per adult household member aged 35–75. Value by region is estimated as a simple country average.

frequency. The key variables and their respective parameter values are summarized in Table 1.

The average annual labor productivity growth rate in most Western EU countries from 1996 to 2018 was positive but below 1%. On the other hand, in Eastern EU countries, the average labor productivity growth rate for the same period was above 3% (see Appendix C Fig. C.1(b)). This observed difference in productivity growth rates is incorporated into our model through the assumption of *generational heterogeneity*. We assume that the productivity level of agents remains constant throughout their lifetimes, but there is an increase of g percent in productivity level from one generation to the next.

In Models (1)–(3), we assign different values, 0%, 1% and 2%, for the productivity growth rate g between cohorts and set the growth rate of population n to zero. In Models (4)–(6), different from Models (1)–(3), the population growth rate is set to 0.25%, implying an economy with a lower OAD ratio. For plausible model comparison, we keep parameters of (inverse of) intertemporal elasticity of substitution σ, the Frisch elasticity of labor supply ψ, price elasticity of demand (and therefore markup $\mathcal{M}$), and the (subjective) discount factor β constant. Population and productivity growth rate parameters are chosen to replicate the OAD ratios, the shape of net wealth distribution, and the change in labor supply and consumption between cohorts observed in the HFCS data for Eastern and Western EU countries.

The average life expectancy in Europe is approximately 85 years. We set T to 65, assuming people start working at the age of 20 and die at the age of 85.[12] According to Eurostat statistics, the OAD ratio in various European Union countries has grown over the last four decades, from 20% in 1980 to 33% in 2018 (see Appendix C Fig. C.1(a)). For calibration purposes, we choose the population growth rate n to fit the OAD ratio for the selected country groups during 2000–2018 (Western EU—29% and Eastern EU countries—27%).

The rest of the parameters in Table 1 are derived from the assumptions made above. The coefficients of the Phillips relation $\phi = \tilde{\beta}\tilde{\Lambda}$ and κ (see Eq. (12)) emphasize that in economies with generational heterogeneity, current inflation depends relatively more on inflation expectation and less on deviations of the real marginal costs. As the productivity gap between cohorts declines, the relative importance of deviation in the real marginal costs increases.

The assumption of a generation-specific productivity level allows us to fit the ratios of net wealth holdings to the results of the 3rd HFCS wave (see Fig. 4).[13] As the productivity gap widens and the OAD ratio declines, wealth distribution skews toward younger age groups. The ratios of net wealth to the mean level of net wealth by cohort obtained from Models (2) and (5) are best suited for Western EU countries, while those from Models (3) and (6) are more appropriate for Eastern EU countries.[14]

Next, to pick the specific version of the model to represent the region, we compare model fit with respect to the growth rates of income

[12] We assume that the agents come into world at the age of 20 and work until the age of 70. After 15 years of retirement, agents die at 85.

[13] The HFCS datasets can be reached at: https://www.ecb.europa.eu/stats/ecb_surveys/hfcs/html/index.en.html.

[14] Fig. D.1 in the Appendix displays the distributions of net wealth by age groups measured by the corresponding population and productivity growth rates defined in all six models.

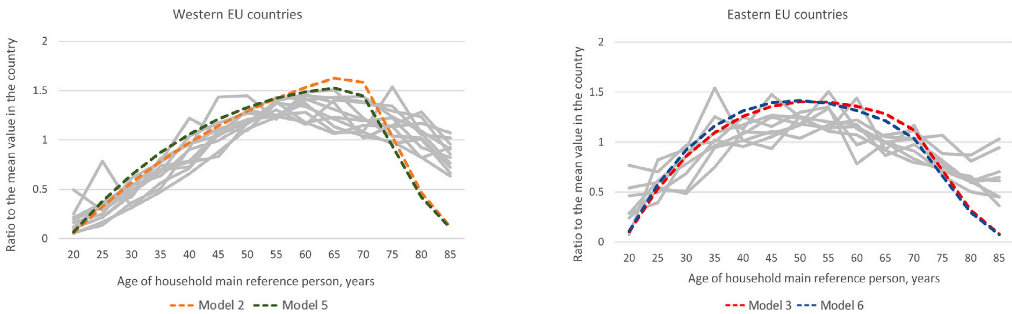


Fig. 4. Calibrated ratios of net wealth to country mean by cohort. Note: gray lines correspond to the lines in Fig. 1.
Source: Authors' estimations for different model specifications and authors' estimations using HFCS Wave 3 data obtained during 2016–2017.

Table 3
Model calibration results—steady state net wealth-to-income ratios.
Source: Authors' assumptions and estimations for different model specifications.

	Western EU	Eastern EU	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
$A^*/(w * N^*)$								
age 25–29	2.35	4.61	0.62	1.82	2.9	0.9	2.1	3.14
age 30–34	2.54	3.88	1.17	2.85	4.3	1.7	3.3	4.77
age 35–39	3.28	5.29	1.92	3.90	5.6	2.6	4.5	6.25
age 40–44	4.22	6.51	1.92	3.90	5.6	2.6	4.5	6.25
age 45–49	5.13	7.85	3.63	5.51	7.2	4.4	6.4	8.10
age 50–54	5.93	7.09	4.77	6.26	7.7	5.6	7.2	8.70
age 55–59	6.85	8.42	6.08	6.94	8.0	6.9	7.9	9.04
age 60–64	8.35	10.63	7.59	7.57	8.0	8.4	8.5	9.11
age 65–69	9.48	10.50	9.30	8.13	7.9	10.0	9.0	8.90
SSE (West.EU)				3.66			6.78	
SSE (East.EU)					18.71			12.33

and consumption between age groups (see Table 2) and the big ratios of net wealth-to-income (see Table 3).[15]

The models assume constant consumption and labor income growth rates across age groups, but the HFCS data shows that these growth rates generally decrease between the ages of 35 and 75. This is because, in most countries, individuals reach their maximum income level by the age of 40. Additionally, growth rates differ significantly between the two groups of countries, with slower changes between cohorts observed in Western EU countries and steeper changes were seen in Eastern EU countries (see Table 2). These findings suggest a productivity gap among generations, which is consistent with the data.

The higher productivity growth rate between the cohorts leads to a steeper decline in wage income among age groups. Consumption is affected by a change in wage income and net wealth; thus, faster accumulation of the net wealth, as in Model (6), results in a slower decline in the consumption growth rate than the labor income growth rate. This result is in line with the estimates for the Eastern EU countries. In Western European countries, there is a comparable rate of decline in both consumption and labor income, as reflected by the findings of Model (5). However, in terms of level, the fit of Model (2) is more precise.

Net wealth-to-income ratios for different age groups increase with age (see Table 3). This ratio tends to be higher in the younger age categories in Eastern EU countries due to faster net wealth accumulation. Model results are similar in size and direction to the net wealth-to-income ratios estimated from the HFCS database. For the models of interest, we estimate the sum of squared errors (SSE) between the wealth-to-income ratios for the corresponding country group and the model. Smaller SSE indicates a better fit. Model (6) confirms the best fit in representing Eastern EU countries, and Model (2) was chosen to represent Western EU countries in the following sections of the paper.

6. Results

This section analyzes the impact of a monetary policy shock on variables related to the aggregate economy and age groups within the context of the economic model detailed earlier. The study proceeds to evaluate the effects of a unit increase in policy rates of comparable magnitude in countries located in the Eastern European region with high productivity and population growth rates and Western European countries with lower productivity and population growth rates.[16]

A tightening monetary policy shock impacts the economy through three channels: First, the *substitution effect* arises as households tend to delay current consumption due to rising prices for goods and services. Second, the *wealth effect* kicks in as the interest rate increases, leading to an increase in the household's future financial income, thereby encouraging more consumption today. However, the wealth effect weakens as individuals age. Third, the *income effect* comes into play as the policy rate shock affects labor supply decisions. As the real interest rate increases, consumption growth also rises, leading to reductions in current consumption and hours worked, which in turn cause a decline in real wages (following Eq. (6)).

