NOVA SCHOOL OF BUSINESS & ECONOMICS

Universidade Nova de Lisboa

Dissertation, presented as part of the requirements for the Degree of Doctor of Philosophy in Finance

Essays on the Financial Economics of a Monetary Union

Daniel Pereira Monteiro

Student nº 14948

A Dissertation carried out as part of the PhD in Economics|Finance, under the supervision of
Professor Francesco Franco (Nova SBE)
Professor João Pedro Vidal Nunes (ISCTE-IUL)

31 October 2022

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Common Sovereign Debt Instruments in the Euro Area

Daniel P. Monteiro*

October 2022

Abstract

This paper presents a novel, integrated framework for the financial assessment of different types of common sovereign debt instruments in a currency union such as the euro area and provides results for their key credit risk properties at Member State and euro area level. The options under assessment include instruments involving full and partial mutualisation of sovereign risk, as well as instruments based on the pooling and tranching of national government debt without mutualisation. The results show that full risk mutualisation can be beneficial for all euro area Member States, and that "eurobonds" would have weathered well the European sovereign debt crisis, even if partial mutualisation remains the most attractive option for the more creditworthy countries. Options involving just the tranching and pooling of Member State debt simply reallocate sovereign risk across instruments, although the "E-bonds" proposal can approximate the characteristics of mutualised "blue bonds" under certain conditions. The analytical framework can also be applied to assess the strength of sovereign risk interlinkages, the evolution of sovereign debt capacity over time and its decomposition into systemic and idiosyncratic factors.

JEL classification: C58, F36, G12, H63

Keywords: Safe Assets, Eurobonds, Blue Bonds, E-bonds, ESBies

*Nova School of Business and Economics and European Commission. E-mail: daniel.monteiro@ec.europa.eu
The author would like to thank João Pedro Vidal Nunes for his very helpful comments.

1 Introduction

A common sovereign debt instrument can allow for a number of macroeconomic and financial benefits in a currency union. Among the advantages that have been ascribed to such instruments is the ability to break the pernicious sovereign-bank loop whereby weak banks enfeeble their domestic governments which, in turn, contributes to further deteriorate the situation of the domestic banking sector. By not being directly linked to a particular sovereign, a common debt instrument can sever the direct channels of the sovereign-bank nexus, while offering credit institutions a safe asset for investment, risk and liquidity management purposes, as well as for use in monetary policy operations.[1] A large pool of safe common debt can also improve the macroeconomic and institutional functioning of the euro area through several other channels. It can bolster the international role of the euro by providing financial markets with a sizable euro-denominated safe asset,[2] while helping to deepen European capital markets.[3] Common European Union (EU) debt can also provide a powerful signal of commitment to the European project, generating positive confidence effects[4] and lowering perceived redenomination risks. In the case of instruments involving some form of debt tranching, common debt can also enhance the role of market discipline in an economic and monetary union by raising marginal sovereign financing costs without negatively impacting average interest rates.[5] More generally, common sovereign debt instruments can expand the supply of safe assets, the relatively scarcity of which has been recognised in the literature as impairing proper macroeconomic functioning.[6]

Furthermore, from a financial viewpoint, the pooling together of imperfectly-correlated sovereign risk can potentially lower overall credit risk premia and financing costs for participating governments, with potential positive spill-over effects for the private sector and the wider economy. A quantification of the credit risk premia on different forms of common debt instruments - as well as the extent and the conditions under which these instruments can achieve risk diversification in a manner not already available to market participants -, is one of the key focuses of this paper. In fact, while the potential interest rate savings or costs associated with different instruments is a matter of interest on its own, it is also intimately linked to the political economy surrounding the common EU issuance debate, given concerns of subsidization of higher-yield Member States by more creditworthy countries.

While there can be various benefits to a common debt instrument in a currency union, potential drawbacks and implementability issues need also be recognized. Foremost among these is the fact that a sizable and permanent common debt instrument may require a higher level of political and economic integration, around which there may be no consensus. This is particularly true in the case of options that involve some form of mutualisation and risk sharing. In these cases, mechanisms should be in place that contain moral hazard issues whereby a Member State may unduly rise its debt issuance knowing that any increases in risk premia will be muted and shared by the participating countries. Also, some of the benefits derived from the existence of a large pool of common safe assets are likely to partly cannibalise the benefits inherent to the status quo, as when this pool partly substitutes for existing safe national bonds, or when a lower liquidity premium on the common safe asset is associated with higher liquidity premia

[1] The sovereign-bank loop, which is thought to have played a large role in the euro area following the 2008 financial and economic crisis, is largely born of banks' home bias, whereby credit institutions tend to own disproportionately high levels of government debt issued by their domestic sovereign. On how a common European safe asset can help sever this loop see, e.g., Brunnermeier et al. (2017), Alogoskoufis and Langfield (2020) and Bellia et al. (2021).

[2] On how the constrained supply of euro-denominated safe assets has hindered the international role of the euro, see Ilzetzki et al. (2020).

[3] On the importance of safe assets for promoting the European Union's Capital Markets Union initiative see, e.g., Lannoo and Thomadakis (2019).

[4] These effects were arguably seen with the announcement of the NextGenerationEU (NGEU) proposal in the midst of the pandemic crisis in 2020, which implied the largest ever EU debt issuance, and which put sovereign risk on a firm downward trend across the euro area. For a sovereign risk timeline surrounding the announcement of NGEU, see Bellia et al. (2021).

[5] On the positive effect of higher marginal financing costs on fiscal prudence see, e.g., Meyermans (2019). The result that debt tranching raises marginal financing costs without negatively impacting average financing costs is discussed in this paper.

[6] See, for instance, Caballero and Farhi (2017).

on national tranches. Finally, fully transitioning to a common debt instrument is an untested procedure which can involve a number of challenges, including the issue of how to deal with legacy debt.

Over the years a number of proposals have been made as to the design features of a common debt instrument in the euro area. One of the first was the blue bond and red bond proposal, as described in Delpla and von Weizsäcker (2010, 2011). According to this partial mutualisation proposal, Member States would issue a commonly guaranteed debt instrument (the blue bond) up until 60% of GDP. Any debt exceeding that level would be subordinated and exclusively guaranteed by the issuing Member State (the red bond). In European Commission (2011) three options were discussed. The first involved full sovereign risk mutualisation whereby national debt would be substituted by a single common debt instrument jointly guaranteed by all participating Member States. This fully mutualised instrument is sometimes called a eurobond. The second option is akin to the blue bond proposal while the third option involves splitting national debt into a senior and junior tranche, and subsequently pooling together the senior tranches into a single instrument. The latter option is akin to what has been called an E-bond in the literature, and has been analysed in, e.g., Leandro and Zettelmeyer (2018) and Giudice et al. (2019). It differs from the blue bond proposal notably because the pool of senior debt does not enjoy the cross-guarantees of the blue bond and is, therefore, directly subject to the credit risk of the issuing sovereigns. Another proposal that has gathered significant interest is that of Brunnermeier et al. (2017), which is based on the pooling together of (part of) national sovereign debts by, e.g., a euro area agency, which would subsequently issue safe European Senior Bonds (ESBies) and riskier European Junior Bonds (EJBies). While neither E-bonds nor ESBies involve risk mutualisation, it should be noted that in the ESBies proposal debt tranching is done *a posteriori*, that is, as part of a securitisation process, after the debt securities have been issued and pooled together. This differs from the E-bond setup where tranching is done *a priori* by issuing debt securities in the primary market with different levels of seniority. In case a common European debt agency is involved in the E-bond construction, tranching can be achieved by having that institution collect funds in the market and lending them on to Member States with a preferred creditor status. Since 2020, the EU has embarked on its largest ever issuance programmes in connection with the NGEU and SURE initiatives, which have been set up as part of the EU's response to the covid-19 crisis. The resulting temporary debt instruments can be understood as involving a degree of partial mutualisation[7] and, although unprecedentedly large,[8] are nevertheless much smaller than some theoretical constructs involving permanent mutualisation, such as the blue bond and eurobond proposals.

The literature on common debt instruments lacks an integrated analytical framework that can be applied to all the different options in order to assess their key financial properties such as probabilities of default, loss given default and credit risk premia. In fact, this quantification is generally lacking as regards instruments involving mutualisation, although progress has been made regarding non-mutualised forms. A first attempt at quantifying the financial properties of a specific common debt instrument was made in Brunnermeier et al. (2017), where a two-stage Monte Carlo simulation is employed to study ESBies. However, such an approach is not extensible to cases involving mutualisation, does not offer a time series dimension allowing for counterfactual simulations over time (as it seeks consistency with a single historical data point), and the choice of probabilities of default and loss given default across countries and states of the world employed in the simulations involves a degree of arbitrariness. Since then, further progress has been made. For instance, ESRB High-Level Task Force on Safe Assets (2018) analyse ESBies (also called sovereign bond-backed securities or SBBS) extending the analysis in Brunnermeier et al. (2017) by relying on broader methodology and empirical evidence. ESBies are also the object of: i) Barucci et al. (2019), who analyse the riskiness of the senior and junior tranches modeling default correlation across individual countries through a static Gaussian copula; ii)

[7] Loans to Member States under the SURE programme benefit from a system of guarantees. As regards NGEU, safeguards have been established in the EU budget allowing for the increase in Member State contributions, which can be interpreted as *de facto* generating limited and temporary mutualisation.

[8] The combined issuance potential of NGEU and SURE can reach up to 6% of euro area GDP by 2026, gradually declining thereafter. See Monteiro (2022).

Frey et al. (2020), who employ an affine credit risk model with regime switching, extending it also to the case of E-bonds; and iii) Gottschalk (2022), who models default correlation using Gaussian and t copulas in a Bernoulli mixture.

This paper presents a novel, integrated framework allowing for the assessment of the financial properties of a wide range of common debt instruments, including options with and without mutualisation. The approach relies on a Merton-type structural credit risk model for the inference of sovereigns' financial strength, debt capacity or "asset" value, from market behaviour. Given the financial strength series of the participating sovereigns as well as key parameters such as their volatility and cross-country correlations, counterfactual simulations can be produced showing how different types of common debt instruments would have behaved over time. The use of structural credit risk models in a sovereign context is scarce in the literature. The fact that sovereigns possess no directly observable asset value which, furthermore, cannot be traded, means that structural models are more easily implementable for the assessment of corporate credit risk, for which they were originally developed (see Merton (1974)). The more common approach of relying instead on reduced-form credit risk models is, however, not appropriate given the aim of the present analysis. While reduced-form models can generally offer a good explanatory power when assessing credit risk due to their data-driven structure and reliance on potentially many explanatory variables, they do not depend on the concept of underlying asset value, which is the economically-meaningful variable forming the basis upon which scenarios involving the pooling together of debt capacities can be simulated. Among the few instances where a structural credit risk model is applied to a sovereign context, Gapen et al. (2005) is the closest in spirit to the approach described in this paper. In that paper the authors present a framework for measuring sovereign risk based on the theory of contingent claims. Specifically, the authors rely on the Black and Scholes (1973) formulae for a call option and for the volatility of the underlying asset and proceed to tease out the unknown asset value and volatility from these two equations using standard methods. Besides pursuing different analytical goals and research questions, there are important methodological differences between the approach in Gapen et al. (2005) and the method presented in this present paper, as discussed in the following section. The approach followed in this paper differs from the previously cited literature on common sovereign debt instruments by allowing for the analysis of instruments involving full and partial risk mutualisation, while offering a general framework that can be applied to analyse and draw comparisons across different options, including non-mutualised ones. Contrary to what has at times been the case in the literature, the present framework offers a dynamic risk analysis that is fully consistent with the evolution of market behaviour over time, and where key model parameters are empirically-derived, rather than assumed.

The remainder of this paper is organised as follows. Section 2 presents the main methodological aspects by discussing the underlying credit risk model, the estimation procedure and the data sources used. Section 3 provides an overview of the results by presenting the gains and losses in terms of risk premia changes at Member State and euro area level, for all the common debt instruments detailed in the following sections. Section 4 discusses the full mutualisation (eurobonds) option and Section 5 explains in detail the framework developed for assessing the partial mutualisation option (blue bonds and red bonds). Section 6 discusses common debt instruments that do not involve explicit mutualisation, namely a tranching and pooling option (akin to E-bonds), a pooling and tranching option (akin to ESBies and EJBies) and, for comparison sake, options simply involving either the pooling or the tranching of national sovereign debt. Section 7 discusses some extensions of the methodology, including an assessment of the strength of sovereign risk interlinkages, a decomposition of the evolution of sovereign debt capacity over time into systemic and idiosyncratic risk components, and a robustness check based on a fat-tailed distribution. Section 8 points out avenues for future research and concludes.

2 Model, data sources and estimation

The approach followed in this paper for assessing the properties of common debt instruments can be illustrated with a full mutualisation (eurobonds) example, as shown in Figure 1. It starts off with the observation of market quotes for sovereign credit default swap (CDS) spreads, a measure of a sovereign's creditworthiness, for the i sovereigns in sample, in a given month t. By assuming a conventional loss given default (LGD), these spreads are then translated into probabilities of default (PD) through standard methods. Each PD thus inferred is then matched with the respective sovereign debt level expected for a future period $t + n$, where the chosen period is consistent with the time horizon of the CDS. In order to infer sovereign i's financial strength in a given month t, a structural credit risk model is imposed on the time series of the estimated PDs and debt levels. In fact, these series represent either the output of the structural model (the PD) or one of its inputs (the debt level). The structure provided by the credit risk model is then used to tease out the remaining parameters of relevance: the level of a sovereign's financial strength (or "asset" value), its trend growth rate and its volatility. Given the time series thus obtained for a sovereign's financial strength, one can then proceed to simulate counterfactual or prospective scenarios where countries' financial strengths and debt levels are partly or fully pooled together. For instance, under full mutualisation, cross-guarantees imply that countries' financial strengths can be added together and compared with the summation of their expected debt levels. The new inputs, i.e., the aggregate financial strength of the participating sovereigns, the volatility and trend growth rate of this aggregate variable and the aggregate expected debt levels are then taken to the original structural credit risk to estimate the PD of the fully mutualised instrument. A new LGD is also derived that is consistent with both the initial LGD assumptions and the characteristics of the common debt instrument under assessment. The counterfactual CDS spreads are then obtained on the basis of the new PD and LGD, providing the credit risk premium on the new instrument. The remainder of this section discusses in more detail each of these steps, and how they are applied to evaluate common debt instruments in the euro area.

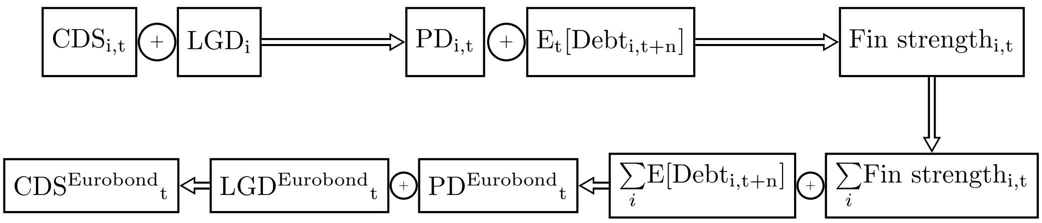

Figure 1: Deriving counterfactual credit risk premia for the case of full sovereign risk mutualisation (eurobonds)

The country sample considered throughout this paper comprises the founding Member States of the Euro (Austria, Belgium, Finland, France, Germany, Italy, Ireland, the Netherlands, Portugal and Spain), safe Luxembourg, and along with Greece, which adopted the Euro two years after its introduction. The time frame runs from January 2003 (i.e., one year after the physical introduction of the euro) to April 2016, for a total of 160 months. The country selection and time frame is partly motivated by data availability considerations and by a focus on the critical period of the sovereign debt crisis. In particular, the second wave of Euro adoption started in 2007, which means that the available time series under the Euro regime are, when available, significantly shorter for the seven Member States that have adopted the Euro since then. At the same time, their combined GDP is relatively small, adding only to approximately 2% of total euro area GDP by year-end 2015. This fact means that their inclusion in the sample would not significantly alter the qualitative and quantitative results shown in the following sections, while significantly restricting the starting date of our sample. The exclusion of Luxembourg from the analysis has to do with the absence of CDS data for that country. Again, Luxembourg's relatively small economic size (representing approximately 0.5% of euro area GDP in our sample period) and low debt levels mean that its exclusion should not noticeably alter the results. The beginning of the sample was set to January 2003 as, by that date, the CDS data for the 2-year horizon used in the estimations are available for all the Member States under analysis, with the exception of the Netherlands.[9] The chronological centrepiece of the analysis are the critical years of the European sovereign debt crisis, when risk premia reached their maximum levels,

[9]The approach for dealing with data gaps for the Netherlands is described below.

and which provide a natural stress test for the different constructions considered in this paper. The time sample stops in 2016, after the crisis has been resolved, and after the Public Sector Purchase Programme of the European Central Bank has been running for one year. In fact, as shown in the literature,[10] this programme exerted a significant downward pressure on sovereign yields, and may have entailed a degree of implicit mutualisation, which motivates focusing the analysis on a sample mostly unaffected by active policy intervention.

The inference of sovereign PDs from quoted sovereign CDS spreads is the first step in the procedure described in Figure 1. Euro-denominated CDS data is taken from IHS Markit for a 2-year maturity. As discussed below, the choice of the maturity is such as to agree with the 2-year ahead debt forecasts used in the estimations. A monthly time frequency is considered throughout this paper. Although CDS spreads are available at a high frequency, debt data is of a lower frequency, motivating the use of monthly data as both a compromise between the frequencies of the two variables and as a safeguard against low trading volumes possibly affecting daily CDS data during some periods. As such, CDS data is based on the monthly average of daily CDS spreads. In some instances, 2-year CDS data is unavailable for short periods of time. In these cases, the dynamics of the 2-year spreads are made to emulate the dynamics of the corresponding 3-year CDS spreads, with any discrepancies in level between the two variables corrected for. PDs are inferred from CDS spreads based on a simple formula used by practitioners:[11]

$$PD = 1 - e^{\frac{-T \times CDS}{1-RR}}, \tag{1}$$

where T denotes the maturity in years (two, in the present case) and RR denotes the recovery rate, i.e., the percentage of the debt exposure that can be recovered by creditors in the event of default. RR is therefore the complement of the LGD, so that $1 - RR = LGD$. This formula is derived from a simplified no-arbitrage condition whereby the total income from the CDS spread accruing to the seller of the CDS contract, $T \times CDS$, should equal the expected loss on the reference bond faced by the seller of that CDS credit protection, $PD \times (1 - RR)$:[12]

$$PD \times (1 - RR) = T \times CDS. \tag{2}$$

It should be noted that both Equations (1) and (2) are simplified versions of more theoretically-correct formulae. The simplifications have essentially to do with the fact that i) both the payment of the CDS premia and the possibility of default are assumed to take place only at the maturity date of the reference bond and ii) cash flows are not discounted to their present value. The fact that a default is assumed to only possibly occur at the maturity date is consistent with the Merton model framework discussed below and, in such a context, can be understood as a desirable property. The fact that the discounting and the time profile of cash-flows are not taken into account is of limited relevance given the short time horizon (two years) and the fact that discount rates are comparatively low for the period under consideration. In fact, as discussed below, the selection of an appropriate (risk-free) discount rate would be, in itself, problematic. For a more theoretically-correct approach for extracting PDs from CDS spreads, see Duffie (1999).

In the particular case of the Netherlands, PDs are inferred from bond yields between 2003 and 2007 due to patchy CDS data during this period. As discussed in Chan-Lau (2006), both bond yields and CDS spreads convey information on credit risk. The formula used to infer PDs from bond yields is the following:

$$PD = \frac{1 - \frac{(1+r)^2}{(1+y)^2}}{(1 - RR)}, \tag{3}$$

[10]See, e.g., the results in Monteiro and Vasicek (2019) and the literature cited therein.

[11]For an application of the formula in an academic context see, e.g., Altman and Rijken (2011).

[12]Through simple algebraic manipulations we have that $PD \times (1 - RR) = T \times CDS \Leftrightarrow -PD = \frac{-T \times CDS}{(1-RR)} \Leftrightarrow e^{-PD} = e^{\frac{-T \times CDS}{1-RR}}$. Given that $e^{-PD} \approx 1 - PD$, we obtain that $PD \approx 1 - e^{\frac{-T \times CDS}{1-RR}}$, as per Equation (1). The logarithmic approximation error is negligible when PDs are low. For exceptionally high CDS spreads, Equation (1) ensures that PDs remain bounded between 0 and 1, which is the reason why a logarithmic approximation is employed. For instance, on the eve of Greece's default in March 2012, Equation (1) produces a PD of 99.9%, whereas in the absence of a logarithmic approximation Greece's inferred PD would be well above 100%.

where r denotes the (annualised) two-year risk free rate and y the (annualised) two-year yields on zero-coupon Dutch bonds.[13]

It should be noted that the sample covers a period when Greece was in default and no CDS spreads were observable. As such, Greece's inferred financial strength for the period between April 2012 to May 2013 deviates from the procedure described hereunder and was linearly interpolated.[14]

The recovery rate RR is also taken from IHS Markit. Its modal value is 40% for each Member State, a conventional figure used in the quotation of many CDS contracts. The country-specific recovery rates are, however, allowed to deviate somewhat from their modal values for some periods in the IHS Markit database. As recovery rates and LGDs are subject to uncertainty, other assumptions would, nevertheless, be possible. When dealing with LGDs, the approach followed in this paper was guided by two criteria:

1. Consistency with usual assumptions made by market participants so that inferred PDs are not distorted and can reflect a representative market assessment;

2. Consistent treatment of LGDs across the different common debt instruments, and between these instruments and the initial LGD assumption used to infer historical PDs, so as to prevent the emergence of spurious results.

As regards Criterion 1, the choice of a conventional 40% figure for the RR (equivalently, of a 60% figure for the LGD) and the use of commercial RR series available to market participants is consistent with the intention of inferring debt capacities from actual market assessment and behaviour. Besides being the market convention for the quotation of sovereign CDS contracts, the use of a 40% RR can also be observed in, e.g., Altman and Rijken (2011).[15] Additionally, while lower sovereign LGD figures may sometimes be found in the literature, there is a case for relying on a more prudent and conservative 60% benchmark when simulating the counterfactual properties of common debt instruments as low LGDs could easily mean that, in some cases, senior debt tranches would be mechanistically assessed as risk-free.[16]

As regards Criterion 2, the detailed description in Sections 4 to 6 explains how overall consistency is achieved. It should be noted that, while a 60% LGD provides a unifying assumption at country-level, specific LGDs emerge endogenously from that assumption in the instruments involving the pooling and tranching of sovereign debt.

The inference of a sovereign's financial strength (which can also be understood as their "asset value" or debt capacity) relies on a standard Merton-type structural credit risk model. Accordingly, the variable $F_{i,t}$ denoting sovereign's i financial strength in month t, evolves according to a geometric Brownian motion process which, in discrete time, can be written as:

$$F_{t+1,i} = F_{t,i} e^{\mu_i + \sigma_i (W_{t+1,i} - W_{t,i})}, \tag{4}$$

where μ_i represents a trend growth rate, σ_i is a volatility parameter and $W_{t+1,i} - W_{t,i}$ are i.i.d and $\sim N(0,1)$. Sovereign i defaults if its financial strength drops below its debt level. As such, its two-year ahead probability of default is given by

[13]This formula is derived from a no-arbitrage condition whereby the market price B of a zero-coupon bond is equal to its discounted expected payout at maturity. As such, we have that $B = \frac{(1-PD)\times M + PD \times RR \times M}{(1+r)^2} \Leftrightarrow \frac{1}{(1+y)^2} = \frac{(1-PD)+PD\times RR}{(1+r)^2} \Leftrightarrow PD = \frac{1-\frac{(1+r)^2}{(1+y)^2}}{(1-RR)}$, where M denotes the face value of the bond at maturity. The use of a risk-free discount rate means that the PDs thus inferred are understood to be risk-neutral. Yields on two-year zero-coupon German bonds were taken as the risk-free rate and, for consistency sake, Dutch PDs obtained from Equation (3) are bounded downwards by German PDs inferred from CDS swaps, a restriction that is only active in some months.

[14]An alternative procedure would be for the interpolation to be informed by the dynamics of other southern European countries. However, the correlation between Greece and other countries is particularly low in our sample, as confirmed by a regression of changes in Greece's financial strength on other Member States'.

[15]For an in-depth discussion of the appropriateness of a 60% LGD assumption, as representing both a conservative and representative figure, see Subsection 3.1 of Giudice et al. (2019).

[16]For instance, with a 40% LGD, a country with debt worth 120% of GDP would not, in the event of default, impose losses on a senior tranche worth as much as 70% of GDP.

$$PD_{t,i} = P(F_{t+24,i} < D_{t+24,i}|\mathcal{F}_t), \tag{5}$$

where $D_{t+24,i}$ denotes the (expected) debt level (in billions of euro) of sovereign i in two years time and $\mathcal{F}_t$ the filtration at time t.[17] From Equation 4, it follows that $ln\left(F_{t+24,i}\right) \sim N\left(ln\left(F_{t,i}\right) + 24\mu_i, 24\sigma_i^2\right)$. As such,

$$PD_{t,i} = P\left(ln\left(F_{t,i}\right) + 24\mu_i + \sigma_i \sum_{n=1}^{24} \left(W_{t+n,i} - W_{t+n-1,i}\right) < ln(D_{t+24,i})\right)$$

$$= P\left(\sum_{n=1}^{24}\left(W_{n,i} - W_{n-1,i}\right) < \frac{ln(D_{t+24,i}) - ln(F_{t,i}) - 24\mu_i}{\sigma_i}\right) = \Phi\left(\frac{ln(D_{t+24,i}) - ln(F_{t,i}) - 24\mu_i}{\sqrt{24}\sigma_i}\right),$$

where Φ denotes the cumulative distribution function of a standard normal random variable. Let us denote $\Phi^{-1}\left(PD_{t,i}\right)$ as $dd_{t,i}$, the distance to default of sovereign i at time t. It follows that

$$\Phi^{-1}\left(PD_{t,i}\right) = \frac{ln(D_{t+24,i}) - ln\left(F_{t,i}\right) - 24\mu_i}{\sqrt{24}\sigma_i},$$

i.e.

$$ln(D_{t+24,i}) = ln(F_{t,i}) + 24\mu_i + \sqrt{24}\sigma_i \times dd_{t,i}. \tag{6}$$

The above equation provides a linear relationship between the logarithm of debt two years ahead, the logarithm of sovereign financial strength and the distance to default. The logarithm of the expected two-year ahead debt is derivable from contemporaneous forecasts while the distance to default can be obtained from the PDs inferred via Equation (1). The remaining variables are unobservable and can be estimated with a Kalman filter by casting the model in state-space form. This is done by defining Equation (6) as the signal equation and the logarithm of Equation (4) as the state equation:

$$\text{Signal equation: } ln(D_{t+24,i}) = ln(F_{t,i}) + 24\mu_i + \sqrt{24}\sigma_i dd_{t,i} \tag{7}$$

$$\text{State equation: } ln(F_{t,i}) = ln(F_{t-1,i}) + \mu_i + \sigma_i\left(W_{t,i} - W_{t-1,i}\right) \tag{8}$$

There are two approaches for obtaining the series for the debt variable $D_{t+24,i}$. One possibility would be to rely on historical general government debt data, which is available at quarterly frequency for euro area Member States, and to interpolate the monthly figures via, e.g., a cubic spline. However, this approach assumes perfect foresight on the part of market participants. In order to sidestep this assumption, one can alternatively rely on contemporaneous debt forecasts. This is the approach followed in this paper, which uses nominal general government debt forecasts obtained from the European Commission's European Economic Forecast series. While this means taking these forecasts as representing the market consensus, there are no superior options for the concerned sample period in terms of country coverage, frequency of publication and cross-country consistency. In addition, given the European Commission's role as enforcer of the Stability and Growth Pact, its public finance forecasts carry non-negligible market weight as far as euro area countries are concerned. It is also worth noting that existing assessments show that European Commission economic forecasts tend to have an accuracy that is comparable to those of other international institutions and consensus-type forecasts (see Fioramanti et al. (2016)). European Commission forecasts were published twice a year between 2003 and 2008, as well as between 2010 and 2012. For 2009 and from 2013 onward three forecasts are available per year. For a given month t let $t^{preceding}$ denote the date of the forecast publication that immediately precedes t. Similarly, let $t^{succeeding}$ denote the publication date of the succeeding forecast document. We have therefore that $t^{preceding} \leq t \leq t^{succeeding}$, with $t^{preceding} < t^{succeeding}$. The two-year ahead

[17] For simplicity, the conditioning of information on the $\mathcal{F}_t$ filtration is dropped in subsequent notation.

forecast debt level in month t was calculated as a weighted average of the debt forecasts of the two neighbouring forecasts publications ($D_{t+24,i}^{preceding}$ and $D_{t+24,i}^{succeeding}$), with the weights adding up to one and reflecting the relative proximity of month t to the forecast document dates:

$$D_{t+24,i} = \left(\frac{t^{succeeding} - t}{t^{succeeding} - t^{preceding}}\right) \times D_{t+24,i}^{preceding} + \left(\frac{t - t^{preceding}}{t^{succeeding} - t^{preceding}}\right) \times D_{t+24,i}^{succeeding} \quad (9)$$

The nominal debt levels D_i are not explicitly shown in the European Commission's forecast publications and are obtained based on the projections for the debt ratio of general government, for real GDP and for the GDP deflator.[18] Also, given that any two-year ahead forecast in year y always refers to December of year $y + 2$ in the forecast documents, D_{t+24} are, when necessary, linearly extrapolated or interpolated by a few months from the forecast debt value for December of year $y + 2$ on the basis of the trend growth rate implicit in the respective forecast document. This is necessary so that D_{t+24} indeed matches the same calendar month as t. Both Equation (9) and the aforementioned intra- and extrapolations are based on the underlying assumption that investors do not abruptly revise their two-year ahead forecasts on a monthly basis.

The reasons for choosing a classic Merton model and some of the underlying model assumptions deserve further consideration. While there are several competing structural credit risk models available in the literature,[19] the Merton model offers two fundamental advantages. First, it is one of the most standard structural credit risk models available. As such, it offers a simple benchmark against which more complex approaches can judged. Second, the structure of the Merton model is sufficiently simple for it to be cast in an exact linear state-space form, thus allowing for the inference of the $F_{t,i}$ variables and related parameters. However, it should be noted that its simplicity also carries significant implications as to the underlying assumptions. For instance, the Merton model assumes that default can only occur at maturity. This differs from the more complex Black and Cox (1976) model where default can happen at any time between t and the maturity horizon. While this would allow for a more theoretically-correct assumption in the present context, the added complexity of the Black-Cox model means that it cannot be cast into a linear state-space form that can be estimated with the standard Kalman filter. Overall, the possibility of default at any point in time might mean higher inferred levels for the $F_{t,i}$ variables, although the dynamics and covariances among sovereigns, which represent more fundamental aspects of the analysis, need not change materially. Other features that could potentially be part of more complex formulations include jump-diffusion dynamics, stochastic volatility and other forms of time-variability in the parameters.

It is also worth noting that the Merton model is usually applied in contexts where the composition and value of the assets of the entity under assessment can be determined with some degree of accuracy, namely by relying on market valuations and balance sheet statements. In a sovereign context, the notion of asset is fuzzier and the market-based measure of financial strength $F_{t,i}$ includes therefore all the hard and soft factors that make up a sovereign's debt capacity. Besides classic elements such as physical and financial assets (including reserves) which play a modest role in a sovereign context when compared with canonical corporate applications, $F_{t,i}$ also comprises a market-based assessment of the government's willingness and capacity to raise revenue and cut expenses as necessary to ensure solvency.

The sovereign-specific standard deviations σ_i represent another area where the Merton framework relies on comparatively simple assumptions. While the estimation procedure considers these standard deviations constant over time and known to investors, more complex formulations could include stochastic volatilities, jump-diffusion processes, other forms of time-variability in the parameters, as well as formulating future debt levels as a stochastic process. As before, however, more complex formulations would not lend themselves to an exact state-space estimation. In addition, should more complex features be empirically relevant, the present implementation of the Merton model will indirectly incorporate them by duly adjusting the inferred $F_{t,i}$.[20] Table 1 shows the set of standard deviation parameters σ_i as estimated via the state-space procedure, as

[18]By definition, $D_{t+24,i} = (General\ Government\ Debt\ Ratio_{t+24,i}) \times GDP_{t+24,i}^{Real} \times \frac{GDP\ Deflator_{t+24,i}}{GDP\ Deflator_{t,i}}$.

[19]For a review, see e.g., Bielecki and Rutkowski (2010).

[20]For instance, an increase in asset volatility would be captured in the model as a drop in the estimated $F_{t,i}$.

Table 1: Space-state and *ex post* empirical estimates of σ_i

	Space-state	Empirical
AT	0.009	0.010
BE	0.005	0.005
DE	0.007	0.008
EL	0.013	0.018
ES	0.013	0.014
FI	0.014	0.015
FR	0.006	0.007
IE	0.021	0.021
IT	0.003	0.004
NL	0.012	0.013
PT	0.008	0.009

well as the same standard deviations empirically calculated *ex post,* on the basis of the obtained $F_{t,i}$ series. As can be observed, space-state standard deviations are highly congruent with their *ex post* empirical counterparts, with the possible exception of Greece where the empirical standard deviation is somewhat larger than the state-space version. The set of trend growth rates μ_i is identical in the state-space and *ex post* empirical version for all countries.

The empirically-calculated correlation matrix for changes in the logarithm of sovereign financial strength, $\Delta ln(F_{t,i})$, is shown as a heat map in Figure 2. This correlation matrix is a key component of the analysis of common debt instruments carried out in Sections 4 to 6. In particular, the analysis in those sections generalises the log-normality assumption of the Merton model embedded in Equation (4) to the stronger assumption of joint log-normality on the basis of the correlations shown in Figure 2. Subsection 7.2 shows how to depart from the joint (log-)normality assumption in order to test for the robustness of the results under a fat-tailed distribution. Alternatively, the analysis in the following sections could also have been carried out on the basis of a non-parametric empirical joint distribution of $\Delta ln(F_{t,i})$.

Increasing average correlation

	FR	ES	NL	FI	BE	AT	DE	PT	IE	IT	EL
FR		0.71	0.74	0.67	0.63	0.59	0.65	0.57	0.58	0.52	0.18
ES	0.71		0.73	0.69	0.79	0.56	0.54	0.53	0.72	0.35	0.10
NL	0.74	0.73		0.72	0.65	0.49	0.65	0.49	0.57	0.42	0.10
FI	0.67	0.69	0.72		0.59	0.54	0.61	0.58	0.38	0.49	0.20
BE	0.63	0.79	0.65	0.59		0.57	0.37	0.42	0.68	0.37	0.14
AT	0.59	0.56	0.49	0.54	0.57		0.50	0.64	0.38	0.44	0.18
DE	0.65	0.54	0.65	0.61	0.37	0.50		0.60	0.46	0.46	0.05
PT	0.57	0.53	0.49	0.58	0.42	0.64	0.60		0.28	0.45	0.22
IE	0.58	0.72	0.57	0.38	0.68	0.38	0.46	0.28		0.34	0.15
IT	0.52	0.35	0.42	0.49	0.37	0.44	0.46	0.45	0.34		0.27
EL	0.18	0.10	0.10	0.20	0.14	0.18	0.05	0.22	0.15	0.27	

Figure 2: Correlation matrix of $\Delta ln(F_{t,i})$

Before concluding the present section, a comparison with Gapen et al. (2005), who derive a measure of sovereign assets based on the theory of contingent claims, can serve to highlight some further methodological aspects. In concrete, Gapen et al. (2005) rely on the Black-Scholes formula for contingent claims, while this paper relies instead on the stochastic differential equation for modeling the asset value process that underpins both the Black-Scholes and the Merton model. This means that in the contingent claims approach only the asset value and volatility can be inferred, while the estimation of the trend growth rate of the asset value is sidestepped thanks to the change of measure embedded in the Black-Scholes option pricing formula, as allowed for by the Girsanov (1960) theorem. As such, while the contingent claims approach relies on standard methods for extracting two unknowns (the level and volatility of the sovereign asset) from two non-linear equations (i.e., the Black-Scholes formulae for a call option and the volatility of an asset), the present approach relies on an exact state-space estimation method using information from market-based probabilities of default. One implication is that the approach described in this section allows for perfect conformity at all times with market-based spreads and PDs, which is not the case in the contingent claims approach. Another important implication stems from the fact that the contingent claims approach requires the input of an observable risk-free interest rate for its inference procedure. Determining the appropriate risk-free rate is, however, challenging in our sample. While interbank lending rates have often been taken as proxies for the risk-free rate, the interbank market stress experienced in connection with 2008 crisis meant that this rate would not be appropriate for part of our sample (see, for instance, European Central Bank (2014)). The alternative approach of considering the yields on the most creditworthy euro area Member States as the risk-free rate is equally problematic as it would impose *a priori* a zero probability of default on any such Member State (or even negative probabilities, in the case of negative spreads), a supposition that is not confirmed by an analysis of CDS spreads and which would partly thwart the objectives of a comparative and counterfactual analysis, as any instrument assumed to be risk-free cannot be improved upon from a credit risk perspective. There are also other differences worth noting between the contingent claims approach of Gapen et al. (2005) and the approach described in this section. While domestic currency liabilities are taken as the equivalent of the notion of equity in the contingent claims approach, as applied to emerging markets, this would would not be appropriate for euro area Member States which, as a rule, issue all of their debt in the domestic euro currency. In the present approach, sovereign equity could be defined as $F_{i,t} - D_{i,t}$. It therefore represents an amount in excess of total debt, rather than a particular type of debt, and can be understood as a measure of fiscal space. In this connection, it is worth observing that sovereign financial strength is measured with respect to total (projected) debt outstanding, which constitutes the sovereign's distress barrier, as per Equation (5). This contrasts with the aforementioned contingent claims approach, where the distress barrier is defined by assumption as equal to short-term external debt plus one half of long-term external debt. Finally, the call option on sovereign assets underlying the contingent claims approach is, of course, of a hypothetical nature, as a sovereign's asset is non-observable, non-tradable and cannot be seized compulsorily in the event of default.