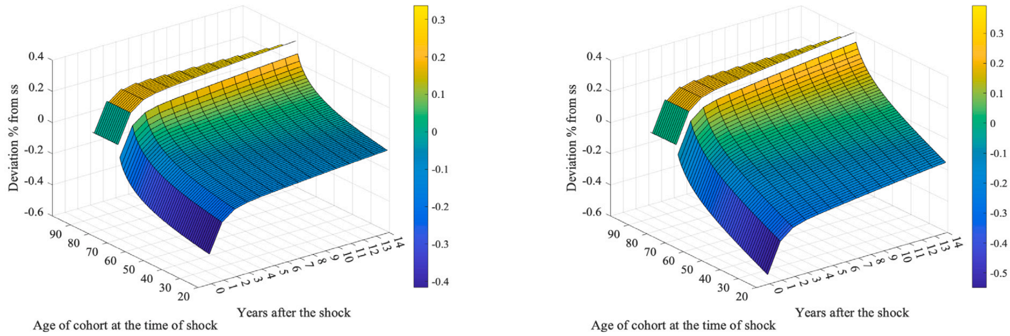
When real wages decline, dividends tend to rise. This affects workers' incomes, as it is a combination of both wages and profits. As household income from dividends increases, individuals may choose to work less. The distribution of wealth across different age groups plays a vital role in determining the income effect. The impact of monetary policy on labor supply varies with the distribution of wealth and also affects response of the aggregate economy. To investigate the dynamics of the model, we set the intertemporal elasticity of substitution, σ, to 1, effectively neutralizing the transmission of interest rate changes through the first two channels. By doing so, the substitution effect resulting from a change in interest rates counteracts the wealth effect on consumption, leaving the income effect as the sole remaining channel.[17]

To begin, we analyze the impact of a 25 basis point monetary policy shock on consumption and labor across different age groups in Western and Eastern EU countries. The Figs. 5(a) and 5(b) depict the impulse

[15] Consumption data in HFCS is self-reported and less reliable than income or net wealth. Thus, we chose to concentrate on the net wealth-to-income ratio for calibration purposes.

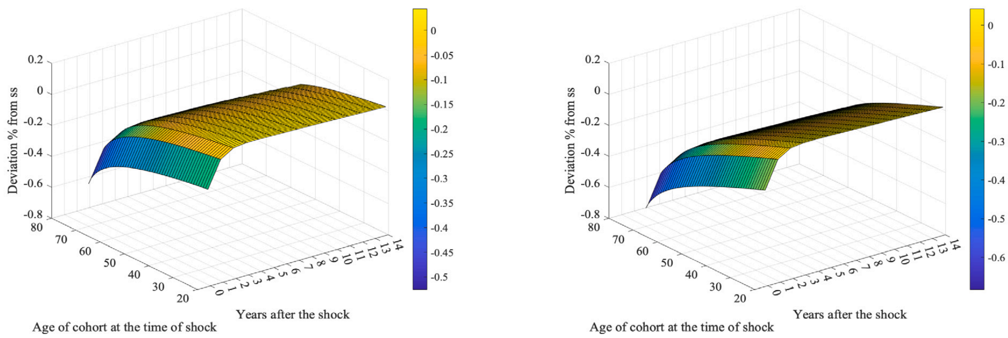
[16] Western EU corresponds to Model(2), and Eastern EU corresponds to Model(6) in the calibration section.

[17] The working paper version of this paper includes analyses for varying degrees of elasticity of substitution. The wealth and substitution channels are also effective.



(a) Western EU (b) Eastern EU

Fig. 5. Consumption responses to 25 bps-tightening monetary policy shock.



(a) Western EU (b) Eastern EU

Fig. 6. Labor responses to 25 bps-tightening monetary policy shock.

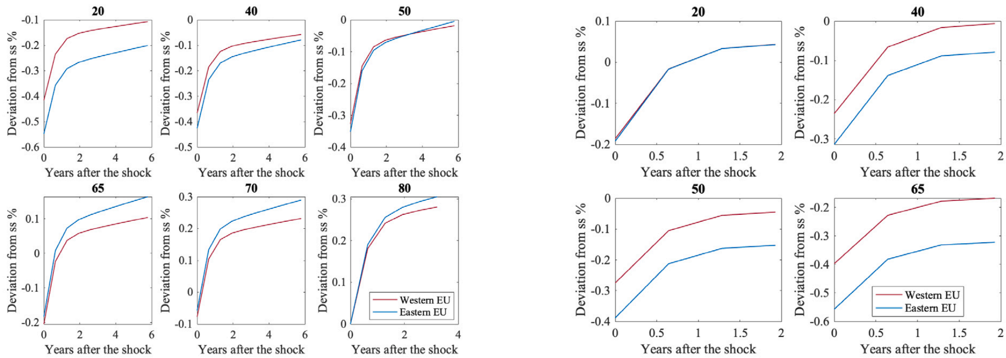
response functions of consumption for each age group, assuming a 0% population growth rate and 1% productivity growth rate for the Western EU countries (Model (2)) and a 0.25% population growth rate and 2% productivity growth rate for the Eastern EU countries (Model (6)).

The x-axis shows the age at the time of the shock, the y-axis is years after the shock, and the z-axis illustrates the deviation of consumption from its steady-state value.[18] Figs. 5(a) and 5(b) exhibit that the consumption levels fall after a positive monetary policy shock. The decline in consumption is less pronounced as workers become older. Moreover, retired agents do not change their consumption in this case, since the *wealth effect* cancels out the *substitution effect* under this parameterization. The only significant channel is the negative *income effect* that is not available to retired agents on impact since their income merely relies on financial assets. On the other hand, the labor income of the working-age population is affected by declines in both wage and labor levels. An increase in the nominal interest rate reduces the output gap and wages. The wage decline results in a lower marginal cost of production, increasing markups and dividend payments to firms' shareholders. Depending on wealth accumulation from the positive income effect, workers suppress the amount of labor they supply. Hence, the labor income of workers falls. Consumption for agents with relatively fewer asset holdings decreases, particularly for young workers. A reduction in the real wage is less detrimental for older people since the decline in real wages increases profits and hence the dividend income of asset holders. In Western EU countries, the accumulation of wealth is maximized at the retirement age; therefore, as workers become older, we observe a higher decline in labor supply (see Fig. 6(a)) and a lower decline in consumption (see Fig. 5(a)). On the other hand, in Eastern EU countries, the majority of wealth is held by middle-aged workers. Therefore, the decline in labor supply (see Fig. 6(b)) is starker, resulting in a more pronounced decline in consumption.

The comparison of consumption and labor impulse responses to a 25 bps-tightening monetary policy shock for specific age groups in Eastern and Western EU countries can be found in Figs. 7(a) and 7(b). The age labels above the graphs indicate the age at the time of the shock. The results demonstrate that the impact of the monetary policy shock varies across age groups in country groups, as well as within each country's age groups.

The decline in labor is more substantial for all age groups in Eastern EU countries due to a more pronounced decline in labor income. Following that, we observe that until the age of 50, consumption responses are stronger in Eastern than Western EU countries. On the other hand, the initial consumption responses in the two country groups become much closer for the age group 50–65 despite stronger labor tightening. This result arises because a decline in the wage level leads

[18] The method of interpreting impulse responses differs in this study from the standard infinite living agent models. Typically, the standard setup involves a representative agent whose consumption response to a shock is depicted on a single graph. However, in this framework, 65 agents coexist within a given period, with their consumption and labor decisions illustrated using surface graphs. This allows for a more nuanced understanding of how agents' choices may vary in response to external shocks.



(a) consumption (b) labor

Fig. 7. Age cohort responses to 25 bps-tightening monetary policy shock.
Note: the youngest worker is 20 years old and the oldest worker is 70 years old. The 80 years old agent represents a retired agent.