3 Who gains, who loses, and how much?

This section presents upfront some key comparative results for the different common debt instruments discussed in this paper. With this overview in mind, the details of each option are then explored in Sections 4 to 6. For each common debt instrument and for each Member State, a measure of counterfactual gains or losses is constructed based on the estimated average decrease or increase in credit risk premia offered by that instrument when compared with historical premia. This measure is labeled the instantaneous steady-state (ISS) gain or loss and is calculated according to the following formula:

$$ISS_i = \frac{\sum_{t=1}^{T} CDS_{t,i}^{Counterfactual} - CDS_{t,i}^{Historical}}{T} \tag{10}$$

The ISS measure reflects the average risk premium gain or loss per month between January 2003 and April 2016, is measured in interest rate basis points and abstracts from the country-specific profile of debt rollover by assuming that changes in a country's credit risk are immediately reflected on the risk premium paid on the entire debt stock. It also abstracts from the country-specific maturity structure of government debt by applying the same differential gain across all maturities (i.e., by assuming in effect a level shift in the sovereign yield curve). In the instruments involving tranching, $CDS^{Counterfactual}$ reflects the average spread and is calculated as the weighted average of the estimated CDS spreads on each tranche, with the weights reflecting the relative size of the tranches at that point in time. In order to purge approximation errors from the ISS measure and to make the counterfactual perfectly comparable, the $CDS^{Historical}$ is a reconstructed historical spread that is similar, but not perfectly identical to the spread taken from our data sources and used in Equation (1). Three changes are introduced in the reconstructed historical spread. Firstly, it assumes a constant RR of 40%, rather than the rates taken from IHS Markit which hover around 40% but allow for deviations in some periods. The reason for this is that a 40% RR (equivalently, a 60% LGD) is a unifying assumption across different debt instruments[21] and, as such, is embedded in the $CDS^{Counterfactual}$. Secondly, historical CDS spreads are recalculated on the basis of the more theoretically-correct Equation (2) rather than Equation (1). This is due to the fact that the logarithmic approximation is no longer necessary when calculating $CDS^{Counterfactual}$ from counterfactual PDs, as the methodology described in Section 2 implies that these are necessarily bounded between 0 and 1. Finally, reconstructed historical PDs rather than the original historical PDs are used when deriving $CDS^{Historical}$ from Equation (2). The reconstructed PDs are similar to the historical PDs, but may diverge slightly as they are based on the empirical standard deviations shown in Table 1 rather than on the space-state standard variations. The reason for relying on the empirical standard deviations and covariances springs from the fact that these form the basis for the analysis of common debt instruments. In fact, a reliance on space-state covariances would be problematic for two reasons. Firstly, while the procedure can extract variances, it is not set in a manner that allows for the extraction of the full covariance matrix. The extraction of this matrix would require estimating $\frac{n\times(n+1)}{2} = \frac{11\times(11+1)}{2} = 66$ parameters for a set of 11 countries while relying on a parsimonious input data structure, something which is neither statistically nor computationally advisable. Secondly, instruments involving mutualisation rely on the summation of log-normally-distributed sovereign financial strengths, for which no exact statistical distribution is known. In those cases, the new variables resulting from the summation of log-normal variables are assumed to be log-normal, in line with standard rule-of-thumb approximations and with the value process assumptions of the Merton model. For the instruments involving mutualisation, the moments of the new log-normal distributions are thus made to match the underlying empirical moments, which can be calculated on the basis of the previously inferred $F_{t,i}$.[22]

Table 2 presents the ISS gains and losses for the different options under assessment for the period running from January 2003 to April 2016. For the sake of comparability, in all options involving some form of debt tranching the cut-off point for the senior tranche was set at 60% of GDP, the reference debt level set out in the European Union's Stability and Growth Pact. The last row of Table 2 shows the average (reconstructed) CDS spread for our sample period, allowing for a comparison of the historical creditworthiness of Member States and providing an upper bound for their respective ISS gains.

[21] Although a 60% LGD acts as a unifying assumption, this does not mean that all instruments and tranches are assumed to have a 60% LGD. The details of the LGD calculations are described in the following sections.

[22] Approximating a sum of lognormal variables with a lognormal distribution by matching the first and second moments is known as the Fenton-Wilkinson approximation. See Fenton (1960).

Table 2: ISS gain (+) / loss (-) (basis points, January 2003 to April 2016)

	Euro Area	AT	BE	DE	EL	ES	FI	FR	IE	IT	NL	PT
Full mutualisation (Eurobonds)	70	26	25	4	707	75	5	14	121	94	10	209
Partial mutualisation (Blue bond and red bond)	19	27	12	11	17	49	17	13	33	16	19	55
Tranching and pooling ("E-bonds")	18	26	11	10	17	48	15	11	33	16	17	55
Simple tranching	18	24	13	11	18	42	1	13	30	17	12	55
Pooling and tranching ("ESBies" and "EJBies")[23]	0	-8	-61	-35	572	26	12	-52	35	-17	-8	121
Simple pooling[23]	0	-43	-45	-66	637	6	-65	-55	51	24	-60	139
Average CDS spread (2003-2016)	82	38	37	16	719	88	17	26	133	106	22	221

Note: the cut-off level of the senior tranches was set at 60% of GDP, where applicable. The euro area figures refer to the total gains accruing to the euro area aggregate composed of the 11 Member States considered in the simulations. Results for i) tranching and pooling and for ii) simple tranching are based on a sequential default assumption (see Subsection 6.1).

[23] The figures shown under i) pooling and tranching and ii) simple pooling represent the gains and losses of a hypothetical common debt agency associated with transacting different sovereign bonds in the market, or the gains and losses that would accrue to Member States under a scheme of mandatory issuance via a common debt agency.

It can be observed that full mutualisation delivers the largest ISS gains for the euro area. These gains are particularly large for Member States that underwent market stress in the crisis period while being much more modest, though still positive overall, for the most creditworthy Member States. Partial mutualisation delivers the second highest ISS gains which, when compared with full mutualisation, tend to be larger for the most creditworthy Member States and significantly lower for Member States that underwent market stress. It should be noted that partial mutualisation and the other two options that involve *a priori* tranching[24] (tranching and pooling, and simple tranching) deliver rather similar gains both at euro area and Member State level. As discussed in the following sections, this is a consequence of the choice for the cut-off point of the senior tranche,[25] and is not a universal result. Overall, the first four options in Table 2 have in common the fact that they would have explicitly allowed for a Pareto movement whereby all eleven Member States would have been better off during the period under analysis when compared with the historical performance.

The pooling and tranching and simple pooling options are neutral in terms of ISS gains at euro area level due to their pure financial engineering nature. This means that if a euro area debt agency were to issue these instruments by acquiring the underlying government bonds in the market and by securitising them, it should break even. Likewise, Member States would be placing their debt on the market under similar conditions as before, and would therefore be indifferent with respect to these schemes. However, if they were to become the compulsory form through which Member States would issue their debt, bypassing placement in primary debt markets by individual sovereigns, the schemes would benefit the least creditworthy Member States and impose ISS costs on the most creditworthy countries. While this paper reserves the term mutualisation for the cases where this happens explicitly through cross-guarantees, as in the eurobond and blue bond instruments, the fact that the simple pooling and the pooling and tranching options imply either ISS costs or ISS benefits depending on the concerned Member States could be understood as a form of implicit mutualisation, if Member States were obliged to issue their debt directly through these common debt instruments. Even in this case, however, it would not mean that these two options could not allow for a Pareto movement in a broader macro-financial sense. In fact, while not delivering overall gains from a strict risk premia perspective and imposing risk premia costs on some Member States, the pooled debt instruments underlying the two options could still deliver positive institutional and stability dividends along the lines discussed in Section 1.

Some additional caveats should be borne in mind when considering the ISS results. Firstly, the counterfactual results refer to a particular sample running from January 2003 to April 2016, which confers a large weight to the sovereign debt crisis period. The inclusion of longer periods of stability would imply tamer CDS dynamics and further increase the ISS gains of the more creditworthy Member States. The analysis can thus be considered conservative from the viewpoint of this group of countries. Secondly, the counterfactual simulations assume unchanged debt issuance and unchanged commitment to debt service on the part of Member States. This implies, for instance, that under full mutualisation the proper institutional mechanisms would have been in place preventing higher or excessive issuance on the back of lower funding costs and cross-guarantees. Likewise, under partial mutualisation and in the options involving *a priori* tranching, higher market discipline imposed on the junior tranche could result in lower marginal issuance, which however is not assumed in the counterfactual. Indeed, the underlying assumption for the mutualised instruments is unchanged moral hazard, and the results should be read in a *ceteris paribus* spirit. Thirdly, the sample covers a period when Greece was in default and no Greek CDS spreads were observable. In order not to shorten the sample size, the assumed historical figures for Greece from April 2012 to May 2013 are consistent with a scenario where Greece progressively retreats from the default edge after having approached a PD of 100%. Finally, the debt weights used to calculate the euro area aggregate ISS and the country-specific

[24]By *a priori* tranching it is a meant a situation where Member States themselves issue two different types of debt securities with different levels of seniority. This contrasts with *a posteriori* tranching where an agency acquires un-tranched debt instruments and repackages them into tranches, as in the case of the pooling and tranching approach.

[25]It is also the consequence of a "sequential default" assumption, which will be discussed in Subsection 6.1.

ISS for the options involving tranching are based on two-year ahead debt projections in order to ensure consistency with expected LGDs, which are also based on projected debt levels. This leads to zero euro area ISS gains for the pooling and tranching and simple pooling options, highlighting the neutrality of pure financial engineering for the overall euro area ISS. However, the aggregation of ISS gains and losses across Member States and tranches could also have been calculated on the basis of current, nowcast debt levels. Such time inconsistency between the nowcast debt levels used in the ISS aggregation and the forecast two-year ahead debt levels used for calculating LGDs (and, therefore risk premia) would generally lead to small changes in the ISS measure, whose sign and magnitude is sample-specific. The alternative ISS results for an aggregation based on nowcast debt shares are shown in Appendix A.

4 Full sovereign risk mutualisation

Under full mutualisation, euro area Member States issue their debt under a single instrument commonly guaranteed by all (i.e., a eurobond). In this case, the euro area defaults if its aggregate financial strength falls below its aggregate debt level:

$$PD_{t,EA} = P\left(\sum_i F_{t+24,i} < \sum_i D_{t+24,i}\right). \tag{11}$$

In the event of default, a standard 60% LGD on aggregate euro area debt is assumed. It can be observed in Table 2 that this option provides, by far, the highest potential gains as reckoned by the ISS measure. All Member States are seen to benefit from a counterfactual reduction in credit risk premia in average terms over the period running from 2003 to 2016. This reduction is very high for sovereigns that have experienced market stress while being comparatively modest for some of the most creditworthy Member States. Furthermore, the counterfactual simulations suggest that full mutualisation would have kept the euro area PD contained throughout even the most acute phases of the crisis period (Figure 3). For a limited period of time concentrated in 2011 and 2012, the full mutualisation counterfactual somewhat underperforms the historical PDs and risk premia of DE, FI and NL, although these ISS losses are more than offset when the full sample is considered (Figure 4).

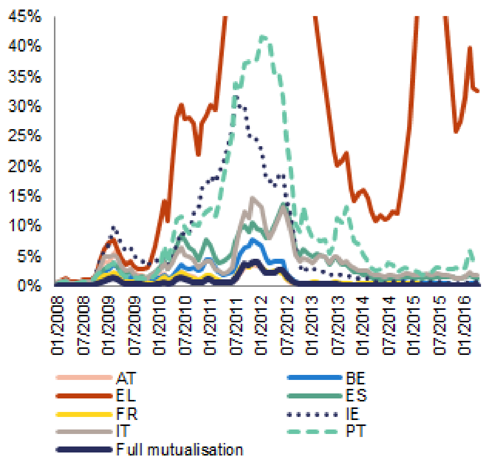

Figure 3: PDs in the crisis period: full mutualisation vs historical (selected Member States)[26]

The strongly positive results observed for the euro area ISS reflect the gains from the diversification of idiosyncratic sovereign risk and from the summation of national fiscal spaces which can only be achieved through mutualisation. These gains cannot be emulated by a market participant holding a diversified portfolio of debt securities, as can be observed by comparing the euro

[26]Vertical axis truncated for visualization purposes, given the outlier dynamics of EL.

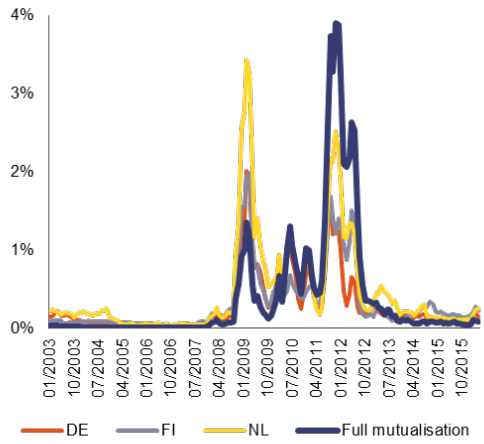

Figure 4: PDs of most creditworthy Member States: full mutualisation vs historical

area results for full mutualisation with those for pure pooling in Table 2. In a corporate context, these gains are akin to the lower financing costs achieved by conglomerates encompassing within a single company a diversified set of imperfectly correlated assets. In effect, the full mutualisation counterfactual is similar in this respect to a corporate merger, which brings together imperfectly correlated assets and different equity buffers under a single corporate structure.[27]

While this section considers the theoretical financial gains from full mutualisation, it does not explore the real-world setting under which eurobonds would operate. It should be noted that while eurobonds diversify and reduce the credit risk of the euro area aggregate, so that a credible eurobond is essentially risk-free, this does not mean that individual Member States would never find themselves in a situation of insolvency. In fact, insolvency remains possible whenever a Member State's debt is too high when compared to its debt capacity. In order for eurobonds to be implementable it is thus necessary that internal euro area mechanisms exist for transferring surplus debt capacity from the euro area aggregate to the Member State where it might be lacking, so that market-facing common debt remains unaffected even in the event of an idiosyncratic default of a Member State. These mechanisms can involve debt restructuring, intergovernmental or institutional loans, and macrofinancial adjustment programmes, as was the historical experience of Greece during the European sovereign debt crisis. Contrary to the historical experience, however, these mechanisms should be set out *ex ante*, for credibility sake. Also, the mere existence of eurobonds may prevent the emergence of idiosyncratic default, as the faltering Member State remains insulated from high interest rates and self-fulling prophecies of default. The need for an internal mechanism for transferring debt capacity extends *mutatis mutandis* to the case of partial mutualisation, as analysed in the next section.

Before concluding the present section, it is worth noting that while the PDs under full mutualisation that can be observed, e.g., in Figure 4 refer to a hypothetical eurobond-like debt instrument, they can also be interpreted as a summary measure of actual systemic stress. This is due to the fact that PDs under full mutualisation capture the aggregate riskiness of the euro area when country-specific risk has been diversified to the maximum possible extent.

5 Partial mutualisation

Partial mutualisation involves, in the present context, a euro area senior debt tranche that is commonly guaranteed by all participating Member States, and which coexists with national junior tranches that are guaranteed only by the issuing Member State. This is the setting of the blue bond and red bond proposal whereby Member States would issue a cross-guaranteed senior debt instrument up until a debt level worth 60% of its GDP (the blue bond). Any debt

[27]For an early discussion of how conglomerate mergers can increase debt capacity, see Lewellen (1971).

issuance exceeding this amount would not be guaranteed and would be issued as a separated junior instrument (the red bond), thus inviting market discipline to bear on the issuing sovereign whenever it exceeds a 60% debt-to-GDP ratio.

The analytical framework for assessing the case of partial mutualisation requires particular consideration. Generally speaking, the framework must capture the fact that a sovereign must be ready and willing to default on its junior tranche in order to safeguard the creditworthiness of the commonly-issued blue bonds. This can be tackled analytically by considering that a sovereign's financial strength is primarily pledged to honouring the blue bond ($F^P_{t,i}$), while the residual financial strength ($F^R_{t,i}$) supports the red bond. As such, we have that total financial strength is decomposed as follows:

$$F_{t,i} = F^P_{t,i} + F^R_{t,i}. \tag{12}$$

While $F_{t,i}$ is an estimated value and $F^R_{t,i}$ is a residual, a rule is needed that can specify $F^P_{t,i}$ in an appropriate manner. The rule underpinning the analysis in this section is such that a sovereign pledges to honour both its share of the blue bond as well as any aggregate financial strength shortcomings arising in other Member States, up to its maximum available financial strength $F_{t,i}$. Analytically, this can be written as:[28]

$$F^P_{t,i} = \begin{cases} D^S_{t,i} + \left[\sum\limits_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ & \text{if } D^S_{t,i} + \left[\sum\limits_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ < F_{t,i} \\ F_{t,i} & \text{if } D^S_{t,i} + \left[\sum\limits_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ \geq F_{t,i} \end{cases} \tag{13}$$

where D^S_i represents the level of senior debt issued by sovereign i under the blue bond instrument. It can be shown that this formulation encapsulates the desirable result that Member States' financial strength is entirely pledged to the commonly-issued blue bonds as the euro area aggregate approaches default. In particular, it can be shown that

$$\sum_i F_{t,i} \leq \sum_i D^S_{t,i} \Rightarrow \left(F^P_{t,i} = F_{t,i} \wedge F^R_{t,i} = 0\right) \ \forall i. \tag{14}$$

Implication (14) tells us that at the critical point where $\sum\limits_i F_{t,i} = \sum\limits_i D^S_{t,i}$, Member States will have defaulted on their junior tranches and will be pledging all of their debt capacity to the blue bonds, as demanded by a credible blue bond scheme. As such, under mutualisation of Member States' senior debt $D^S_{t,i}$, the euro area will only default on the blue bonds if its aggregate financial strength falls below the total amount of outstanding blue bond debt:

$$PD_{t,EA} = P\left(\sum_i F_{t+24,i} < \sum_i D^S_{t+24,i}\right). \tag{15}$$

It can be shown additionally that the framework provided by Equations (12) and (13) satisfies the following set of desirable properties:

1. Analytical tractability: bivariate normal distributions can be derived allowing for the calculation of PD^J_i, the probability of default on the junior tranches (the red bonds);
2. As long as the rest of the euro area is solvent on their blue bonds, sovereigns are the residual beneficiary of their own financial strength: $\left(\sum\limits_{j\neq i} F_{t,j} > \sum\limits_{j\neq i} D^S_{t,j}\right) \Rightarrow \frac{\partial F^P_{t,i}}{\partial F_{t,i}} = 0 \ \forall i$;

[28] An equivalent specification would be $F^P_{t,i} = min\left(D^S_{t,i} + \left[\sum\limits_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+, \ F_{t,i}\right)$. However, representing the function in terms of branches arguably makes for an easier presentation of the proofs in Appendix B.

3. Sovereign financial strength is fully pooled as euro area debt approaches default: $F^P_{t,i} \uparrow F_{t,i}\ \forall i$ as $\sum_i F_{t,i} \downarrow \sum_i D^S_{t,i}$;

4. The probability of default on the junior tranches is higher under partial mutualisation than under simple tranching without mutualisation: $PD^J_i > P\left(F_{t+24,i} < D_{t+24,i}\right)$.

Appendix B proves these properties as well as Implication (14). Property 2 means that marginal improvements in a sovereign's financial strength are generally to their own direct benefit, rather than to the euro area's. Property 3 and the related Implication (14) show that the present formalisation works as intended as regards credible common debt: a sovereign will first default on its red bond before permitting the euro area to default on the common blue bond. Property 4 means that the present formalisation works as intended as regards junior national debt: default on the red bonds can happen not only due to a drop in a sovereign's financial strength, as is the case in the absence of mutualisation,[29] but also due to systemic failure in partner countries. In fact, under partial mutualisation, default on junior national debt can occur under two circumstances:

1. Idiosyncratic country default;

2. Systemic financial strength insufficiency of partner countries conducive to default on the blue bond.

Let D^J_i denote the level of junior debt issued by sovereign i under the red bond instrument. We have that the probabilities of default on the junior tranches (the red bond) are given by:

$$PD^J_{t,i} = P\left(F^R_{t+24,i} < D^J_{t+24,i}\right). \tag{16}$$

Appendix B shows how $PD^J_{t,i}$ can be calculated based on the law of total probability.

In the event of a euro area default on the senior blue bond, the LGD is assumed to be a standard 60%. The LGD on junior red bonds is given by

$$LGD^J_{_{t,i}} = min\left(100\%, \frac{60\% \times \left(D^S_{t,i} + D^J_{t,i}\right)}{D^J_{t,i}}\right). \tag{17}$$

Formula (17) means that the junior tranche is wiped out in the event of default (a 100% LGD), except in the cases where the junior tranche is so large as to represent more than 60% of debt outstanding. As a 60% LGD is the unifying assumption, the LGD on the junior tranche is therefore capped at a maximum representing 60% of total debt outstanding.[30]

Partial mutualisation delivers the second largest ISS gain for the euro area. All Member States are seen to benefit in ISS terms, but the gain is much smaller for sovereigns that have experienced market stress when compared to the full mutualisation scenario. This is due to the fact that these countries would have paid a high risk premium on their junior tranches, partly offsetting the lower premium paid on the senior tranche (see Figure (5)). Conversely, the ISS gains are somewhat higher for some of the most creditworthy Member States when compared with the full mutualisation case as the level of the cross guarantees that the latter option implies would have caused a non-negligible deterioration in their risk profile during the peak crisis period, in 2012 (see Figure (4)). At the same time, the risk premia on the junior tranches of the most creditworthy Member States remains an order of magnitude lower than that of countries that have experienced market stress, in case of partial mutualisation (see Figure (6)).

[29]See Subsection 6.1 for the calculation of the probabilities of default on the junior tranche in the absence of mutualisation.

[30]There is a moot theoretical situation not captured by Equation (17) related to a type two default (systemic default of partner countries). Suppose that $D^J_{t,i}$ is sufficiently large so that Equation (17) yields $LGD^J_{_{t,i}} < 100\%$. In this case, full theoretical correctness would require splitting the default space into two mutually exclusive events: i) the case where the financial strength insufficiency of partner countries is less severe so that country i can impose in effect an $LGD^J_{_{t,i}} < 100\%$ and still ensure that the blue bond is honoured and ii) the case where the financial strength insufficiency of partner countries is more severe so that default on the blue bond is unavoidable,

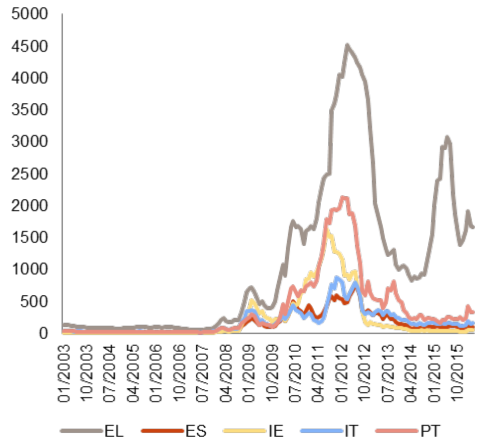

Figure 5: Risk premia on junior tranches under partial mutualisation and other options involving *a priori* tranching for EL, ES, IE, IT and PT (in basis points, 60% of GDP cut-off point)

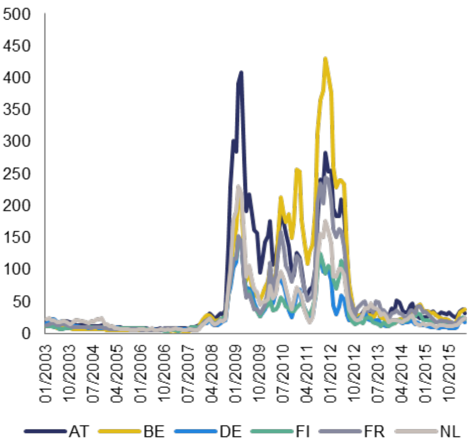

Figure 6: Risk premia on junior tranches under partial mutualisation and other options involving *a priori* tranching for AT, BE, DE, FI, FR and NL (in basis points, 60% of GDP cut-off point)

It can also be observed that the ISS gain is only slightly higher than under the tranching and pooling, and tranching options. This is due to the chosen cut off point which, at 60% of GDP, produces senior tranches characterized by very low risk of default.[31] Due to the very low risk inherent in the senior tranches, mutualisation cannot provide a significant enhancement. For higher cut-off points, however, the additional euro area gains provided by partial mutualisation become more evident. This point is illustrated in Table 3 which compares the results for a 60% and an 80% cut-off point. It can also be observed how partial mutualisation sits between the full mutualisation and the tranching and pooling options, approaching the former for high cut-off points, and the latter for low cut-off points. In fact, the PD on the blue bonds converges to that of the eurobonds as the cut-off point increases. In such a case, $\sum_i D^S_{t+24,i} \to \sum_i D_{t+24,i}$ and, given the continuity of the normal distribution function, convergence of the blue bond's PD follows readily from Equations (11) and (15). It is also worth noting how different Member

or at least an LGD higher that the one resulting from Formula (17) is required in order to honour the blue bond, in which case one could impose $LGD^J_{t,i} = 100\%$. While Equation (17) will be re-used in the next section, this situation is specific to the partial mutualisation option and does concern other instruments.

[31]This quantitative result is consistent with the historical experience whereby defaults in advanced economies experiencing a sovereign debt-to-GDP ratio of only 60% are virtually unknown.

States show different optimal mutualisation levels. While increasing mutualisation from 60% of GDP to 80% increases ISS gains for all Member States, going from 80% of GDP to full debt mutualisation decreases the ISS gains for the most creditworthy countries. Full mutualisation is thus ISS-optimal only for a subset of Member States.

Finally, it should be noted that for a cut-off point of 60% of GDP, the ISS gains observed under the partial mutualisation, pooling and tranching, and tranching options are essentially driven by the fact that tranching allows for sequential default whereby a sovereign can default on the junior tranche and still preserve the senior tranche, unless faced with the (unlikely) event of its financial strength falling so much as to render the senior debt unserviceable. As will be discussed in Subsection 6.1, while sequential default is a characteristic inherent in the design of blue bonds and red bonds, it is a behavioural assumption in the case of other instruments involving *a priori* tranching. Also for this reason, partial mutualisation can be understood as a superior option from an ISS perspective when compared with non-mutualised instruments.

6 Common debt instruments without mutualisation

This section considers a set of debt instruments that do not involve any form of explicit mutualisation.

6.1 Tranching and pooling

Under the tranching and pooling approach, euro area Member States issue senior and junior bonds, with the former being pooled together into a single euro area debt instrument. The tranching and pooling approach can also be understood as a situation where participating countries confer a preferred creditor status to a euro area debt agency, which funds itself in the market through a common bond and lends on the proceeds to Member States. The debt issued by such an agency is, in this case, the senior tranche, and is akin to "E-bonds", as first proposed in Monti (2010), and again in Juncker and Tremonti (2010).

Given that the junior tranche is the marginal tranche, its PD equals the historical PD inferred via Equation (1). Alternatively, $PD^J_{t,i}$ can be calculated as

$$PD^J_{t,i} = P\left(F_{t+24,i} < D_{t+24,i}\right) = \Phi\left(\frac{ln(D_{t+24,i}) - ln\left(F_{t,i}\right) - 24\mu_i}{\sqrt{24}\sigma_i}\right), \tag{18}$$

where $D_{t,i} = D^S_{t,i} + D^J_{t,i}$ represents the total debt level of sovereign i (i.e., the sum of the junior and senior tranches). Either approach yields the same PD as the signal Equation (7) ensures that the model-based PDs of Equation (18) equal the CDS-based PDs at all times. The LGD on the junior tranche is given by Equation (17) and follows the same rationale of the previous section. The PD on the senior tranche is the probability of the financial strength $F_{t+24,i}$ falling so much as to render the senior debt unserviceable:

$$PD^S_{t,i} = P\left(F_{t+24,i} < D^S_{t+24,i}\right) = \Phi\left(\frac{ln(D^S_{t+24,i}) - ln\left(F_{t,i}\right) - 24\mu_i}{\sqrt{24}\sigma_i}\right). \tag{19}$$

Table 3: ISS gain (+) / loss (-) for 60% and 80% cut-off points (basis points, January 2003 to April 2016)

	Euro Area	AT	BE	DE	EL	ES	FI	FR	IE	IT	NL	PT
Full mutualisation (no cut-off point)	70	26	25	4	707	75	5	14	121	94	10	209
Partial mutualisation (80% cut-off point)	38	38	25	16	99	76	17	22	71	45	22	120
Tranching and pooling (80% cut-off point)	27	25	14	3	91	63	4	10	61	37	9	110
Partial mutualisation (60% cut-off point)	19	27	12	11	17	49	17	13	33	16	19	55
Tranching and pooling (60% cut-off point)	18	26	11	10	17	48	15	11	33	16	17	55

Note: The cut-off level of the senior tranches was set at 60% and 80% of GDP, where applicable. The euro area figures refer to the total gains accruing to the euro area aggregate composed of the 11 Member States considered in the simulations. Results for tranching and pooling are based on a sequential default assumption (see Subsection 6.1).

Equation (19) embodies the principle of sequential default allowed for by the existence of two tranches. In effect, Equation (19) is based on the assumption that a sovereign will not default simultaneously on both tranches, unless forced to by a large drop in $F_{t,i}$. Under the alternative assumption of simultaneous default, the probability of default on the senior tranche equals $PD^J_{t,i}$ as long as $\frac{D^J_{t,i}}{D_{t,i}} < 60\%$ (i.e., as long as $D^J_{t,i}$ is not large enough to absorb a standard LGD of 60% on total debt), and zero otherwise. Under sequential default, sovereign i only defaults on $D^S_{t,i}$ after having defaulted first on $D^J_{t,i}$ and finding $F_{t+24,i} < D^S_{t+24,i}$. Moving from a simultaneous default assumption to a sequential default assumption tends to imply a decrease in expected losses on total debt, which is the driver of the ISS gains shown in Table (2).[32] For an illustration of this mechanism, see Appendix (C).

A sovereign's LGD in the event of default on its senior tranche is a standard 60%. However, given that senior bonds are pooled together, the LGD on this pooled senior instrument must be calculated from the individual sovereign LGDs and the respective debt amounts involved. As the LGD on the pooled instrument depends, inter alia, on the particular combination of countries defaulting, this implies considering all possible, mutually-exclusive default events. With 11 countries, there are 2047 default events depending on the number of countries defaulting and, for that number, on the possible country combinations:

$$\text{Number of possible default events} = \sum_{k=1}^{11} \binom{11}{k} = 2047. \tag{20}$$

The set of PDs associated with each of the 2047 default events j that are possible at time t, $\left\{PD^{2047}_{t,j}\right\}$, can be calculated based on the multivariate log-normal distribution of $F_{t,i}$ taking into account the assessed financial strength and projected debt levels at time t, as well as the correlation matrix in Figure (2). The expected LGD on the senior tranche is then given by

$$LGD^S_t = \sum_{j=1}^{2047} PD^{2047}_{t,j} \times LGD^{2047}_{t,j},$$

where $\left\{LGD^{2047}_{t,j}\right\}$ represents the set of all possible 2047 LGDs on the senior tranche. A particular $LGD^{2047}_{t,j}$ will depend on the number of countries defaulting in event j, their respective senior debt levels at time t and the size of the pool of senior debt at time t. Say that for a particular default event j the set of countries defaulting is given by I_j. Then

$$LGD^{2047}_{t,j} = \frac{0.6 \times \sum_{k \in I_j} D^S_{t,k}}{\sum_i D^S_{t,i}}. \tag{21}$$

At a cut-off point equal to 60% of GDP, the PDs and expected losses on the senior tranches will be very low, implying negligible risk premia. The risk premia on junior tranches will be comparatively high. On the one hand, given that the junior tranches are the marginal tranches, they are exposed to the historical PDs inferred from CDS data, which reached high levels in some cases. On the other hand, LGDs will be 100% if the junior tranches are not particularly large, meaning that relatively thin junior tranches are wiped out in the event of default. Figures (5) and (6) display the counterfactual risk premia on the junior tranches.

6.2 Simple tranching

The pure tranching option is presented for illustration purposes as it does not represent a type of common debt instrument. It is similar to the pooling and tranching option in terms of design and ISS results, with the difference lying in the fact that senior tranches are not pooled into a single debt instrument by a euro area agency. The case of Finland merits, however, closer

[32] In fact, ISS gains from tranching and pooling can be shown to be zero for the euro area aggregate under a simultaneous default assumption, while being either positive or negative at Member State level, depending on the riskiness of the concerned sovereign.

consideration as the one instance showing significant ISS differences between the two options. In fact, Finland's case is illustrative of how tranching and pooling can provide incentives for keeping government debt levels low. Projected government debt in Finland remained below 60% of GDP during most of our time sample meaning that, during such periods, Finland would not have incurred any risk premia penalty via a junior tranche while, at the same time, benefiting from the possibility of issuing all of its debt via a very safe senior common debt instrument.

It should be noted that, in order for the aforementioned benefits to materialise, an hypothetical euro area debt agency with a preferred creditor status would need to have issued a senior common debt instrument on behalf of Member States. Otherwise, if this agency were to simply acquire existing securities in the market, tranche and repackage them, any ISS gains for Finland under the tranching and pooling option would spring exclusively from the existence of tranching and would thus be identical to those shown in Table (2) for the simple tranching option.[33] The observation that Member States' ISS gains and losses under the options involving pooling will vary depending on whether the hypothetical euro area debt agency simply acquires and pools existing government debt securities, or is the vehicle through which governments issue their debt (or a tranche thereof), will be further discussed in the following subsection.

6.3 Pooling and tranching

Pooling and tranching can describe a situation where a euro area agency acquires government bonds of participating Member States, pools these bonds together and securitises the bond pool by issuing senior and junior debt tranches. The instruments discussed in this subsection are similar in nature, though not identical in detail, to the ESBies and EJBies proposal of Brunnermeier et al. (2017). For direct comparability with the other options, the ESB instrument considered in this subsection pools together national debt worth up to 60% of GDP and the EJB instrument pools together the remaining national debt in excess of 60% of GDP.[34] As such, the euro area-wide senior tranche (i.e., the ESB) is given by $D_t^{ESB} = \sum_i D_{t,i}^S$ while the euro area-wide junior tranche (i.e., the EJB) is given by $D_t^{EJB} = \sum_i D_{t,i}^J$. The ESB is senior to EJB and will only take losses after the EJB has been wiped out.

The PD on the EJB is driven by the worst country performers as it suffices that a Member State defaults for the EJB to be affected. With 11 countries in sample, default can occur in 2047 ways, as per Equation (20). To each of these mutually exclusive events will correspond a particular LGD on the EJB. Let I_j denote the set of countries defaulting in a particular default event j. Then

$$LGD_{t,j}^{EJB} = max\left(100\%, \frac{0.6 \times \sum_{k \in I_j} D_{t,k}}{D_t^{EJB}}\right). \tag{22}$$

Equation (22) says that a defaulting country will impose a 60% loss on its debt outstanding, in line with the standard LGD assumption. The LGD on the EJB will then depend on the number of countries defaulting, on their debt levels and on the total size of the EJB pool. Depending on the combination of these factors, the LGD on the EJB may reach 100%, in which case any remaining losses will pass on to the ESB. Consequently, the LGD on the ESB for an event j with a set I_j of defaulting countries is given by

[33] If, furthermore, the sequential default assumption is abandoned in favour of the simultaneous default assumption, simple tranching becomes a pure financial engineering operation, producing zero ISS gains and losses at both Member State and euro area level.