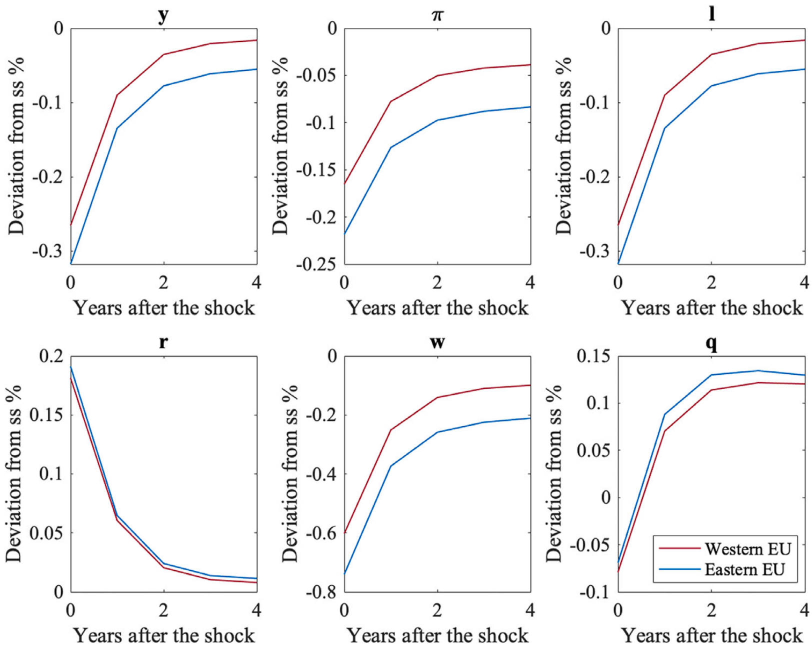


Fig. 8. Responses to 25 bps-tightening monetary policy shock.

to an increase in shareholders' dividend income. The wage increase is more pronounced in Eastern EU countries, with higher productivity growth and lower OAD ratios. Thus, the relatively fast consumption recovery for this age group in Eastern EU countries is partly explained by the higher return from asset holdings. Moreover, since in the Eastern EU countries, wealth accumulation reaches a maximum around 50 to 55 years of age, the slope of the immediate consumption responses of age groups is steeper than it is for Western EU countries.

Fig. 8 illustrates the response of aggregate variables to a monetary policy tightening shock. Depending on the demographic composition and productivity levels of the society (and therefore, the distribution of net wealth), the magnitude of decreased output varies between Eastern and Western EU countries. Due to a greater decline in consumption in Eastern EU countries, output falls more than in Western EU countries. Since labor is the only input in the production of final goods, equilibrium labor decreases with the output level. The reduction in consumption and labor puts downward pressure on wages, with the fall being more pronounced in Eastern EU countries. In the New Keynesian model, inflation is driven by marginal cost, and accordingly, we observe a stronger decline in inflation in Eastern EU countries. This result is consistent with empirical evidence provided in the works of Feldkircher and Huber (2016), Fadejeva et al. (2017), Burriel and Galesi (2018), and Hajek and Horvath (2018), who demonstrate that the response of output and inflation to monetary policy shocks in Central and Eastern European countries could be greater than those observed in other euro area countries. Moreover, the more substantial decrease in asset values observed in Western EU countries can be attributed to the larger financial asset holdings of older individuals in aging economies than their counterparts in younger economies. Consequently, the impact of a similar monetary policy shock on asset prices is more pronounced in such countries. During retirement, individuals typically sell their assets to fund living expenses. However, in Eastern EU economies, wealth is primarily held by middle-aged individuals due to generational heterogeneity. As a result, people tend to spend their savings earlier, knowing that their earning potential will likely decrease in the future compared with younger generations. This leads to a limited supply of financial assets during retirement, with high demand from younger individuals. Consequently, asset prices experience a smaller decrease than in Western EU countries. In contrast, Western EU countries have a higher OAD ratio, resulting in a higher supply of financial assets during retirement. As a result, asset prices tend to decline more with increases in real interest rates.

7. Conclusion

This paper investigates whether differences in wealth distribution by age in Eastern and Western European countries impact the effectiveness of the monetary policy. Within this context, we first identify the sources of differences in wealth distribution by age in these two groups of countries. Next, we develop a coherent theoretical model incorporating these features to analyze the impact of monetary policy shocks.

Understanding the determinants of wealth distribution is a crucial first step. In Eastern EU countries, which were part of a centrally planned economic system until the end of the 20th century, notable disparities exist in productivity levels between generations. The system's collapse has resulted in implicit barriers for older workers in terms of adopting new resources and contributing to the productivity of the new system compared with their younger counterparts. As a result, younger individuals earn higher labor income than their older peers, creating a productivity gap between generations that affects the shape of age–net wealth distribution across countries. This implies that younger workers are more productive at a given time than older workers, allowing them to accumulate more wealth. In addition, we demonstrate that the age structure of economies plays a significant role in the differences in wealth distribution between these two groups of countries.

Theoretically, we develop a modified New Keynesian model that merges the multiperiod OLG and DNK frameworks. The household side of the model assumes an OLG structure, which enables us to introduce a productivity gap between generations and demographic characteristics into the model economy. The augmented framework is used to analyze the impact of wealth accumulation originating from the demographics and the productivity gap among generations on monetary policy effectiveness in a coherent general equilibrium model. We calibrate the model with HFCS data for Eastern and Western EU countries. Subsequently, we provide evidence that the effectiveness of monetary policy on output and inflation weakens as net wealth distribution moves toward older ages, i.e., in Western EU countries. Furthermore, we show that consumption by younger agents in Western and Eastern EU countries responds differently to the same monetary policy shocks.

Accordingly, our findings for responses to monetary policy shock suggest that the differently shaped net wealth distribution caused by differing productivity levels plays a key role in monetary policy effectiveness both individually and in the aggregate. We also show that the natural interest rate decreases monotonically as the OAD ratio increases and the productivity gap among generations disappears. Overall, the findings in this paper suggest that the stronger reactions of Eastern EU countries to monetary policy shocks compared to their Western EU counterparts can be partly attributed to differences in net wealth distribution by age.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We share the links of the data sources.

Appendix A. Household

The first-order conditions of the household's problem are

$$C_t^k(j)^{-\sigma}\frac{W_t Z_t}{P_t} = N_t^k(j)^{\psi} \quad k \in \{1, R\}. \tag{A.1}$$

$$C_t^k(j)^{-\sigma} = \beta E_t\left\{(1+i_t)\frac{P_t}{P_{t+1}}C_{t+1}^{k+1}(j)^{-\sigma}\right\} \quad k \in (1, T-1). \tag{A.2}$$

$$C_t^k(j)^{-\sigma} = \beta E_t\left\{\left[\frac{Q_{t+1}(s)+Div_{t+1}(s)}{Q_t(s)}\right]C_{t+1}^{k+1}(j)^{-\sigma}\right\} \quad k \in (1, T-1). \tag{A.3}$$

$$\Lambda_{t,t+1} = \frac{1}{(1+i_t)} = \beta E_t\left\{\left(\frac{C_{t+1}^{k+1}}{C_t^k}\right)^{-\sigma}\frac{P_t}{P_{t+1}}\right\} \tag{A.4}$$

Rearranging Eqs. (A.2) and (A.3), we obtain the no-arbitrage condition,

$$Q_t(s) = \frac{1}{1+r_t}\left[Q_{t+1}(s) + Div_{t+1}(s)\right].$$

Appendix B. Production side of the economy and derivation of the Phillips equation

Consumption (final) good producers:

$$Y_t = \left[\int_0^1 Y_t(s)^{\frac{\epsilon-1}{\epsilon}}ds\right]^{\frac{\epsilon}{\epsilon-1}}$$

$\epsilon > 1$: elasticity of substitution among differentiated intermediate goods.
Y_t: final good.
$Y_t(s)$: intermediate good s.

The profit maximization problem of the final goods producer is

$$\max_{Y_t(s)} P_t Y_t - \int_0^1 P_t(s) Y_t(s) ds$$

subject to

$$Y_t = \left[\int_0^1 Y_t(s)^{\frac{\epsilon-1}{\epsilon}}ds\right]^{\frac{\epsilon}{\epsilon-1}}$$

First-order condition(s)

$$Y_t(s) = \left(\frac{P_t(s)}{P_t}\right)^{-\epsilon} Y_t$$

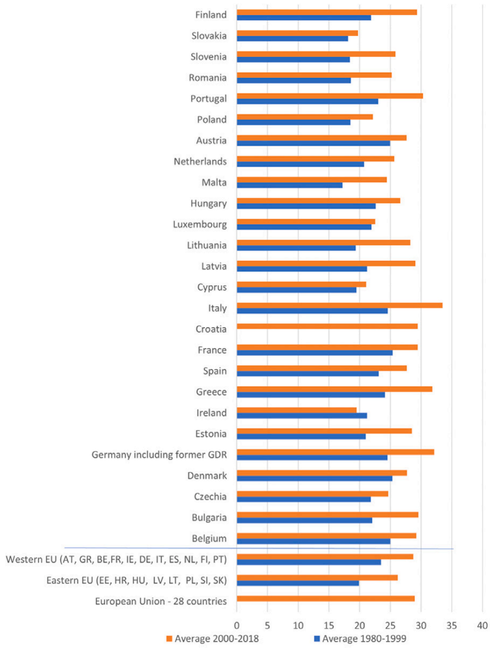
The final (consumption) goods industry is perfectly competitive, thus

$$P_t Y_t = \int_0^1 P_t(s) Y_t(s) ds$$

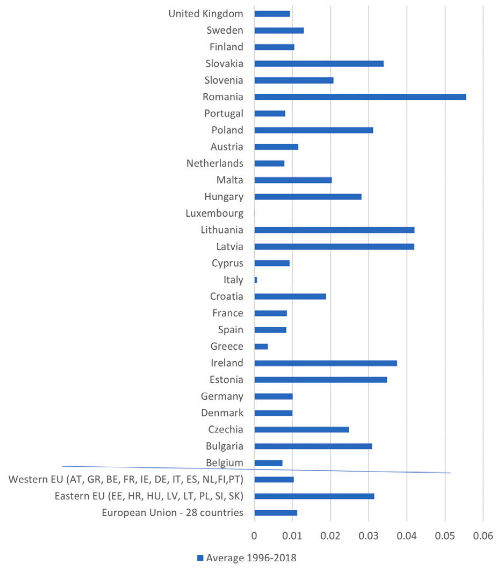
$$P_t Y_t = \int_0^1 P_t(s)\left(\frac{P_t(s)}{P_t}\right)^{-\epsilon} Y_t ds$$

The aggregate price index is

$$P_t = \left[\int_0^1 P_t(s)^{1-\epsilon}ds\right]^{\frac{1}{1-\epsilon}}$$



(a) Old-age dependency ratio



(b) Productivity growth rate

Fig. C.1. Old-age dependency ratio and productivity growth rate.
Note: Old-age dependency ratio shows % of 65+ relative to 20–64 age category. The productivity growth rate is measured as annual real labor productivity growth per person (1=100%).
Source: Authors' estimations using the EUROSTAT database, labor productivity, and unit labor costs [nama_10_lp_ulc] & Population: Structure indicators [demo_pjanind].

Intermediate good producers:

The production function of the intermediate goods industry is

$$Y_t(s) = Z_t N_t^1 + Z_{t-1} N_t^2 + \cdots + Z_{t-R-1} N_t^R$$

where N_t^k is the per worker hours worked of an individual at the age of k at time t. R is the retirement age. Z_t denotes the productivity level of the youngest agent of the cohort at time t and $Z_{t+1} = Z_t(1+g)$. *Productivity-adjusted* production function[19] is

$$\mathcal{Y}_t(s) = \frac{Y_t(s)}{Z_t} = N_t^1(s) + \frac{N_t^2(s)}{(1+g)} + \cdots + \frac{N_t^R(s)}{(1+g)^{R-1}}$$

Cost minimization

$$\min_{N_t^k(s)} W_t \left[N_t^1(s) + \frac{N_t^2(s)}{(1+g)} + \cdots + \frac{N_t^R(s)}{(1+g)^{R-1}} \right]$$

subject to

$$\mathcal{Y}_t(s) = \left(\frac{P_t(s)}{P_t} \right)^{-\epsilon} \mathcal{Y}_t$$

$$\mathcal{Y}_t(s) = N_t^1(s) + \frac{N_t^2(s)}{(1+g)} + \cdots + \frac{N_t^R(s)}{(1+g)^{R-1}}$$

$$\mathcal{L} = -W_t \left[N_t^1(s) + \frac{N_t^2(s)}{(1+g)} + \cdots + \frac{N_t^R(s)}{(1+g)^{R-1}} \right] + \varphi_t \left[N_t^1(s) + \frac{N_t^2(s)}{(1+g)} + \cdots + \frac{N_t^R(s)}{(1+g)^{R-1}} - \left(\frac{P_t(s)}{P_t} \right)^{-\epsilon} \mathcal{Y}_t \right]$$

First-order conditions

$$\begin{aligned} N_t^1(s) &= -W_t + \varphi_t = 0 \\ N_t^2(s) &= -\frac{W_t}{(1+g)} + \frac{\varphi_t}{(1+g)} = 0 \\ &\vdots \\ N_t^R(s) &= -\frac{W_t}{(1+g)^{R-1}} + \frac{\varphi_t}{(1+g)^{R-1}} = 0 \end{aligned}$$

where φ_t is the marginal cost at time t. $w_t = \frac{\varphi_t}{P_t} = \frac{W_t}{P_t}$ is the real marginal cost.

Profit maximization

$$\max_{P_t(s)} P_t(s) Y_t(s) - W_t L_t(s)$$

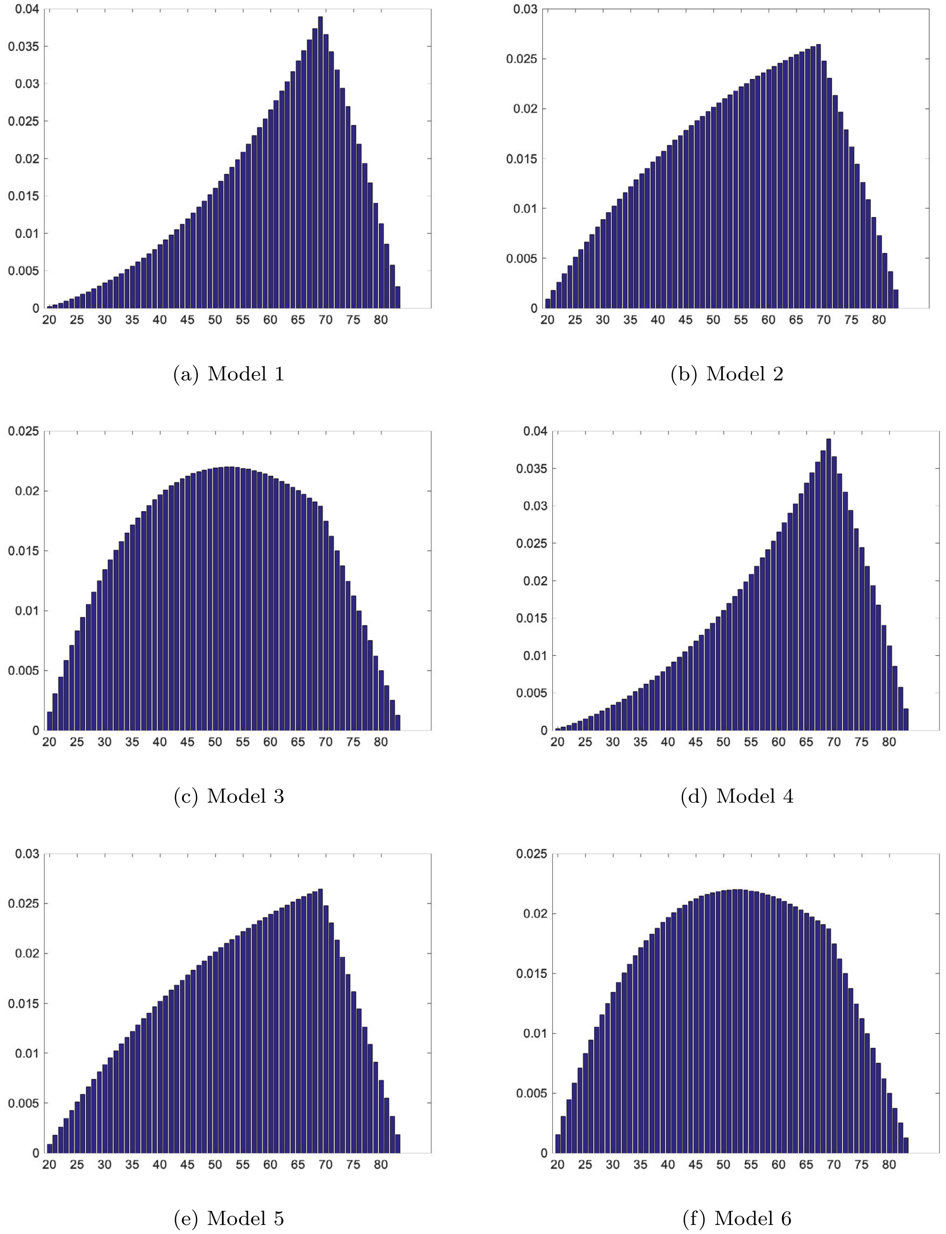
subject to

$$\begin{aligned} \mathcal{Y}_t(s) &= \left(\frac{P_t(s)}{P_t} \right)^{-\epsilon} \mathcal{Y}_t \\ W_t &= \varphi_t \end{aligned}$$

where

$$L_t(s) = \left[N_t^1(s) + \frac{N_t^2(s)}{(1+g)} + \cdots + \frac{N_t^R(s)}{(1+g)^{R-1}} \right] = Y_t(s)$$

[19] Variables are adjusted by the productivity level of the youngest agent at a given time.