[34] In the original ESBies/EJBies proposal, the level of outstanding debt eligible for purchase by the euro area agency is simultaneously capped per country at 60% of GDP and by a portfolio key based on that country's GDP weight vis-à-vis the euro area. The cut-off (or "subordination") levels for the senior tranche are then set as a percentage of the total debt acquired by the agency.

$$LGD^{ESB}_{t,j} = max\left(0\%,\ \frac{0.6 \times \sum\limits_{k \in I_j} D_{t,k} - D^{EJB}_t}{D^{ESB}_t}\right). \tag{23}$$

As in Subsection (6.1), the set of PDs on the EJB for each of the 2047 default events, $\{PD^{2047}_{t,j}\}$, can be calculated based on the multivariate log-normal distribution of $F_{t,i}$ taking into account the assessed financial strength and projected debt levels at time t, as well as the correlation matrix in Figure (2). The expected LGD on the EJB is then given by

$$LGD^{EJB}_t = \sum_{j=1}^{2047} PD^{2047}_{t,j} \times LGD^{EJB}_{t,j}.$$

The probability of default on the senior tranche in event j equals $PD^{2047}_{t,j}$ as long as $LGD^{ESB}_{t,j} > 0\%$ (i.e., as long as the EJB is not large enough to entirely absorb the losses from default), and zero otherwise. The expected LGD on the ESB can be calculated as

$$LGD^{ESB}_t = \sum_{j=1}^{2047} PD^{2047}_{t,j} \times LGD^{ESB}_{t,j}.$$

As can be observed in Table (2), ESBies and EJBies do not change overall expected losses and are thus ISS-neutral for the euro area. A euro area agency implementing the scheme by acquiring government debt securities in the market will break even from an ISS perspective, making gains on the comparatively cheap securities of the least creditworthy Member States and incurring offsetting losses on the comparatively expensive securities of the most creditworthy countries. These gains and losses would accrue to the respective Member States in case they were forced to issue their debt directly via ESBies and EJBies, and required to pay the interest on these instruments. This would imply a form of implicit mutualisation as some of the most creditworthy countries would be forced to issue part of their debt via an EJB whose risk profile would be contaminated by the worst performers. Conversely, the latter would benefit from the credit enhancement provided by a large debt pool, which lowers the LGD. The hypothetical ISS losses would affect, in particular, countries simultaneously displaying a comparatively favourable risk profile and debt levels in excess of 60%. Finland provides an example where the first condition is met, but not the second for most of the sample period. As such, Finland would stand to gain from an ISS perspective, thereby illustrating how mandatory direct issuance via ESBies and EJBies can provide incentives for containing debt levels.

As regards risk profiles, the EJB makes for a risky instrument, particularly in times of crisis. Given that the worst country performers drive the default risk, it is exposed to PDs on the high side even in normal times and can reach very high PDs during crisis periods (see Figure (7) for the counterfactual dynamics of PDs and LGDs). The counterfactual LGD^{EJB}_t are relatively low and decreased over time as the size of the EJB pool increased. For a cut-off point as high as 60% of GDP, the ESB is a safe asset showing low counterfactual PDs even in peak crisis periods, as well as low counterfactual LGDs (Figure (8)).

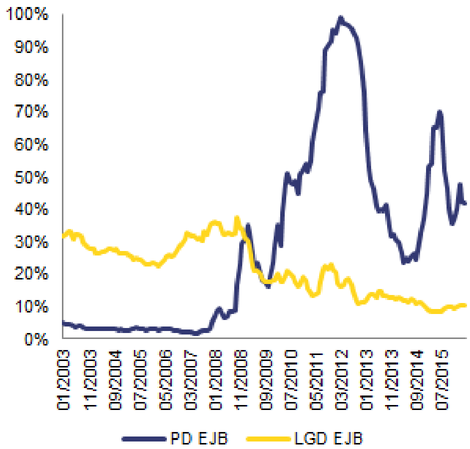

Figure 7: Counterfactual PDs and LGDs on European Junior Bonds (EJBies)

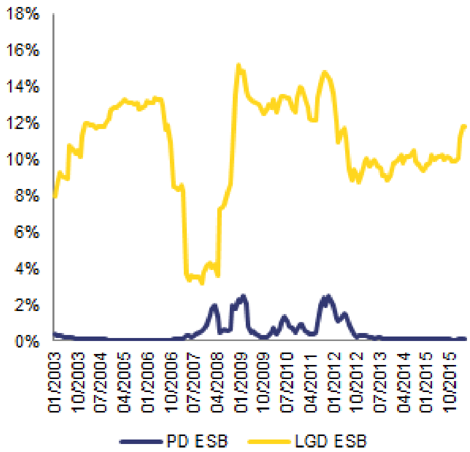

Figure 8: Counterfactual PDs and LGDs on European Senior Bonds (ESBies)

6.4 Simple pooling

The simple pooling approach is presented for illustration purposes. It differs from the previous option in the sense that the agency acquiring the debt stock of euro area Member States issues a single debt instrument without any type of tranching. The PD on the pool equals the PD on an EJB, as shown in Figure (7). The LGD on the pool is given by the following two equations:

$$LGD_{t,j}^{Pool} = \frac{0.6 \times \sum_{k \in I_j} D_{t,k}}{\sum_{i} D_{t,i}}$$

and

$$LGD_{t}^{Pool} = \sum_{j=1}^{2047} PD_{t,j}^{2047} \times LGD_{t,j}^{Pool},$$

where j and I_j have the same meaning as before. As expected, pooling presents no ISS gains or losses for the euro area aggregate. Compared with the ESB/EJB option, simple pooling widens the divergence between the hypothetical ISS gains and losses of the least and most creditworthy countries in case of mandatory issuance via a common debt agency.

7 Extensions

7.1 Systemic euro area risk and idiosyncratic national risk

The framework presented in Section 2 allows for the derivation of a euro area factor measuring systemic sovereign financial strength and for the decomposition of national dynamics into systemic and idiosyncratic components. In particular, say X_t is the first principal component of the set of financial strength variables $\{\Delta ln\,(F_{t,i})\}$. Then X_t is a weighted average of the normalised variations in the logarithm of financial strength, $\Delta ln\,(F_{t,i})^N$, across sovereigns. Normalisation implies that the $\Delta ln\,(F_{t,i})^N$ have mean zero and variance one, and that X_t has therefore mean zero. The loadings corresponding to the first principal component are shown in Table 4. Let X_t^N denote the re-scaled, or normalised, X_t, so that X_t^N has variance one. The respective normalised loadings are also shown in Table 4.

Table 4: Loadings of X_t

	Loadings	Normalised loadings
AT	0.30	0.09
BE	0.32	0.10
DE	0.31	0.09
EL	0.10	0.03
ES	0.35	0.11
FI	0.33	0.10
FR	0.35	0.11
IE	0.28	0.09
IT	0.25	0.08
NL	0.34	0.11
PT	0.29	0.09

For a given sovereign i, $\Delta ln\,(F_{t,i})^N$ can be decomposed as

$$\Delta ln\,(F_{t,i})^N = \frac{\Delta ln\,(F_{t,i}) - \mu_i}{\sigma_i} = \rho_i X_t^N + \sqrt{1-\rho_i^2}\varepsilon_{t,i}, \tag{24}$$

where

$$\begin{pmatrix} \Delta ln\,(F_{t,i})^N \\ X_t^N \\ \varepsilon_{t,i} \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{bmatrix} 1 & \rho_i & \sqrt{1-\rho_i^2} \\ \rho_i & 1 & 0 \\ \sqrt{1-\rho_i^2} & 0 & 1 \end{bmatrix} \right).$$

X_t^N can be understood as the systemic euro area component and $\varepsilon_{t,i}$ as the idiosyncratic component driving the dynamics of the (normalised, logged) financial strength of sovereign i. Given that X_t is the first principal component, it is uncorrelated with the $\varepsilon_{t,i}$ residual by construction. Also, given that both $\Delta ln\,(F_{t,i})^N$ and X_t^N have variance one, ρ_i represents the correlation between the evolution of the (normalised) sovereign financial strength and the systemic euro area factor. Likewise, $\sqrt{1-\rho_i^2}$ represents the correlation between a sovereign's financial strength and its idiosyncratic component. From Equation (24) it follows that

$$\Delta ln\,(F_{t,i}) = \mu_i + \sigma_i \rho_i X_t^N + \sigma_i \sqrt{1-\rho_i^2}\varepsilon_{t,i}. \tag{25}$$

The correlation parameter ρ_i can be obtained from an OLS estimation of Equation (24). Given ρ_i, the $\varepsilon_{t,i}$ can be inferred from the OLS residuals. Given that μ_i and σ_i are known from

Section 2, the parameters in Equation (25) are fully known. Table 5 presents the parameters of relevance. It is worth noting that Equation (25) implies that the bilateral correlations between sovereign financial strengths shown in Figure 2 can be decomposed into two elements: an indirect correlation intermediated by the systemic factor X_t^N and a direct correlation via the $\varepsilon_{t,i}$ residuals. For sovereigns i and j the former is given by $\rho_i \times \rho_j$ while the latter is given by $\sqrt{1-\rho_i^2} \times \sqrt{1-\rho_j^2} \times \rho_{\varepsilon_i,\varepsilon_j}$, where $\rho_{\varepsilon_i,\varepsilon_j}$ denotes the correlation between the residuals of sovereign i and j. This type of decomposition can be applied to simulate the financial strength responses to different types of shocks, as illustrated in Appendix D for two historical periods. For example, by negatively shocking the systemic risk factor it is possible to observe how the deterioration in creditworthiness varies across countries. Generally speaking, this deterioration will be higher for Member States that are more dependent on the systemic factor X_t^N, as well as for those countries with a worse starting position. Alternatively, it is also possible to negatively shock the idiosyncratic component, as exemplified for Italy in Appendix D. The transmission of this type of shock is assumed to be based on the correlation matrix of $\varepsilon_{t,i}$, and tends to be muted. Also, a negative, purely idiosyncratic shock in one country can lead to positive spill-overs in another country, which can be the result of safe haven effects. Finally, "non-discriminated" country shocks can be simulated by relying simply on the correlation matrix of financial strengths as shown in Figure 2, without further consideration as to their systemic or idiosyncratic nature. This is exemplified for comparison purposes in the last column of the tables in Appendix D.

Table 5: Decomposition parameters for $\Delta ln\left(F_{t,i}\right)$

	μ_i	σ_i	ρ_i	$\sqrt{1-\rho_i^2}$	$\sigma_i\rho_i$	$\sigma_i\sqrt{1-\rho_i^2}$
AT	0.004	0.010	0.74	0.68	0.008	0.007
BE	0.003	0.005	0.79	0.61	0.004	0.003
DE	0.003	0.008	0.75	0.66	0.006	0.005
EL	0.004	0.018	0.23	0.97	0.004	0.017
ES	0.007	0.014	0.86	0.50	0.012	0.007
FI	0.005	0.015	0.82	0.58	0.012	0.009
FR	0.005	0.007	0.87	0.50	0.006	0.003
IE	0.008	0.021	0.70	0.71	0.015	0.015
IT	0.003	0.004	0.61	0.79	0.002	0.003
NL	0.004	0.013	0.84	0.54	0.011	0.007
PT	0.006	0.009	0.72	0.70	0.006	0.006

Appendix E shows for each Member State the decomposition of the evolution of $\Delta ln\left(F_{t,i}\right)$ into a systemic and idiosyncratic component. It can be noticed that debt capacities increased markedly during the second half of 2008 and the first half of 2009 for most Member States. This reflects a market-based assessment of sovereigns' determination to increase their debt capacity in order to cope with higher expected debt levels following the onset of the financial crisis. This can be achieved by, for example, increasing projected tax-raising capacity and revenue, decreasing projected expenditure and investment, or by embarking on structural reforms. Due to the simultaneous nature of the shock, the systemic component tends to be the main driver of the dynamics during this period. The observed increase in debt capacity does not mean, however, that sovereigns were able to fully rise to the challenges posed by the financial crisis. This point is illustrated in Appendix F which compares, for each Member State, how financial strength, as assessed by market participants, evolved vis-à-vis expected debt levels. In particular, Appendix F shows for each sovereign the cumulated difference between the two variables from the beginning of the sample period until a given month $t^{current}$:

$$\text{Cumulated financial gap}_{i,t^{current}} = \sum_{t=1}^{t^{current}} \left(\Delta ln\left(F_{t,i}\right) - \Delta ln\left(D_{t+24,i}\right)\right). \tag{26}$$

As can be observed, a negative cumulated financial gap opened up for all euro area Member States in either 2007 or 2008, although its size and subsequent closure processes differed markedly across countries. While for the stronger euro area economies the gap was mostly or fully closed by 2016, for the more vulnerable countries a significant negative gap still persisted by the end of the sample period. An increasing trend in the cumulated financial gap measure requires $\Delta ln\left(F_{t,i}\right) > \Delta ln\left(D_{t+24,i}\right)$ and reflects therefore a period of improving creditworthiness. In this connection, it can also be interesting to focus on a sovereign's idiosyncratic efforts towards improving its credit standing. These can be reckoned as:

$$\begin{aligned} \text{Idiosyncratic sovereign efforts}_{i,t} &= \left(\Delta ln\left(F_{t,i}\right) - \sigma_i \rho_i X_t - \Delta ln\left(D_{t+24,i}\right)\right) \\ &= \mu_i + \sigma_i \sqrt{1-\rho_i^2}\varepsilon_{t,i} - \Delta ln\left(D_{t+24,i}\right). \end{aligned} \tag{27}$$

By subtracting the zero-meaned systemic component $\sigma_i \rho_i X_t$ in Equation (27) one can focus on sovereign-specific elements. The idiosyncratic sovereign effort series are shown in Appendix F as centred three-month moving averages, for a smoother depiction.

7.2 Assessing robustness under a fat-tailed distribution

The Merton model underpinning the analysis in the preceding sections relies on a log-normality assumption for the evolution of a sovereign's financial strength over time. As such, the evolution of the logarithm of a sovereign's financial strength is governed by the quintessential mesokurtic distribution, the normal distribution. The literature suggests, however, that the dynamics of (logged) asset prices may be better approximated by distributions with fat tails (see, e.g., Campbell et al. (1996)), which place higher probability weight on extreme movements. This subsection shows how the analysis in the preceding sections can be adapted to a fat-tails framework and how the robustness of some results can be checked by comparing them with results obtained under a fat-tailed multivariate t distribution with 4 degrees of freedom.

In order to account for fat tails, a multivariate log-t distribution can be derived that matches the baseline multivariate log-normal distribution in the sense of being based on the same first and second moments. This matching (log-)t distribution is obtained as follows. Let $ln\left(F_t\right)$ denote the vector composed of elements $ln\left(F_{t,i}\right)$. Given that $ln\left(F_{t+24}\right) \sim N\left(ln\left(F_t\right) + 24\mu, 24\Sigma\right)$, then

$$\sqrt{2} \times ln\left(F_{t+24}\right) \sim N\left(\sqrt{2}\left(ln\left(F_t\right) + 24\mu\right), 2 \times 24\Sigma\right), \tag{28}$$

where Σ denotes the covariance matrix of $\Delta ln\left(F_t\right)$. A matching t distribution possessing the same mean and covariance matrix as $\sqrt{2} \times ln\left(F_{t+24}\right)$ can then be defined has having 4 degrees of freedom ν and covariance parameter $24\mathit{\Sigma}$. Let us denote this distribution as $t_4\left(ln\left(F_t\right) + 24\mu, 24\Sigma\right)$. Then, the covariance matrix of t_4 is $\frac{\nu}{\nu-2} \times 24 \times \Sigma = 2 \times 24 \times \Sigma = covar\left(\sqrt{2} \times ln\left(F_{t+24}\right)\right)$.

As an example, the matching probability under t_4 that $ln\left(F_{t+24}\right) < ln\left(D_{t+24}\right)$ is given by the cumulative distribution function of t_4 assessed at $\frac{ln(D_{t+24})}{\sqrt{2}}$, where the normalisation of the debt level by the square root of two is done so as to ensure consistency of the critical levels with the original normal distribution. The matching t distribution with 4 degrees of freedom is thus based on the same mean and correlation matrix as the original normal distribution, with critical levels adjusted to reflect the multiplication by $\sqrt{2}$ in Equation (28). This probability calculated under a fat-tailed t distribution will be higher than $PD\left(ln\left(F_{t+24}\right) < ln\left(D_{t+24}\right)\right)$ calculated under the normal distribution for extreme events (i.e., in the cases where the PD calculated under the normal distribution is very low).[35]

[35] In a situation where the multivariate t distribution is normalised to a zero mean and defined in terms of a correlation matrix, as is the case of some software implementations, an equivalent normalisation can be implemented. If $ln\left(F_{t+24}\right) \sim N\left(ln\left(F_t\right) + 24\mu, 24\Sigma\right)$, then

$$\frac{\sqrt{2}}{\sqrt{24}} \times diag\left(\Sigma\right)^{-\frac{1}{2}} \times \left[ln\left(F_{t+24}\right) - ln\left(F_t\right) - 24\mu\right] \sim N\left(0, 2R\right),$$

where $diag\left(\mathit{\Sigma}\right)$ is a diagonal matrix with the variances of F in the diagonal, and R is the correlation matrix of F. The matching t distribution with 4 degrees of freedom will then have zero mean and covariance matrix R.

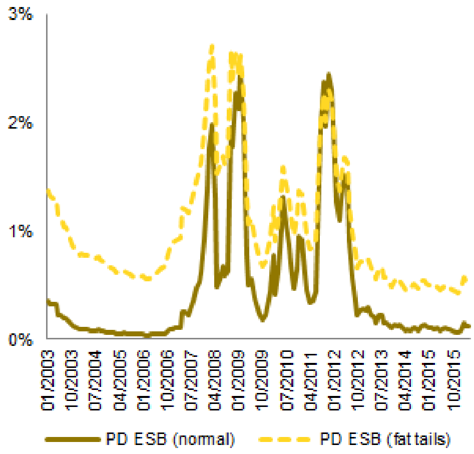

Figure 9: PDs on European Senior Bonds (ESBies) under normal and fat-tailed distributions

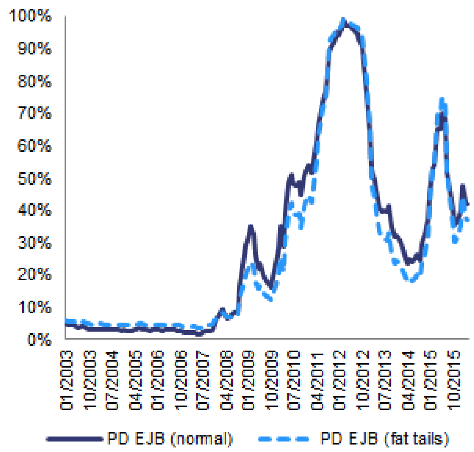

Figure 10: PDs on European Junior Bonds (EJBies) under normal and fat-tailed distributions

Allowing for fat-tails shifts the probability mass towards extreme events, but does not necessarily increase the probability of events that are merely deemed unlikely. Figures (9) and (10) illustrate this point for the PDs of ESBies and EJBies. Given that default on an ESB is an extreme event, a fat-tailed distribution assumption yields higher PDs, thus producing a more conservative assessment of the ESB instrument. In contrast, default on an EJB may be unlikely most of the time, but it is not an extreme event. As such, the fat-tailed distribution assumption produces PDs that are often lower than the baseline PDs obtained under the normal distribution. In this case, relying on a fat-tailed distribution does not make for a more conservative assessment. Given that expected LGDs are calculated, inter alia, on the basis of PDs, they also vary under a fat-tailed distribution.