(a) Model 1

(b) Model 2

(c) Model 3

(d) Model 4

(e) Model 5

(f) Model 6

Fig. D.1. Distribution of net wealth by cohort.

First-order condition

$$P_t(s) = \frac{\epsilon}{1-\epsilon}\varphi_t$$

where $\frac{\epsilon}{1-\epsilon}$ is the markup. At steady state $\varphi = \frac{\epsilon}{1-\epsilon} = 1/\mathcal{M}$.

Reoptimizing firms' profit maximization problem is

$$\max_{P_t^*} E_t \sum_{k=0}^{\infty} \theta^k \tilde{\beta}^k \tilde{\Lambda}_{t,t+k} \left(P_t^* Y_{t+k}(s) - \varphi_{t+k} Y_{t+k}(s)\right)$$

subject to

$$\mathcal{Y}_{t+k}(s) = \left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon} \mathcal{Y}_{t+k}$$

where $\tilde{\Lambda}_{t,t+k} = \left(\frac{C_{t+k}^{k+1}}{C_t^k}\right)^{-\sigma}$.

The maximization problem becomes

$$\max_{P_t^*} E_t \sum_{k=0}^{\infty} (\theta\tilde{\beta})^k \tilde{\Lambda}_{t,t+k} \left(\frac{P_t^*}{P_{t+k}} \left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon} \mathcal{Y}_{t+k} - \frac{\varphi_{t+k}}{P_{t+k}} \left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon} \mathcal{Y}_{t+k}\right)$$

First-order condition

$$E_t \sum_{k=0}^{\infty} (\theta\tilde{\beta})^k \tilde{\Lambda}_{t,t+k} \left((1-\epsilon)(P_t^*)^{-\epsilon}(P_{t+k})^{\epsilon-1}Y_{t+k}\right)$$

$$= E_t \sum_{k=0}^{\infty} (\theta\tilde{\beta})^k \tilde{\Lambda}_{t,t+k} \left((-\epsilon)(P_t^*)^{-\epsilon-1}\varphi_{t+k}(P_{t+k})^{\epsilon-1}Y_{t+k}\right)$$

$$P_t^* = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{k=0}^{\infty} (\theta\tilde{\beta})^k \tilde{\Lambda}_{t,t+k} \left(\varphi_{t+k}\mathcal{Y}_{t+k}(P_{t+k})^{\epsilon-1}\right)}{E_t \sum_{k=0}^{\infty} (\theta\tilde{\beta})^k \tilde{\Lambda}_{t,t+k} \left((P_{t+k})^{\epsilon-1}\mathcal{Y}_{t+k}\right)}$$

$$P_t^* = \frac{\epsilon}{\epsilon-1} \frac{A_t}{B_t}$$

where

$$A_t = E_t \sum_{k=0}^{\infty} (\theta\tilde{\beta})^k \tilde{\Lambda}_{t,t+k} \left(\varphi_{t+k}\mathcal{Y}_{t+k}(P_{t+k})^{\epsilon-1}\right)$$

$$B_t = E_t \sum_{k=0}^{\infty} (\theta\tilde{\beta})^k \tilde{\Lambda}_{t,t+k} \left((P_{t+k})^{\epsilon-1}\mathcal{Y}_{t+k}\right)$$

They can be written as

$$A_t = \tilde{\Lambda}_{t,t}\varphi_t\mathcal{Y}_t(P_t)^{\epsilon-1} + \theta\tilde{\beta}\tilde{\Lambda}_{t,t+1}E_t\{A_{t+1}\}$$

$$B_t = \tilde{\Lambda}_{t,t}\mathcal{Y}_t(P_t)^{\epsilon-1} + \theta\tilde{\beta}\tilde{\Lambda}_{t,t+1}E_t\{B_{t+1}\}$$

where $\tilde{\Lambda}_{t,t} = \left(\frac{C_t^{k+1}}{C_t^k}\right)^{-\sigma}$.

The aggregate price index is

$$P_t = \left[\int_0^1 P_t(s)^{1-\epsilon}ds\right]^{\frac{1}{1-\epsilon}}$$

$$P_t = \left[\int_0^1 [(1-\theta)(P_t^*(s))^{1-\epsilon} + \theta(P_{t-1})^{1-\epsilon}]ds\right]^{\frac{1}{1-\epsilon}}$$

Divide both sides by P_{t-1}

$$\frac{P_t}{P_{t-1}} = \left[\int_0^1 [(1-\theta)(P_t^*(s))^{1-\epsilon} + \theta(P_{t-1})^{1-\epsilon}]ds\right]^{\frac{1}{1-\epsilon}} \frac{1}{P_{t-1}}$$

$$(1+\pi_t)^{1-\epsilon} = (1-\theta)\left(\frac{P_t^*(s)}{P_{t-1}}\right)^{1-\epsilon} + \theta \tag{B.1}$$

$$\frac{P_t^*}{P_{t-1}} = \frac{\epsilon}{\epsilon-1}\frac{A_t}{P_{t-1}}\frac{1}{B_t}$$

$$\frac{A_t}{P_{t-1}} = \frac{1}{P_{t-1}}\left[\tilde{\Lambda}_{t,t}\varphi_t\mathcal{Y}_t(P_t)^{\epsilon-1} + \theta\tilde{\beta}\tilde{\Lambda}_{t,t+1}E_t\{A_{t+1}\}\right]$$

$$\frac{A_t}{P_{t-1}} = \frac{\varphi_t}{P_t}\frac{P_t}{P_{t-1}}(P_t)^{\epsilon-1}\mathcal{Y}_t\tilde{\Lambda}_{t,t} + \theta\tilde{\beta}\tilde{\Lambda}_{t,t+1}E_t\frac{A_{t+1}}{P_{t-1}}\frac{P_t}{P_t}$$

where $\frac{\varphi_t}{P_t} = mc_t^R$. Rearrange the above expression, we get

$$\tilde{A}_t = (1+\pi_t)mc_t^R(P_t)^{\epsilon-1}\mathcal{Y}_t\tilde{\Lambda}_{t,t} + \theta\tilde{\beta}\tilde{\Lambda}_{t,t+1}E_t\tilde{A}_{t+1}$$

$$\frac{P_t^*}{P_{t-1}} = \frac{\epsilon}{\epsilon-1}\frac{\tilde{A}_t}{B_t}$$

Let $\tilde{a}_t = \frac{\tilde{A}_t}{(P_t)^{\epsilon-1}}$ and $\tilde{b}_t = \frac{B_t}{(P_t)^{\epsilon-1}}$.

$$\frac{P_t^*}{P_{t-1}} = \frac{\epsilon}{\epsilon-1}\frac{\tilde{a}_t}{\tilde{b}_t} \tag{B.2}$$

$$\tilde{a}_t = \frac{\tilde{A}_t}{(P_t)^{\epsilon-1}} = (1+\pi_t)[mc_t^R\mathcal{Y}_t\tilde{\Lambda}_{t,t} + \theta\tilde{\beta}\tilde{\Lambda}_{t,t+1}E_t(1+\pi_t)^{\epsilon-1}\tilde{a}_{t+1}]$$

$$\tilde{b}_t = \frac{B_t}{(P_t)^{\epsilon-1}} = \mathcal{Y}_t\tilde{\Lambda}_{t,t} + \theta\tilde{\beta}\tilde{\Lambda}_{t,t+1}E_t(1+\pi_t)^{\epsilon-1}\tilde{b}_{t+1}$$

At steady state

$$\tilde{a}^* = \frac{mc^*\mathcal{Y}^*\tilde{\Lambda}^*}{1-\theta\tilde{\beta}\tilde{\Lambda}^*}$$

$$\tilde{b}^* = \frac{\mathcal{Y}^*\tilde{\Lambda}^*}{1-\theta\tilde{\beta}\tilde{\Lambda}^*}$$

$$\frac{P^*}{P^*} = 1 = \frac{\epsilon}{\epsilon-1}\frac{\tilde{a}^*}{\tilde{b}^*} \quad \Longrightarrow \quad mc^* = \frac{\epsilon}{\epsilon-1} = \frac{1}{\mathcal{M}}$$

Log-linearize equation (B.2)

$$\hat{p}_t^* - \hat{p}_{t-1} = \hat{\tilde{a}}_t - \hat{\tilde{b}}_t \tag{B.3}$$

$$\hat{\tilde{a}}_t = \pi_t + \frac{mc^*\mathcal{Y}^*\tilde{\Lambda}^*}{a^*}[\widehat{mc}_t^R + \widehat{\tilde{\Lambda}}_{t,t} + \hat{y}_t] + \theta\tilde{\beta}\tilde{\Lambda}^*[\hat{\tilde{a}}_{t+1} + \widehat{\tilde{\Lambda}}_{t,t+1} + (\epsilon-1)\pi_{t+1}] \tag{B.4}$$

$$\hat{\tilde{b}}_t = \frac{\tilde{\Lambda}^*\mathcal{Y}^*}{\tilde{b}^*}[\hat{y}_t + \widehat{\tilde{\Lambda}}_{t,t}] + \theta\tilde{\beta}\tilde{\Lambda}^*[\hat{\tilde{b}}_{t+1} + \widehat{\tilde{\Lambda}}_{t,t+1} + (\epsilon-1)\pi_{t+1}] \tag{B.5}$$

Plug Eqs. (B.4) and (B.5) into (B.3):

$$\hat{p}_t^* - \hat{p}_{t-1} = \pi_t + (1-\theta\tilde{\beta}\tilde{\Lambda}^*)\widehat{mc}_t^R + \theta\tilde{\beta}\tilde{\Lambda}^*(\hat{\tilde{a}}_{t+1} - \hat{\tilde{b}}_{t+1}) \tag{B.6}$$

Log-linearize equation (B.1)

$$\pi_t = (1-\theta)[\hat{p}_t^* - \hat{p}_{t-1}] \tag{B.7}$$

Plugging Eq. (B.6) into the above-linearized expression, we obtain the forward-looking *Phillips equation*

$$\pi_t = \tilde{\beta}\tilde{\Lambda}^*E_t\pi_{t+1} + \frac{(1-\theta)(1-\theta\tilde{\beta}\tilde{\Lambda}^*)}{\theta}\widehat{mc}_t^R \tag{B.8}$$

Appendix C. Descriptive statistics

See Fig. C.1.

Appendix D. Wealth distribution

See Fig. D.1.

Appendix E. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.econmod.2023.106336.

References

Berg, K.A., Curtis, C.C., Lugauer, S., Mark, N.C., 2019. Demographics and Monetary Policy Shocks. Working Paper 25970, National Bureau of Economic Research.

Bielecki, M., Brzoza-Brzezina, M., Kolasa, M., 2018. Demographics, Monetary Policy, and the Zero Lower Bound. NBP Working Papers 284, Narodowy Bank Polski, Economic Research Department.

Bielecki, M., Brzoza-Brzezina, M., Kolasa, M., 2021. Intergenerational redistributive effects of monetary policy. J. Eur. Econom. Assoc. jvab032.

Braun, R., Ikeda, D., 2021. Monetary Policy Over the Life Cycle. Technical Report, Federal Reserve Bank of Atlanta.

Burriel, P., Galesi, A., 2018. Uncovering the heterogeneous effects of ECB unconventional monetary policies across euro area countries. Eur. Econ. Rev. 101 (C), 210–229.

Calvo, G.A., 1983. Staggered prices in a utility-maximizing framework. J. Monetary Econ. 12 (3), 383–398.

Calza, A., Monacelli, T., Stracca, L., 2013. Housing finance and monetary policy. J. Eur. Econom. Assoc. 11, 101–122.

Carvalho, C., Ferrero, A., Nechio, F., 2016. Demographics and real interest rates: Inspecting the mechanism. Eur. Econ. Rev. 88, 208–226, SI: The Post-Crisis Slump.

Clarida, R., Galí, J., Gertler, M., 1999. The science of monetary policy: A new keynesian perspective. J. Econ. Lit. 37 (4), 1661–1707.

Cloyne, J., Ferreira, C., Surico, P., 2018. Monetary Policy When Households Have Debt: New Evidence on the Transmission Mechanism. Working Papers 1813, Banco de España; Working Papers Homepage.

Fadejeva, L., Feldkircher, M., Reininger, T., 2017. International spillovers from Euro area and US credit and demand shocks: A focus on emerging Europe. J. Int. Money Finance 70 (C), 1–25.

Feldkircher, M., Huber, F., 2016. The international transmission of US shocks: Evidence from Bayesian global vector autoregressions. Eur. Econ. Rev. 81 (C), 167–188.

Garriga, C., Kydland, F.E., Šustek, R., 2021. MoNK: Mortgages in a New-Keynesian model. J. Econom. Dynam. Control 123, 104059.

Hajek, J., Horvath, R., 2018. International spillovers of (un)conventional monetary policy: The effect of the ECB and the US fed on non-euro EU countries. Econ. Syst. 42 (1), 91–105.

Jappelli, T., 1999. The age-wealth profile and the life-cycle hypothesis: A cohort analysis with a time series of cross-sections of Italian households. Rev. Income Wealth 45 (1), 57–75.

Kantur, Z., 2013. Aging and Monetary Policy. Technical Report.

Kapteyn, A., Alessie, R., Lusardi, A., 2005. Explaining the wealth holdings of different cohorts: Productivity growth and social security. Eur. Econ. Rev. 49 (5), 1361–1391.

Kara, E., von Thadden, L., 2016. Interest rate effects of demographic changes in a New Keynesian life-cycle framework. Macroecon. Dyn. 20 (1), 120–164.

Lagakos, D., Moll, B., Porzio, T., Qian, N., Schoellman, T., 2018. Life cycle wage growth across countries. J. Polit. Econ. 126 (2), 797–849.

Leahy, J.V., Thapar, A., 2019. Demographic Effects on the Impact of Monetary Policy. NBER Working Papers 26324, National Bureau of Economic Research, Inc.

Lovász, A., Rigó, M., 2013. Vintage effects, aging and productivity. Labour Econ. 22 (C), 47–60.

Modigliani, F., Brumberg, R., 1954. Utility Analysis and the Consumption Function: An Interpretation of Cross-Section Data, Kurihara, K.K. In: Post-Keynesian Economics, NJ Rutgers University Press, pp. 388–436.

Papetti, A., 2021. Demographics and the natural real interest Rate: historical and projected paths for the euro area. J. Econom. Dynam. Control 132, 104209, Secular Stagnation, Low Interest Rates and Low Inflation: Causes and Implications for Policy.

Selezneva, V., Schneider, M., Doepke, M., 2015. Distributional Effects of Monetary Policy. 2015 Meeting Papers 1099, Society for Economic Dynamics.

Taylor, J.B., 1993. Discretion versus policy rules in practice. Carnegie-Rochester Conf. Ser. Public Policy 39 (1), 195–214.

Wong, A., 2016. Population Aging and the Transmission of Monetary Policy to Consumption. 2016 Meeting Papers 716, Society for Economic Dynamics.