8 Conclusions and future research

This paper introduced a novel, integrated framework for the assessment of the key financial properties of common sovereign debt instruments in a currency union such as the euro area. By relying on market-based information extracted from CDS spreads or bond yields, on projected debt levels and on the structure provided by a structural credit risk model, a measure of a sovereign's debt capacity or financial strength can be extracted using state-space methods. By taking into account the empirical properties of the financial strength series thus derived, different types of common debt instruments can be simulated and their performance assessed based on a simple measure of counterfactual credit risk premia gains and losses. The approach is suitable for the assessment of instruments involving full or partial mutualisation of sovereign risk, whose quantitative analysis had been lacking in the literature.

Of the different types of common debt instruments considered in this paper, fully mutualised "eurobonds" provide, by far, the largest counterfactual benefit as far as the euro area aggregate is concerned. This is due to the diversification of idiosyncratic risks afforded by mutualisation and to the pooling together of national fiscal spaces under a single instrument. These benefits are largest for euro area Member States that underwent market stress following the 2008 financial crisis, but also remain in evidence, albeit modestly, for the most creditworthy countries. In fact, while the counterfactual simulations show that eurobonds could result in higher risk premia for specific countries during peak crisis periods, these losses are more than offset when our full sample period is considered.

Another type of instrument simulated in this paper involves partial mutualisation of sovereign risk through the issuance of commonly-guaranteed "blue bonds" and of national "red bonds". The analytical approach for assessing partial mutualisation requires particular consideration. This paper developed a framework which operationalises the partial mutualisation concept and that is shown to fulfill a number of desirable properties. Partial mutualisation delivers the second highest euro area gains for the sample period under analysis. As before, all Member States are seen to gain from a blue bond/red bond scheme, although the gains are larger for the more creditworthy Member States and smaller for the less creditworthy countries when compared with the case of full mutualisation. This is due to the market discipline imposed on Member States via the red bond which, for a mutualisation threshold representing 60% of GDP, can command a significant risk premium. Overall, different Member States show different optimal levels of mutualisation. While full mutualisation is optimal for the less creditworthy Member States, the more creditworthy countries stand to gain the most from high, but incomplete, levels of mutualisation.

Two options were then simulated that do not involve mutualisation but rather the *a priori* tranching of national debt by Member States into a junior and a senior instrument. This can be achieved by issuing debt instruments with different seniority levels in primary markets, or by conferring a preferred creditor status to a common European debt agency. For a cut-off point of 60% of GDP for the senior tranche, these instruments can present gains which are akin to those achieved by partial mutualisation. This result rests, however, upon the assumption that Member States default only sequentially under *a priori* tranching (i.e., that they avoid defaulting on the senior tranche unless forced to by a precipitous drop in their debt capacity). In such cases, the "firewall" effect provided by the junior tranches lowers the expected loss on total debt outstanding, leading to lower overall financing costs. The fact that mutualisation of the senior tranches can hardly improve upon simple *a priori* tranching is also linked to the cut-off point chosen in the simulations which, at 60% of GDP, renders the senior tranches very low risk. For such a cut-off point, mutualisation provides only a modest credit enhancement, although its design offers the advantage that the sequential default assumption is necessarily met.

Alternatively, a common debt agency may acquire in the market debt securities of participating Member States and repackage them into senior and junior instruments, in line with the "ESBies" and "EJBies" proposal. This operation does not change overall financing costs for the euro area aggregate, nor for participating Member States, reflecting its pure financial engineering nature. In case Member States were compelled to issue directly via ESBies and EJBies, this would represent an implicit form of mutualisation producing no aggregate gains while imposing higher counterfactual risk premia on the more creditworthy Member States due to the risk contamination of the common debt instruments as a result of the participation of the riskiest Member States in the scheme. Conversely, the least creditworthy Member States would benefit from a lower risk premium due to the relatively small loss given default on the common instruments afforded by the large pool of underlying debt. The ESBies are assessed as safe instruments even at a cut-off point as high as 60% of GDP, while the EJBies can be highly risky, particularly in times of stress.

As an extension of the analysis, it was shown how sovereign financial strength dynamics can be decomposed into systemic and idiosyncratic factors allowing for, inter alia, the simulation of shock responses. As expected, countries most affected by systemic shocks are those starting from a more vulnerable position, or which are more dependent on the systemic risk factor. A purely idiosyncratic negative shock to one country tends to transmit only mutely to other sovereigns and may generate positive spill-overs, as in the case of safe haven effects. The aforementioned decomposition also allows for the reckoning of a sovereign's idiosyncratic efforts in maintaining its creditworthiness over time.

Finally, it was shown how the robustness of the results can be tested by relying on a "matching" log-t distribution. This fat-tailed distribution is based on the same first and second moments of the baseline log-normal distribution and allows for a more conservative assessment when considering low probability events.

Two broad avenues open up as regards future research, which can be classified as either of an intensive or of an extensive nature. The intensive avenue would involve exploring the financial properties of common debt instruments under variations of the previously-introduced framework. This could include the employment of structural credit risk models other than the Merton model, the use of market information for maturities other than the two-year horizon or the consideration of different sample periods. While the main intent of this paper was to assess the credit risk properties of various instruments under a benchmark framework, there is a case for considering other structural models capturing more complex features of sovereign risk dynamics such as the possibility of instantaneous default, stochastic volatility or time variation in the parameters. It should be noted, however, that more sophisticated models are not, in general, amenable to the exact linear state-space representation forming the basis for the estimation strategy developed in this paper.

The extensive avenue for future research would involve quantifying the gains and losses from common debt instruments under a broader framework encompassing macroeconomic aspects. Such a framework can incorporate the partial-equilibrium financial assessment developed in this paper, which can be understood as providing a lower bound for overall net gains should the broader stability and institutional benefits mentioned in Section 1 materialise. This requires tackling the implications for moral hazard of some of these instruments, a question that can be addressed through reference to the conclusions of the fiscal reaction function literature on how marginal financing costs affect fiscal prudence, or through the incorporation of fully-fledged strategic default models into the analysis. At the limit, a full consideration of the effects of introducing a common sovereign debt instrument requires a general equilibrium framework, with Monteiro (2023) providing an instance of such a type of analysis by employing a dynamic stochastic general equilibrium model to simulate the role of eurobonds in the context of a capital flight within the euro area.

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A ISS gains/losses based on nowcast debt shares

Table 6: ISS gain (+) / loss (-) based on nowcast debt shares (basis points, January 2003 to April 2016)

	Euro Area	AT	BE	DE	EL	ES	FI	FR	IE	IT	NL	PT
Full mutualisation (Eurobonds)	70	26	25	4	707	75	5	14	121	94	10	209
Partial mutualisation (Blue bond and red bond)	22	30	13	11	42	64	17	15	54	17	20	72
Tranching and pooling ("E-bonds")	21	29	13	10	42	63	15	14	53	17	19	71
Simple tranching	21	27	14	11	43	57	2	15	50	17	14	72
Pooling and tranching ("ESBies" and "EJBies")[36]	5	-3	-59	-37	578	48	13	-41	50	-17	1	132
Simple pooling[36]	0	-43	-45	-66	637	6	-65	-55	51	24	-60	139

Note: the cut-off level of the senior tranches was set at 60% of GDP, where applicable. The euro area figures refer to the total gains accruing to the euro area aggregate composed of the 11 Member States considered in the simulations. Results for i) tranching and pooling and for ii) simple tranching are based on a sequential default assumption (see Subsection 6.1).

[36] The figures shown under i) pooling and tranching and ii) simple pooling represent the gains and losses of a hypothetical common debt agency associated with transacting different sovereign bonds in the market, or the gains and losses that would accrue to Member States under a scheme of mandatory issuance via a common debt agency.

B A framework for analysing partial sovereign risk mutualisation

This appendix proves the properties of the framework for analysing partial mutualisation introduced in Section 5.

In order to prove **Implication (14)** it suffices to show that $\sum_i F_{t,i} \leq \sum_i D^S_{t,i} \Rightarrow F^P_{t,i} = F_{t,i}\ \forall i$, given that $F^R_{t,i} = 0$ whenever $F^P_{t,i} = F_{t,i}$, according to Equation (12). For a given time t let the set I of participating countries be partitioned into $S_< = \left\{i \in I : F_{t,i} < D^S_{t,i}\right\}$ and $S_\geq = \left\{i \in I : F_{t,i} \geqslant D^S_{t,i}\right\}$. If $i \in S_<$, Equation (13) implies that $F^P_{t,i} = F_{t,i}$. If $i \in S_\geq$ observe that

$$\sum_i F_{t,i} \leq \sum_i D^S_{ti} \Leftrightarrow D^S_{t,i} - F_{t,i} + \sum_{j \neq i} \left(D^S_{t,j} - F_{t,j}\right) \geqslant 0. \tag{29}$$

Given that $i \in S_\geq$, we have that $D^S_{t,i} - F_{t,i} \leq 0$ and therefore Inequality (29) implies that $\sum_{j \neq i} \left(D^S_{t,j} - F_{t,j}\right) \geqslant 0$. It then follows that $D^S_{t,i} - F_{t,i} + \sum_{j \neq i} \left(D^S_{t,j} - F_{t,j}\right) \geqslant 0 \Leftrightarrow D^S_{t,i} - F_{t,i} + \left[\sum_{j \neq i} \left(D^S_{t,j} - F_{t,j}\right)\right]^+ \geqslant 0 \Leftrightarrow D^S_{t,i} + \left[\sum_{j \neq i} \left(D^S_{t,j} - F_{t,j}\right)\right]^+ \geqslant F_{t,i}$. Per Equation (13) this condition implies that $F^P_{t,i} = F_{t,i}$.

Let us now see how the probabilities of default on the junior tranche, PD^J, can be calculated from **Equation (16)**. We have that

$$PD^J_{t,i} = P\left(F^R_{t+24,i} < D^J_{t+24,i}\right)$$

$$= P\left(\sum_{j \neq i} F_{t+24,j} > \sum_{j \neq i} D^S_{t+24,j}\right) \times P\left(F^R_{t+24,i} < D^J_{t+24,i} \middle| \sum_{j \neq i} F_{t+24,j} > \sum_{j \neq i} D^S_{t+24,j}\right)$$

$$+P\left(\sum_{j \neq i} F_{t+24,j} < \sum_{j \neq i} D^S_{t+24,j}\right) \times P\left(F^R_{t+24,i} < D^J_{t+24,i} \middle| \sum_{j \neq i} F_{t+24,j} < \sum_{j \neq i} D^S_{t+24,j}\right),$$

where the second equality follows from the law of total probability whereby the default space is split into a idiosyncratic country default (the first term) and a systemic default setting (the second term). By incorporating Equations (12) and (13), we have that

$$PD^J_{t,i} = P\left(\sum_{j \neq i} F_{t+24,j} > \sum_{j \neq i} D^S_{t+24,j}\right) \times P\left(F_{t+24,i} < D_{t+24,i} \middle| \sum_{j \neq i} F_{t+24,j} > \sum_{j \neq i} D^S_{t+24,j}\right)$$

$$+P\left(\sum_{j \neq i} F_{t+24,j} < \sum_{j \neq i} D^S_{t+24,j}\right) \times P\left(\sum_i F_{t+24,i} < \sum_i D^S_{t+24,i} + D^J_{t+24,i} \middle| \sum_{j \neq i} F_{t+24,j} < \sum_{j \neq i} D^S_{t+24,j}\right),$$

i.e.

$$PD^J_{t,i} = P\left(F_{t+24,i} < D_{t+24,i} \bigcap \sum_{j \neq i} F_{t+24,j} > \sum_{j \neq i} D^S_{t+24,j}\right) \tag{30}$$

$$+P\left(\sum_j F_{t+24,j} < \sum_j D^S_{t+24,j} + D^J_{t+24,i} \bigcap \sum_{j \neq i} F_{t+24,j} < \sum_{j \neq i} D^S_{t+24,j}\right).$$

The first term in Equation (30) can be calculated from the bivariate distribution function of $\left(F_{t+24,i}, \sum_{j\neq i} F_{t+24,j}\right)$ while the second term can be calculated based on the bivariate distribution of $\left(\sum_{i} F_{t+24,i}, \sum_{j\neq i} F_{t+24,j}\right)$.[37] Under the assumption of joint normality of $\left\{\triangle ln(F_{t,i})\right\}$ and taking into account the empirical covariance matrix of $\triangle ln(F_t)$, the required bivariate distributions can be obtained as shown below, allowing for the calculation of the probabilities of idiosyncratic country default (the first term) and systemic default of partner countries for each sovereign and for each point in time (see below). $PD^J_{t,i}$ is then the sum of these two probabilities.

We now proceed to prove Properties 1 to 3, as listed in Section 5.

Property 1 is based on the fact that a distribution is multivariate normal if and only if every linear combination of its component variables is normally distributed. Therefore, under the assumption of joint normality for $\{\triangle ln\,(F_{t,i})\}$, we have that for a given sovereign i

$$\begin{bmatrix} 0 & ... & 1 & ... & 0 \end{bmatrix} \times \begin{bmatrix} \triangle ln\,(F_{t,1}) \\ ... \\ \triangle ln\,(F_{t,i}) \\ ... \\ \triangle ln\,(F_{t,n}) \end{bmatrix} = \triangle ln\,(F_{t,i}) \sim N\left(\mu_i, \sigma_i^2\right)$$

and

$$\begin{bmatrix} 1 & ... & 0 & ... & 1 \end{bmatrix} \times \begin{bmatrix} \triangle ln\,(F_{t,1}) \\ ... \\ \triangle ln\,(F_{t,i}) \\ ... \\ \triangle ln\,(F_{t,n}) \end{bmatrix} = \sum_{j\neq i} \triangle ln\,(F_{t,j}) \sim N\left(\sum_{j\neq i}\mu_j, \sigma^2_{\sum_{j\neq i}\triangle ln(F_{t,j})}\right),$$

where $\sigma^2_{\sum_{j\neq i}\triangle ln(F_{t,j})}$ denotes the variance of the variable $\sum_{j\neq i}\triangle ln\,(F_{t,j})$. In order to show that $\left(\triangle ln\,(F_{t,i}), \sum_{j\neq i}\triangle ln\,(F_{t,j})\right)$ are joint normally distributed observe that any linear combination of the two variables is normally distributed:

$$a \times \triangle ln\,(F_{t,i}) + b \times \sum_{j\neq i} \triangle ln\,(F_{t,j}) =$$

$$= \begin{bmatrix} b & ... & a & ... & b \end{bmatrix} \times \begin{bmatrix} \triangle ln\,(F_{t,1}) \\ ... \\ \triangle ln\,(F_{t,i}) \\ ... \\ \triangle ln\,(F_{t,n}) \end{bmatrix} \sim N\left(a \times \mu_i + b \times \sum_{j\neq i}\mu_j, \sigma^2_{a\times\triangle ln(F_{t,i})+b\times\sum_{j\neq i}\triangle ln(F_{t,j})}\right).$$

A similar reasoning can be applied to show that $\left(\sum_{i}\triangle ln\,(F_{t,i}), \sum_{j\neq i}\triangle ln\,(F_{t,j})\right)$ are also joint normally distributed variables. Given the bivariate normal distributions of $\left(\triangle ln\,(F_{t,i}), \sum_{j\neq i}\triangle ln\,(F_{t,j})\right)$ and $\left(\sum_{i}\triangle ln\,(F_{t,i}), \sum_{j\neq i}\triangle ln\,(F_{t,j})\right)$, the probability of default on the red bonds, $PD^J_{t,i}$, can be calculated from Equation (30).

[37] As before, the Fenton-Wilkinson approximation is used when dealing with the sum of log-normal variables.

Property 2 follows from the fact that if $\left(\sum_{j\neq i} F_{t,i} > \sum_{j\neq i} D^S_{ti}\right)$, then the first branch of Equation (13) implies that $F^P_{t,j} = D^S_{t,i}$. As $F_{t,j}$ does not enter the previous equality, we have that $\frac{\partial F^P_{t,j}}{\partial F_{t,j}} = 0$. It should be noted that this conclusion does not apply when both $\left(\sum_{j\neq i} F_{t,i} > \sum_{j\neq i} D^S_{ti}\right)$ and $F_{t,j} < D^S_{t,i}$. In this case, the second branch of Equation (13) yields $F^P_{t,j} = F_{t,j}$. However, this is a case where sovereign i is in idiosyncratic default and any financial strength gains are immediately pledged to that sovereign's share of the blue bond, $D^S_{t,i}$. As such, sovereign i is arguably the residual beneficiary of its own financial strength also in this case.

Property 3 says that $F^P_{t,i} \uparrow F_{t,i}\ \forall i$ as $\sum_i F_{t,i} \downarrow \sum_i D^S_{t,i}$. In continuous time, $F_{t,i}$ is a geometric brownian motion and, therefore, a continuous process. Let us assume that $D^S_{t,i}$ is also a continuous process. The property can be verified by proving each of the following statements:

1. $\sum_i F_{t,i} \geq \sum_i D^S_{t,i}. \Rightarrow F^P_{t,i} \leq F_{t,i}\ \forall i$.

2. $F^P_{t,i} - F_{t,i}\ = f\left(\sum_i \left(F_{t,i} - D^S_{t,i}\right)\right)$ is continuous.

3. $\sum_i F_{t,i} = \sum_i D^S_{t,i} \Rightarrow F^P_{t,i} = F_{t,i}\ \forall i$.