Curriculum Vitae

1. Personal data

Name	Ludmila Fadejeva
Date and place of birth	18 September 1981 Riga, Latvia
Nationality	Latvian

2. Contact information

Address	Tallinn University of Technology, School of Business and Governance, Department of Economics and Finance, Akadeemia tee 3, 12616 Tallinn, Estonia
E-mail	ludmila.fadejeva@taltech.ee

3. Education

2024–...	Tallinn University of Technology, School of Business and Governance, Department of Economics and Finance, PhD studies (Extern contract)
2020–2024	University of Latvia, Faculty of Economics and Social Sciences, programm Economics and Business, PhD studies
2010–2011	Barcelona School of Economics (previously Barcelona Graduate School of Economics), Master Degree in Specialized Economic Analysis (awarded jointly with Universitat Pompeu Fabra and Universitat Autonoma de Barcelona), program in Macroeconomic Policy and Financial Markets, MSc
2003–2005	University of Latvia, Faculty of Economics and Social Sciences, program Business and Environment Management, MSc
1999–2003	University of Latvia, Faculty of Economics and Social Sciences, program Business and Environment Management, BSc

4. Language competence

Latvian	native
Russian	native
English	fluent
Spanish	Intermediate

5. Professional employment

2020– ...	Central Bank of Latvia (Latvijas Banka), principal researcher
2008–2020	Central Bank of Latvia (Latvijas Banka), senior researcher
2013–2013	Central Bank of Austria (Oesterreichische Nationalbank), visiting researcher (September-November, 2013)
2006–2008	Central Bank of Latvia (Latvijas Banka), econometrician
2002–2006	Latvian State Institute of Agrarian Economics, researcher

6. Computer skills

- Microsoft Office: Word, Excel, Powerpoint
- Programming languages: R, Stata, Matlab, Eviews, Python
- Document preparation: Power BI, LaTeX (Overleaf)

7. Field of research

- monetary credit and fiscal policy transmission
- price and wage settings
- income and wealth inequality

8. Scientific work
Published papers used in the thesis defence

1. Fadejeva, L. and Kantur, Z. (2023). Wealth distribution and monetary policy. *Economic Modelling*, 125(C):DOI 10.1016/j.econmod.2023.10
2. Benecká, S., Fadejeva, L., and Feldkircher, M. (2020). The impact of Euro area monetary policy on Central and Eastern Europe. *Journal of Policy Modeling*, 42(6):1310–1333, DOI 10.1016/j.jpolmod.2020.05
3. Fadejeva, L., Feldkircher, M., and Reininger, T. (2017). International spillovers from Euro area and US credit and demand shocks: A focus on emerging Europe. *Journal of International Money and Finance*, 70(C):1–25, DOI 10.1016/j.jimonfin.2016.0

Other published papers

1. Gautier, E., Conflitti, C., Faber, R. P., Fabo, B., Fadejeva, L., Jouvanceau, V., Menz, J.-O., Messner, T., Petroulas, P., Roldan-Blanco, P., Rumler, F., Santoro, S., Wieland, E., and Zimmer, H. (2024). New Facts on Consumer Price Rigidity in the Euro Area. *American Economic Journal: Macroeconomics*, 16(4):386–431
2. K. Beņkovskis, L. Fadejeva, A. Pluta, A. Zasova (2024). Keeping the Best of Two Worlds: Linking CGE and Microsimulation Models for Policy Analysis. *International Journal of Microsimulation*, 17(1), 122-144, 2024.
3. Brinke, A., Fadejeva, L., Siliverstovs, B., and Vilerts, K. (2023). Assessing the informational content of card transactions for nowcasting retail trade: Evidence for Latvia. *Journal of Forecasting*, 42(3):566–577
4. Fadejeva, L. and Tkacevs, O. (2022). The effectiveness of tax incentives to encourage private savings. *Baltic Journal of Economics*, 22(2):110–125
5. Bodnár, K., Fadejeva, L., Hoeberichts, M., Peinado, M. I., Jadeau, C., and Viviano, E. (2021). The impact of credit shocks on the European labour market. *Baltic Journal of Economics*, 21(1):1–25
6. Babecký, J., Berson, C., Fadejeva, L., Lamo, A., Marotzke, P., Martins, F., and Strzelecki, P. (2019). Non-base wage components as a source of wage adaptability to shocks: evidence from European firms, 2010–2013. *IZA Journal of Labor Policy*, 8(1):1–18
7. Bodnár, K., Fadejeva, L., Iordache, S., Malk, L., Paskaleva, D., Pesliakaitė, J., Jemec, N. T., Tóth, P., and Wyszyński, R. (2018). How do firms adjust to rises in the minimum wage? Survey evidence from Central and Eastern Europe. *IZA Journal of Labor Policy*, 7(1):1–30
8. Fadejeva, L. and Opmane, I. (2016). Internal labour market mobility in 2005–2014 in Latvia: the micro data approach. *Baltic Journal of Economics*, 16(2):152–174

9. Benkovskis, K. and Fadejeva, L. (2014). The effect of VAT rate on inflation in Latvia: evidence from CPI microdata. *Applied Economics*, 46(21):2520–2533

10. Benkovskis, K., Fadejeva, L., and Wörz, J. (2013). How Important Is Total Factor Productivity for Growth in Central, Eastern and Southeastern European Countries? *Focus on European Economic Integration*, (1):8–27

11. Benkovskis, K., Fadejeva, L., and Kalnberzina, K. (2012). Price setting behaviour in Latvia: Econometric evidence from CPI micro data. *Economic Modelling*, 29(6):2115–2124

12. Fadejeva, L. and Melihovs, A. (2010). Measuring Total Factor Productivity and Variable Factor Utilization. *Eastern European Economics*, 48(5):63–101

13. Fadejeva, L. and Melihovs, A. (2008). The Baltic states and Europe: common factors of economic activity. *Baltic Journal of Economics*, 8(1):75–96

Conference presentations (since 2017)

1. L. Fadejeva, A. Paulus, V. B. Jouvanceau *'Spillovers from Euro Area Monetary Policy: A Focus on Emerging Europe'*, 6th Baltic Economic Conference: 27-28 June 2024, Tallinn, Estonia

2. L. Fadejeva, K. Kalnberzina *'Circumstances defining the inequality of opportunity in Europe: what trees are telling us?'*, 5th Baltic Economic Conference: 19-20 June 2023, Riga, Latvia

3. E. Gautier, P. Karadi, J.Amann, C.Conflitti, R. Faber, B. Fabo, L. Fadejeva, C. Fuss, T. Kosma, V. Jouvanceau, F. Martins, J.O. Menz, T. Messner, P. Petroulas, P. Roldan-Blanco, F. Rumler, B. J. Sánchez, S. Santoro, D. Seward, I. Stanga, E. de Veirman, E. Wieland, L. Wintr, J. Wursten, H. Zimmer *'Price Adjustment in the Euro Area in the Low Inflation Period: Evidence from Consumer and Producer Micro Price Data'*, 14th International Conference "Challenges of Europe": 17-19 May 2023, Split, Croatia

4. L. Fadejeva, K. Kalnberzina *'Circumstances defining the inequality of opportunity in Europe: what trees are telling us?'*, 8th European User Conference for EU-Microdata: 16-17 March 2023, Mannheim, Germany

5. L. Fadejeva, K. Benkovskis *'Chasing the shadow: the evaluation of unreported wage payments in Latvia'*, 4th Baltic Economic Conference: 27-28 June 2022, Kaunas, Lithuania

6. L. Fadejeva, Z. Kantur. 'Wealth Distribution and Monetary Policy"', 10th UECE Conference: Economic and Financial Adjustments in Europe: 22 July 2022, Lisbon, Portugal & online

7. A. Brinke, L. Fadejeva, B.Siliverstovs, K. Vilerts *'Consumer Spending in the Covid-19 Pandemic: Evidence from Card Transactions in Latvia'*, 10th UECE Conference: Economic and Financial Adjustments in Europe: 22 July 2022, Lisbon, Portugal & online

8. A. Brinke, L. Fadejeva, B.Siliverstovs, K. Vilerts *'Consumer Spending in the Covid-19 Pandemic: Evidence from Card Transactions in Latvia'*, Deutsche Bundebank and EABCN Conference: Challenges in Empirical Macroeconomics since 2020: 19-20 May 2022, Eltville am Rhein, Germany

9. L. Fadejeva, K. Benkovskis *'CGE-EUROMOD Model for Latvia: Focus on Shadow Economy '*, 8th International Microsimulation Association Congress: 1-3 December 2021, online
10. L. Fadejeva, O. Tkacevs *'Are tax-favourded savings plans effective in raising private savings?'*, 3rd Baltic Economic Conference: 7-8 June 2021, Tartu, Estonia
11. E. Gautier, C. Conflitti, R. Faber, B. Fabo, L. Fadejeva, V. Jouvanceau, J.O. Menz, T. Messner, P. Petroulas, P. Roldan-Blanco, F. Rumler, S. Santoro, E. Wieland, H. Zimmer *'New facts on consumer price rigidity in the euro area'*, 3Joint ECB and Federal Reserve Bank of Cleveland Conference: Inflation - Drivers and Dynamics Conference 2021: 7-8 October 2021, online
12. L. Fadejeva, Z. Kantur. *'Monetary policy transmission to consumption and net wealth / age distribution of population'*, 4th CESEEnet research workshop: 25–27 March 2019, Vienna, Austria
13. L. Fadejeva, Z. Kantur. '*Aging, Wealth Distribution and Monetary Policy'*, 7th Luxembourg Workshop on Household Finance and Consumption, Central Bank of Luxembourg: 20–21 June 2019, Luxembourg, Luxembourg
14. L. Fadejeva, Z. Kantur. *'Aging, wealth distribution and monetary policy'*, ESCB Research Cluster on Monetary Economics, Third Annual Workshop, Bank of England: 31 October -– 1 November 2019, London, The United Kingdom
15. L. Fadejeva, Z. Kantur. *'Aging, wealth distribution and monetary policy'*, Sixth Conference on Household Finance and Consumption, Central Bank of Ireland: 16–17 December 2019, Dublin, Ireland
16. L. Fadejeva, Z. Kantur. *'Aging, Wealth Distribution and Monetary Policy'*, Baltic Economic Conference: 10–11 June 2019, Riga, Latvia
17. L. Fadejeva, S. Benecka, and M. Feldkircher. *'Spillovers from Euro Area Monetary Policy: A Focus on Emerging Europe'*, Inaugural Baltic Economic Conference: 11–12 June 2018, Vilnius, Lithuania
18. L. Fadejeva, S. Benecka, and M. Feldkircher. *'Spillovers from Euro Area Monetary Policy: A Focus on Emerging Europe'*, CESEEnet Research Workshop, Národná banka Slovenska: 14–16 May 2018, Bratislava, Slovakia
19. L. Fadejeva, M. Feldkircher and T. Reininger. *'International Spillovers from Euro Area and US Credit and Demand Shocks: A Focus on Emerging Europe'*, 9th Nordic Econometric Meeting (NEM 2017): 24–27 May 2017, Tartu, Estonia

Elulookirjeldus

1. Isikuandmed

Nimi	Ludmila Fadejeva
Sünniaeg ja -koht	18-09-1981, Riia, Läti
Kodakondsus	Läti

2. Kontaktandmed

Aadress	Tallinna Tehnikaülikool, Majandusteaduskond, Majanduse ja rahanduse instituut, Akadeemia tee 3, 12616 Tallinn, Eesti
E-mail	ludmila.fadejeva@taltech.ee

3. Haridus

2024–. . .	Tallinna Tehnikaülikool, Majandusteaduskond, Majanduse ja rahanduse instituut, doktorantuur (välisleping)
2020–2024	Läti Ülikool, Majandusteaduskond ja sotsiaalteaduskond, programm Majandus ja ettevõtlus, doktorantuur
2010–2011	Barcelona Majanduskool (varem Barcelona Graduate School of Economics), Spetsialiseeritud majandusanalüüsi magistrikraad (väljastatud koos Universitat Pompeu Fabra ja Universitat Autonoma de Barcelona), programm Makromajanduspoliitika ja finantsturud, MSc
2003–2005	Läti Ülikool, Majandusteaduskond ja sotsiaalteaduskond, programm Ettevõtlus ja keskkonnajuhtimine, MSc
1999–2003	Läti Ülikool, Majandusteaduskond ja sotsiaalteaduskond, programm Ettevõtlus ja keskkonnajuhtimine, BSc

4. Keeleoskus

Läti keel	emakeel
Vene keel	emakeel
Inglise keel	sorav
Hispaania keel	keskastme

5. Professionaalne töökogemus

2020–. . .	Läti Pank (Latvijas Banka), peauurija
2008–2020	Läti Pank (Latvijas Banka), vanemteadur
2013–2013	Austria Pank (Oesterreichische Nationalbank), külalisteadur (september-november, 2013)
2006–2008	Läti Pank (Latvijas Banka), ökonometrik
2002–2006	Läti Põllumajandusökonoomika Riiklik Instituut, teadlane

6. Arvutioskus

- Microsoft Office: Word, Excel, Powerpoint
- Programming languages: R, Stata, Matlab, Eviews, Python

- Document preparation: Power BI, LaTeX (Overleaf)

7. Teadustöö põhisuunad

- rahandus- ja fiskaalpoliitika edasikandumine
- hindade ja palkade kujunemine
- sissetuleku ja varade ebavõrdsus

8. Teadustegevus

Väitekirja kaitsmisel kasutatud avaldatud artiklid

1. Fadejeva, L. and Kantur, Z. (2023). Wealth distribution and monetary policy. *Economic Modelling*, 125(C):DOI 10.1016/j.econmod.2023.10
2. Benecká, S., Fadejeva, L., and Feldkircher, M. (2020). The impact of Euro area monetary policy on Central and Eastern Europe. *Journal of Policy Modeling*, 42(6):1310–1333, DOI 10.1016/j.jpolmod.2020.05
3. Fadejeva, L., Feldkircher, M., and Reininger, T. (2017). International spillovers from Euro area and US credit and demand shocks: A focus on emerging Europe. *Journal of International Money and Finance*, 70(C):1–25, DOI 10.1016/j.jimonfin.2016.0

Muud avaldatud artiklid

1. Gautier, E., Conflitti, C., Faber, R. P., Fabo, B., Fadejeva, L., Jouvanceau, V., Menz, J.-O., Messner, T., Petroulas, P., Roldan-Blanco, P., Rumler, F., Santoro, S., Wieland, E., and Zimmer, H. (2024). New Facts on Consumer Price Rigidity in the Euro Area. *American Economic Journal: Macroeconomics*, 16(4):386–431
2. K. Beņkovskis, L. Fadejeva, A. Pluta, A. Zasova. Keeping the Best of Two Worlds: Linking CGE and Microsimulation Models for Policy Analysis. *International Journal of Microsimulation*, 17(1), 122-144, 2024.
3. Brinke, A., Fadejeva, L., Siliverstovs, B., and Vilerts, K. (2023). Assessing the informational content of card transactions for nowcasting retail trade: Evidence for Latvia. *Journal of Forecasting*, 42(3):566–577
4. Fadejeva, L. and Tkacevs, O. (2022). The effectiveness of tax incentives to encourage private savings. *Baltic Journal of Economics*, 22(2):110–125
5. Bodnár, K., Fadejeva, L., Hoeberichts, M., Peinado, M. I., Jadeau, C., and Viviano, E. (2021). The impact of credit shocks on the European labour market. *Baltic Journal of Economics*, 21(1):1–25
6. Babecký, J., Berson, C., Fadejeva, L., Lamo, A., Marotzke, P., Martins, F., and Strzelecki, P. (2019). Non-base wage components as a source of wage adaptability to shocks: evidence from European firms, 2010–2013. *IZA Journal of Labor Policy*, 8(1):1–18
7. Bodnár, K., Fadejeva, L., Iordache, S., Malk, L., Paskaleva, D., Pesliakaitė, J., Jemec, N. T., Tóth, P., and Wyszyński, R. (2018). How do firms adjust to rises in the minimum wage? Survey evidence from Central and Eastern Europe. *IZA Journal of Labor Policy*, 7(1):1–30

8. Fadejeva, L. and Opmane, I. (2016). Internal labour market mobility in 2005–2014 in Latvia: the micro data approach. *Baltic Journal of Economics*, 16(2):152–174

9. Benkovskis, K. and Fadejeva, L. (2014). The effect of VAT rate on inflation in Latvia: evidence from CPI microdata. *Applied Economics*, 46(21):2520–2533

10. Benkovskis, K., Fadejeva, L., and Wörz, J. (2013). How Important Is Total Factor Productivity for Growth in Central, Eastern and Southeastern European Countries? *Focus on European Economic Integration*, (1):8–27

11. Benkovskis, K., Fadejeva, L., and Kalnberzina, K. (2012). Price setting behaviour in Latvia: Econometric evidence from CPI micro data. *Economic Modelling*, 29(6):2115–2124

12. Fadejeva, L. and Melihovs, A. (2010). Measuring Total Factor Productivity and Variable Factor Utilization. *Eastern European Economics*, 48(5):63–101

13. Fadejeva, L. and Melihovs, A. (2008). The Baltic states and Europe: common factors of economic activity. *Baltic Journal of Economics*, 8(1):75–96

ISSN 2585-6901 (PDF)
ISBN 978-9916-80-282-3 (PDF)