In order to show Statement 1., partition the set I of participating countries into sets $S_<$ and $S_\geq$, as previously defined. Given that $\sum_i F_{t,i} \geq \sum_i D^S_{t,i}$, we have that $S_\geq$ will be non-empty, while $S_<$ may or may not be empty. If $i \in S_<$, Equation (13) implies that $F^P_{t,i} = F_{t,i}$ and Statement 1. holds. If $i \in S_\geq$, consider the following two cases. If $\left[\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ = 0$ then Equation (13) implies that $F^P_{t,i} = D^S_{t,i} \leq F_{t,i}$ and statement 1 holds. If $\left[\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ > 0$ then $\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right) + D^S_{t,i} - F_{t,i} = \sum_i D^S_{t,i} - \sum_i F_{t,i} \leq 0 \Leftrightarrow D^S_{t,i} + \left[\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ \leq F_{t,i}$. The last inequality together with Equation (13) mean that $F^P_{t,i} \leq F_{t,i}$, implying that Statement 1. also holds in this case.

In order to show Statement 2., let us consider in turn each branch of Equation (13). Regarding the first branch of the equation, if $D^S_{t,i} + \left[\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ < F_{t,i}$, then $F^P_{t,i} - F_{t,i}\ = D^S_{t,i} - F_{t,i} + \left[\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+$. If, in turn, $\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right) > 0$, then $F^P_{t,i} - F_{t,i}\ = -\sum_i\left(F_{t,i} - D^S_{t,i}\right)$, which is continuous. Otherwise, $F^P_{t,i} - F_{t,i}\ = -\left(F_{t,i} - D^S_{t,i}\right)$, which is also continuous. Finally, $F^P_{t,i} - F_{t,i}$ is continuous at the critical point where $\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right) = 0$ given the continuity of the maximum function. Regarding the second branch of the equation, if $D^S_{t,i} + \left[\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ \geq F_{t,i}$, then $F^P_{t,j} - F_{t,i} = 0$, which is trivially continuous. It remains to establish continuity at the threshold where $F^P_{t,i}$ switches branches, i.e., at $D^S_{t,i} + \left[\sum_{j\neq i}\left(D^S_{t,j} - F_{t,j}\right)\right]^+ = F_{t,i}$. Continuity in this case follows from the fact that $F^P_{t,i}$ can be written as the minimum between $D^S_{t,i} +$

$\left[\sum_{j\neq i}\left(D^S_{t,j}-F_{t,j}\right)\right]^+$ and $F_{t,i}$,[38] which is a continuous function of two functions we have shown to be continuous.

Finally, as regards Statement 3., we have seen from Implication (14) that when $\sum_i F_{t,i} = \sum_i D^S_{t,i}$, we have that $F^P_{t,i} = F_{t,i}\ \forall i$.

In order to show **Property 4,** let us denote the probability of default on the blue bond as $PD^{J,Blue}$ and the probability of default on the junior bond under a tranching approach as $PD^{J,Tranche}$. We have seen in this appendix that

$$PD^{J,Blue}_{t,i} = P\left(\sum_{j\neq i} F_{t+24,j} > \sum_{j\neq i} D^S_{t+24,j}\right)\times P\left(F_{t+24,i} < D_{t+24,i} | \sum_{j\neq i} F_{t+24,j} > \sum_{j\neq i} D^S_{t+24,j}\right)$$

$$+P\left(\sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right)\times P\left(\sum_i F_{t+24,i} < \sum_i D^S_{t+24,i} + D^J_{t+24,i} | \sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right).$$

At the same time, we have seen in Subsection 6.1 that

$$PD^{J,Tranche} = P\left(F_{t+24,i} < D_{t+24,i}\right)$$

$$= P\left(\sum_{j\neq i} F_{t+24,j} > \sum_{j\neq i} D^S_{t+24,j}\right)\times P\left(F_{t+24,i} < D_{t+24,i} | \sum_{j\neq i} F_{t+24,j} > \sum_{j\neq i} D^S_{t+24,j}\right)$$

$$+P\left(\sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right)\times P\left(F_{t+24,i} < D_{t+24,i} | \sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right).$$

Therefore, in order to show that $PD^{J,Blue} > PD^{J,Tranche}$, it suffices to show that

$$P\left(\sum_i F_{t+24,i} < \sum_i D^S_{t+24,i} + D^J_{t+24,i} | \sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right) > P\left(F_{t+24,i} < D_{t+24,i} | \sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right).$$

This is true, as

$$P\left(\sum_i F_{t+24,i} < \sum_i D^S_{t+24,i} + D^J_{t+24,i} | \sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right)$$

$$= P\left(F_{t+24,i} < D_{t+24,i} + \left(\sum_{j\neq i} D^S_{t+24,j} - \sum_{j\neq i} F_{t+24,j}\right) | \sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right)$$

$$> P\left(F_{t+24,i} < D_{t+24,i} | \sum_{j\neq i} F_{t+24,j} < \sum_{j\neq i} D^S_{t+24,j}\right).$$

[38] See footnote 28.

C Simultaneous default versus sequential default: an example

The following example illustrates the gains in terms of expected loss on total debt obtained from moving from a situation where an issuer defaults simultaneously on its junior and senior tranches to a situation where it defaults only sequentially. Take the case of sovereign i with debt D_i worth 100% of GDP, a PD_i of 10% and a standard LGD of 60%. The expected loss for this sovereign before tranching is $PD_i \times LGD = 10\% \times 60\% = 6\%$. Assume now that sovereign i's debt has been split 60% into a senior tranche D_i^S and 40% into a junior tranche D_i^J. We now have two possibilities:

1. **Simultaneous default**: irrespective of tranching, in the event of default, sovereign i defaults simultaneously on both tranches imposing an LGD of 60% on total debt outstanding. This is the type of behaviour underlying the pooling and tranching option of Subsection (6.3) where sequential default is not possible due to the fact that there is only one type of debt security issued in the primary market. The expected loss on total debt outstanding is the weighted average of the expected loss on each tranche: $PD_i^J \times LGD_i^J \times \frac{D_i^J}{D_i} + PD_i^S \times LGD_i^S \times \frac{D_i^S}{D_i} = 10\% \times 100\% \times 40\% + 10\% \times \frac{(60\% - 40\%)}{60\%} \times 60\% = 6\%$. There are no credit risk premia gains from tranching as the expected loss is the same.

2. **Sequential default**: sovereign i only defaults on the senior tranche after having defaulted first on the junior tranche. This is the assumption underlying the options with *a priori* tranching, which open up this possibility for the sovereign. The expected loss on overall debt outstanding is $PD_i^J \times LGD_i^J \times \frac{D_i^J}{D_i} + PD_i^S \times LGD_i^S \times \frac{D_i^S}{D_i} = 10\% \times 100\% \times 40\% + 0\% \times 60\% \times 60\% = 4\%$ where PD_i^S is assumed to be zero, for illustration sake,[39] and LGD_i^S is a conventional 60%. The gains from tranching result from this lower expected loss.

[39] A PD of approximately zero for a senior tranche worth 60% of GDP is consistent with model-based results for several countries and sample periods.

D Systemic euro area shocks and idiosyncratic country shocks: an illustration

	Situation in Apr-08		Systemic EA shock (2 std dev)				Idiosyncratic shock to IT (2 std dev)				Combined systemic (2 std dev) and idiosync. shock (2 std dev) to IT				Non-discriminated shock to IT (2 std dev)			
	CDS	PD	CDS	PD	Δ CDS	Δ PD	CDS	PD	Δ CDS	Δ PD	CDS	PD	Δ CDS	Δ PD	CDS	PD	Δ CDS	Δ PD
AT	15	0.5%	36	1.2%	20	0.7%	15	0.5%	0	0.0%	35	1.2%	20	0.7%	26	0.9%	11	0.4%
BE	14	0.5%	34	1.1%	21	0.7%	12	0.4%	-2	-0.1%	29	1.0%	16	0.5%	22	0.7%	8	0.3%
DE	8	0.3%	20	0.7%	12	0.4%	8	0.3%	0	0.0%	20	0.7%	12	0.4%	14	0.5%	6	0.2%
EL	111	3.7%	138	4.6%	27	0.9%	129	4.3%	18	0.6%	158	5.3%	47	1.6%	142	4.7%	31	1.0%
ES	23	0.8%	58	1.9%	35	1.2%	18	0.6%	-5	-0.2%	46	1.5%	23	0.8%	34	1.1%	11	0.4%
FI	10	0.3%	27	0.9%	17	0.6%	10	0.3%	0	0.0%	27	0.9%	17	0.6%	19	0.6%	9	0.3%
FR	10	0.3%	27	0.9%	18	0.6%	10	0.3%	0	0.0%	27	0.9%	17	0.6%	18	0.6%	9	0.3%
IE	16	0.5%	37	1.2%	20	0.7%	15	0.5%	-2	-0.1%	33	1.1%	16	0.5%	25	0.8%	8	0.3%
IT	33	1.1%	64	2.1%	30	1.0%	76	2.5%	42	1.4%	132	4.4%	99	3.3%	92	3.1%	59	2.0%
NL	9	0.3%	24	0.8%	16	0.5%	8	0.3%	-1	0.0%	21	0.7%	13	0.4%	15	0.5%	6	0.2%
PT	36	1.2%	75	2.5%	39	1.3%	37	1.2%	1	0.0%	76	2.5%	40	1.3%	58	1.9%	22	0.7%

	Situation in Apr-16		Systemic EA shock (2 std dev)				Idiosyncratic shock to IT (2 std dev)				Combined systemic (2 std dev) and idiosync. shock (2 std dev) to IT				Non-discriminated shock to IT (2 std dev)			
	CDS	PD	CDS	PD	Δ CDS	Δ PD	CDS	PD	Δ CDS	Δ PD	CDS	PD	Δ CDS	Δ PD	CDS	PD	Δ CDS	Δ PD
AT	19	0.6%	43	1.4%	24	0.8%	19	0.6%	0	0.0%	42	1.4%	24	0.8%	31	1.0%	13	0.4%
BE	22	0.7%	53	1.8%	31	1.0%	19	0.6%	-3	-0.1%	46	1.5%	24	0.8%	34	1.1%	12	0.4%
DE	10	0.3%	24	0.8%	14	0.5%	10	0.3%	0	0.0%	24	0.8%	14	0.5%	17	0.6%	8	0.3%
EL	1103	36.8%	1215	40.5%	111	3.7%	1178	39.3%	75	2.5%	1290	43.0%	187	6.2%	1231	41.0%	127	4.2%
ES	53	1.8%	122	4.1%	69	2.3%	43	1.4%	-11	-0.4%	99	3.3%	46	1.5%	76	2.5%	23	0.8%
FI	13	0.4%	34	1.1%	21	0.7%	13	0.4%	0	0.0%	33	1.1%	20	0.7%	24	0.8%	10	0.3%
FR	14	0.5%	38	1.3%	24	0.8%	14	0.5%	0	0.0%	37	1.2%	23	0.8%	26	0.9%	12	0.4%
IE	25	0.8%	54	1.8%	29	1.0%	23	0.8%	-2	-0.1%	48	1.6%	23	0.8%	37	1.2%	12	0.4%
IT	92	3.1%	160	5.3%	68	2.3%	185	6.2%	93	3.1%	295	9.8%	203	6.8%	218	7.3%	126	4.2%
NL	14	0.5%	37	1.2%	23	0.8%	12	0.4%	-2	-0.1%	33	1.1%	19	0.6%	23	0.8%	9	0.3%
PT	197	6.6%	338	11.3%	141	4.7%	200	6.7%	3	0.1%	340	11.3%	144	4.8%	279	9.3%	82	2.7%

Figure 11: Systemic euro area shock and idiosyncratic shock to Italy

Note: CDS denotes the 2-year sovereign CDS spreads in basis points and PD the 2-year sovereign probability of default. For an explanation of the shocks, see the discussion in Subsection 7.1.

E Decomposition of the evolution of sovereign financial strength into systemic and idiosyncratic components

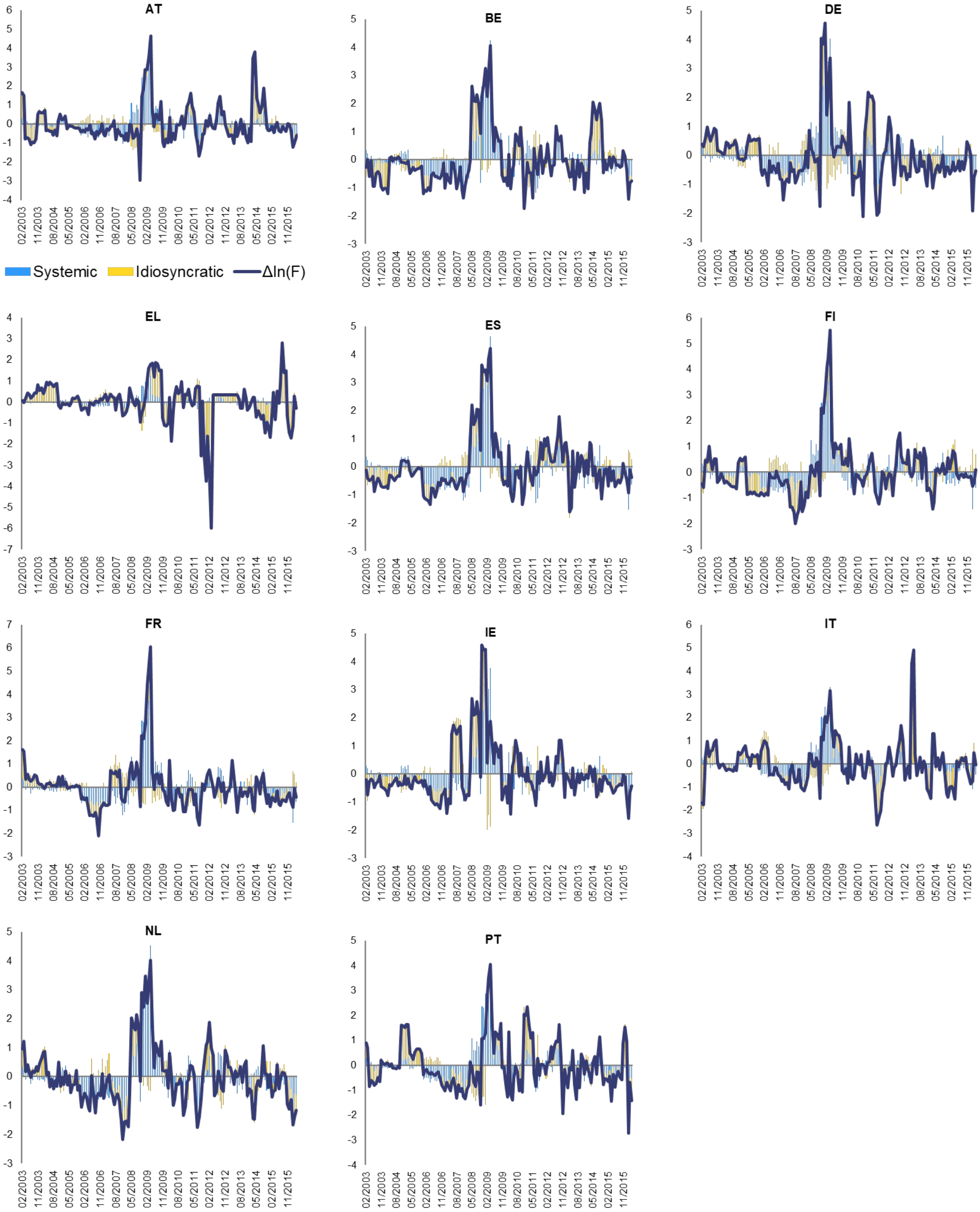


Figure 12: Decomposition of $\Delta ln\left(F_{t,i}\right)^{N}$: systemic vs. idiosyncratic components

F Cumulated financial gap and idiosyncratic sovereign efforts

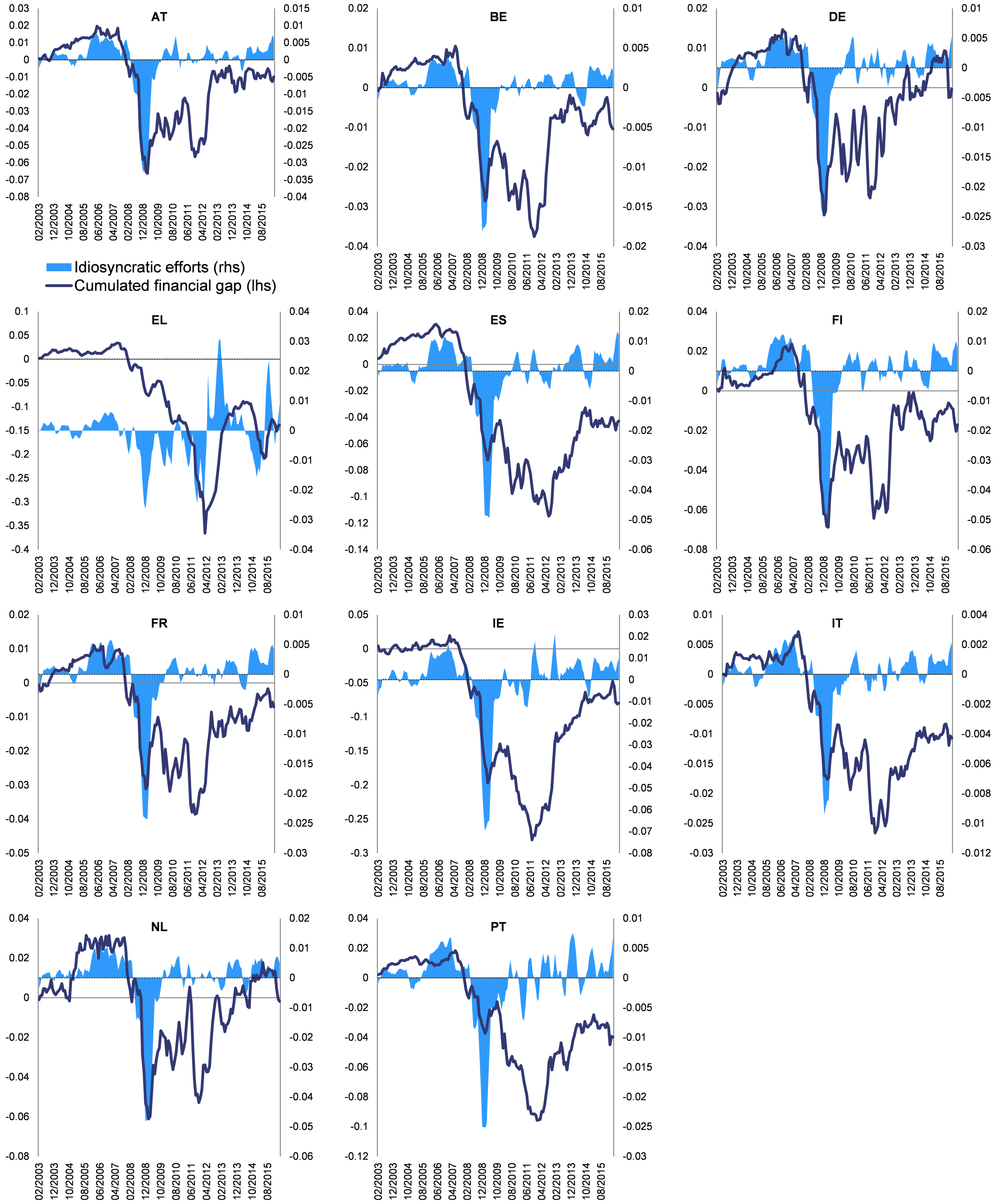


Figure 13: Cumulated financial gap and idiosyncratic sovereign efforts

Note: for the definitions of cumulated financial gap and idiosyncratic sovereign efforts see Equations (26) and (27) in Subsection 7.1. Idiosyncratic sovereign effort is shown as a centred three-month moving average.

Mountains of debt, peaks of illiquidity and a lake of QE

Daniel P. Monteiro ([1])

March 2019

The past decade was characterized by highly asymmetric dynamics in the sovereign bond markets of euro area countries. We examine these dynamics through the lens of constant and time-varying parameter panel data models and conclude that they appear to have been largely driven by differences in debt ratios, bouts of illiquidity and divergent market sensitivities. The latter aspect is captured by the time-varying parameters and is suggestive of flight-to-safety phenomena. In particular, results point to market participants discounting debt levels as a risk factor in some "core" Member States in the post-2008 period, while at the same time becoming highly sensitive to the debt ratios of "periphery" countries. Unconventional monetary policy is seen to have delivered a powerful time-varying and country-specific contribution to stabilize sovereign yields and to offset asymmetric market sensitivities since 2012. All Member States experienced this effect, even if it has generally benefited higher-risk countries the most. Finally, model-based evidence is suggestive of instances of price misalignment from fundamentals, in different moments and countries.

JEL classification: G12, E52, F32, C32, C23

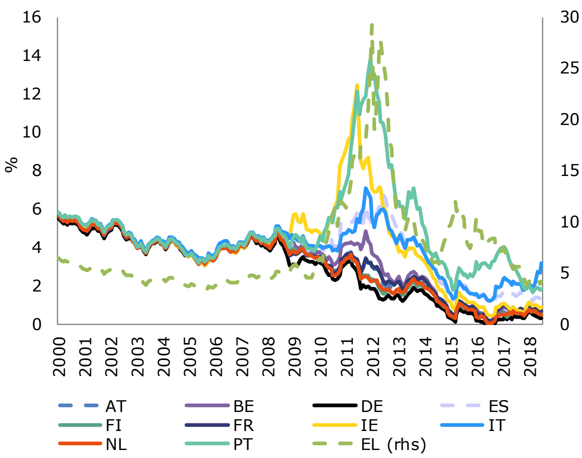
1. Introduction

Sovereign bond markets are now completing two decades of existence under the single currency in several Member States. Throughout these years they have experienced distinct phases, from a period of quietude and synchronous dynamics before the global financial crisis, through years of turbulence and marked cross-country divergences, to a period of imperfect re-convergence in a context of resuming growth, an improved institutional framework and unconventional monetary policy.

Sovereign bond prices are generally expected to reflect the risk-free rate and a credit risk premium which is specific to the sovereign issuer. However, as discussed in the following sections, a large body of economic literature has found that, besides these fundamental drivers, sovereign bond prices also reflect other factors, namely those related to bond market structure, liquidity and investor sentiment. Given the close linkages between euro area countries, such factors can have a significant euro area dimension.

Graph 1 depicts the evolution of sovereign funding costs of selected euro area countries since the introduction of the common currency. It is possible to distinguish three structurally different periods. First, by the time the common currency had been introduced, exchange rate risk had been fully eliminated and sovereign bond yields had almost perfectly converged for the euro-area Member States. Such alignment lasted until 2008, when sovereign funding costs started to significantly diverge amidst the global financial crisis and the consecutive euro area debt crisis.

Graph 1: **Evolution of 10-year sovereign bond yields in euro area countries**



(1) Country sample comprises the 11 largest euro area economies.
Source: Eurostat

Finally, the ECB's announcement of the Outright Monetary Transactions program in August 2012 represented a turning point in the euro area debt crisis and initiated a period of renewed, if imperfect, interest rate convergence, which was further supported by the economic recovery that started in 2013, by an on-going process of balance sheet repair in crisis-hit countries, by an improved

([1]) Nova School of Business and Economics and European Commission. E-mail: daniel.monteiro@ec.europa.eu
The author is grateful to Bořek Vašíček for the literature review presented in this article.

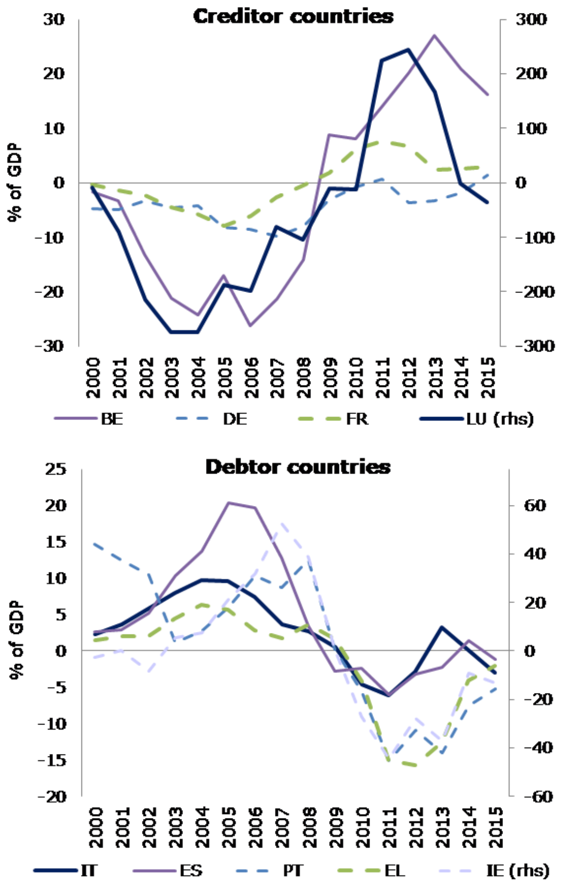
institutional framework, as well as by the Eurosystem's Public Sector Purchase Programme, initiated in 2015.

This article provides a retrospective look at sovereign bond dynamics in the euro area countries since the introduction of the euro. It is structured as follows. Section 2 first reviews the evolution of cross-border debt flows in the euro area. Section 3 reviews the literature on the determinants of bond yields, as well as the euro area dimension of sovereign bond price dynamics. Moreover, it provides empirical evidence on these determinants based both on a standard panel regression as well as on a time-varying parameter model. The latter allows tracking both the impact of changes in each yield determinant, as well as changes in market sensitivities to these determinants, across Member States and across time. Section 4 concludes.

2. The evolution of euro area cross-border debt flows

Cross-border flows represent an alternative dimension to prices when analysing euro area sovereign bond dynamics. In equilibrium, capital flows must reflect the confluence of push (supply-side) factors and pull (demand-side) factors so that it will be hard to attribute the observed flows exclusively to one side or the other. (2) The literature on cross-border flows has mainly focused on emerging markets, where it is generally more meaningful to consider the determinants of inflows that are abnormally large, referred to as "surges". (3)

Graph 2: **Net debt inflows vis-à-vis rest of euro area in creditor and debtor countries**



(1) The net debt inflows are the difference between debt inflows (+) and outflows (-) vis-à-vis RoEA (% of the GDP, 3-year centred moving average). France was included among the set of creditor countries notwithstanding its modestly negative NIIP due to the similarity in net debt flow dynamics when compared with other countries in this group.
Source: Based on an update of the database described in Hobza, A. and S. Zeugner (2014). 'Current accounts and financial flows in the euro area', Journal of International Money and Finance, Vol. 48, pp. 291-313; own calculations.

Cross-border debt data for the euro area shows that the crisis period witnessed a reversal from positive net debt inflows (4) to net debt outflows vis-à-vis the rest of the euro area in some of the debtor countries more severely affected by the crisis. These dynamics had their counterpart in creditor countries, where debt outflows are seen to have reversed into inflows from the rest of the euro area, or at least to move into balanced

(2) The determinants of financial flows can be broadly classified into three categories of variables: 1. global or push factors (e.g., foreign growth, global interest rates, global liquidity, global risk, commodity prices and policy uncertainty), 2. domestic or pull (e.g., industrial production, domestic interest rates, inflation, equity returns, exchange rate dynamics and regime, trade openness, credit growth, stock market capitalization and financial openness) and 3. contagion (i.e., mostly factors outside of country control such as geographical proximity, trade and financial linkages). See for example: Calderón, C., and M. Kubota (2013), 'Sudden stops: Are global and local investors alike?', *Journal of International Economics*, Vol. 89, No 1, pp. 122-142.

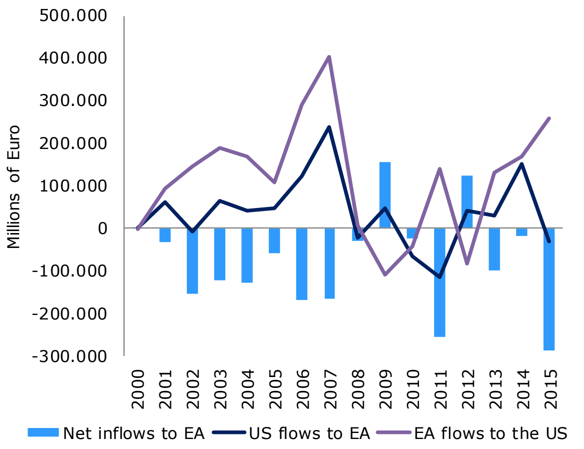
(3) Ghosh, A., M. Qureshi, J. Kim and J. Zalduendo (2014), 'Surges', *Journal of International* Economics, No 92, pp. 266–285.

(4) The financial flow data refers to overall bilateral debt flows between countries, irrespective of the institutional sector originating or receiving the flows. It includes portfolio investment and other investment (e.g., loans), but excludes official debt flows such as financial assistance and asset purchase programmes.

dynamics, with the onset of the crisis (see Graph 2). ([5])

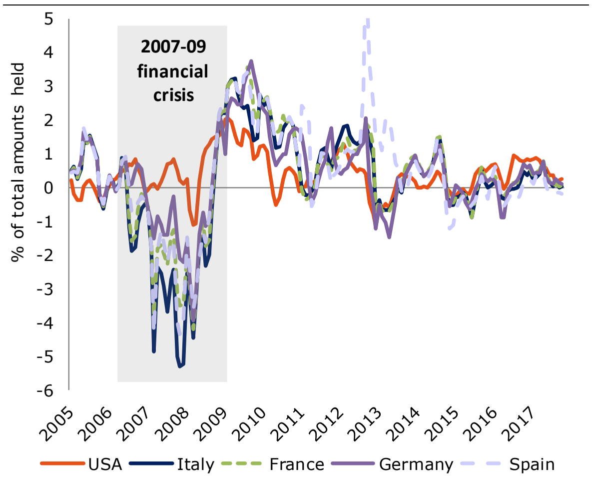
An analysis of bilateral flows reveals consistently positive net debt inflows from the euro area to the US in the pre-crisis period, possibly reflecting the dollar's pre-eminence as a reserve currency. A general retrenchment of cross-border movements in both economies can be observed with the onset of the 2008 financial crisis (Graph 3). The emergence of the sovereign debt crises in the euro area appears to have coincided with a surge in outflows in 2011. Focusing specifically on the bond flows of global investment funds ([6]) there is some evidence of flight-to-safety dynamics during the financial crisis years of 2007 to 2009 (Graph 4). ([7]) In particular, outflows linked to bond instruments were noticeably less pronounced in "core" EU economies when compared with more "peripheral" economies. In fact, while the four largest euro area sovereign bond markets are depicted in Graph 4 for illustration purposes, similar dynamics are seen to broadly apply to other "core" and "periphery" countries. At the same time, the US appears comparatively insulated from bond outflows driven by investment funds, suggesting that it was perceived as the main "safe haven", despite the fact that the financial crisis originated in its financial and housing markets. It is worth noting that in the post-financial crisis years, bond flow dynamics of investment funds are broadly convergent across US, "core" and "periphery" countries.

Graph 3: **Debt flows between the US and the euro area**



Source: Based on an update of the database described in Hobza and Zeugner (2014), op. cit.; own calculations.

Graph 4: **Net investment flows into bonds by global investment funds, per country of issuance**



(1) The net flows represent the difference between inflows (+) and outflows (-); based on the flows and amounts held by bond funds; 3-month centred moving averages
Source: EPFR, own calculations

3. A lookback at the evolution of bond prices in euro area countries

The following subsections review the literature on the determinants of sovereign bond yields, consider some of the specificities implied by a currency union and present an empirical assessment of the drivers of yields in euro area countries based on constant-parameter and time-varying parameter models.

([5]) Also, Bijlsma, M. and R. Vermeulen, R. (2016), 'Insurance companies' trading behaviour during the European sovereign debt crisis: Flight home or flight to quality?', *Journal of Financial Stability*, Vol. 27, pp. 137-154 analyse whether Dutch insurers exhibit a flight to home or a flight to quality behaviour during the recent financial crisis using a detailed micro dataset. They find that these insurance companies engaged in procyclical investment behaviour during the height of the European debt crisis, selling periphery assets and investing into core assets, but not specifically of the Netherlands.

([6]) There is no single dataset that covers all the types of cross-border flows on a bilateral basis at infra-annual frequency. Empirical studies mostly look at one specific type of financial flow. Some studies cover international investment fund flows as these are among the most volatile capital flows (Eichengreen, B., P. Gupta and O. Masetti (2017), 'Are Capital Flows Fickle? Increasingly? And Does the Answer Still Depend on Type?', *World Bank Policy Research Working Paper*, No. 7972; Fratzscher, M. (2012), 'Capital flows, push versus pull factors and the global financial crisis', *Jounal of International Economics,* Vol. 88 (2), pp. 341–356; Li, S., J. de Haan and B. Scholtens (2018), 'Surges of international fund flows', *Journal of International Money and Finance*, Vol. 82, pp. 97-119) or cross-border banking flows (Choi, S. and D. Furceri (2018), 'Uncertainty and Cross-Border Banking Flows', *IMF Working Papers*, No 18/4).

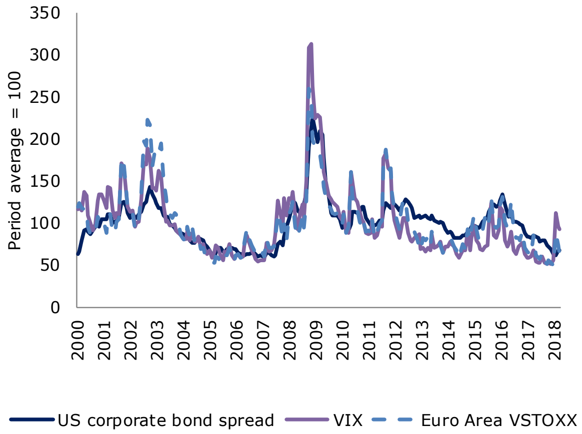
([7]) The data is based on the EPFR Global Database, which tracks the flows and allocations of global investment funds.

3.1. The determinants of bond yields

This subsection reviews the determinants of sovereign bond yields, as presented in the literature, and lays the ground for their joint empirical assessment in Subsection 3.2. As mentioned in the introductory section, in the absence of exchange rate risk, sovereign bond yields in the euro area are expected to primarily reflect the **risk-free yield curve** plus a premium for **credit risk.** The risk-free yield curve is itself driven by short-term rates and longer-term expectations for the risk-free rate at different maturities, which are linked to inflation expectations. Credit risk is usually related to fundamental macroeconomic variables such as current and expected debt-to-GDP ratios and potential growth. The pre-crisis evidence for the euro area countries confirmed the role of both of these factors but also of **liquidity risks** that are related to the size and depth of bond markets (as proxied, e.g., by bid-ask spreads and the volume of transactions) and **international risk factors.** ([8]) While liquidity will be further discussed in Subsection 3.3, the dynamics of global risk factors can be observed in Graph 5 which plots two risk measures for the US (the corporate bond spread and the VIX index of implied stock market volatility) and one for the euro area (VTSOXX, the euro area counterpart of the VIX index). Two periods of heightened volatility are discernible across all the measures, one during the recession of the early 2000s, and the second around the 2008 Global Financial Crisis.

The role of country fundamentals in the **pricing of sovereign bonds during the crisis** remains a contentious issue. The tumultuous yield developments observed after 2008 and depicted in Graph I.1 have been both interpreted as an overreaction that largely ignored Member States' fundamentals and as a "wake up call" after a long pre-crisis period of oversight of fundamentals by investors. However, there is a broad agreement on a greater sensitivity of government bond yields to fundamentals in euro area "peripheral" countries during the debt crisis of 2010-2012, and on sovereign risk premium being reinforced by the riskiness of domestic banks, ([9]) by existing external imbalances ([10]) and by international risk and liquidity factors. ([11]) Furthermore, it has been found that part of the risk premia on some sovereigns was a reflection of **redenomination risk**, i.e., the risk that one or more countries would leave the European Monetary Union and reintroduce their own national currencies, which would likely depreciate subsequently. ([12])

Graph 5: **Measures of global risk**



(1) The corporate bond spread refers to the difference between the bond yields of Baa-rated US companies and 10-year US treasuries.
Source: FRED, DataInsight, STOXX and own calculations

The widely discussed **loop between sovereigns and domestic banks** is also understood to have been reflected in a two-sided link between sovereign and bank funding costs at country level. ([13]) This loop, whereby banks and their sovereigns

([8]) See, for example: Manganelli, S. and G. Wolswijk (2009), 'What drives spreads in the euro-area government bond market?', *Economic Policy*, Vol. 24 (58), pp. 191-240; Favero, C., M. Pagano and E.-L. von Thadden (2010), 'How does liquidity affect government bond yields?', *Journal of Financial and Quantitative Analysis*, Vol. 45(1), pp. 107-134.

([9]) See for example: Afonso, A., M. Arghyrou and A. Kontonikas (2014), 'Pricing sovereign bond risk in the European Monetary Union area: an empirical investigation', *International Journal of Finance & Economics*, Vol. 19(1), pp. 49-56; Bruneau, C., A. Delatte and J. Fouquau (2014), 'Was the European sovereign crisis self-fulfilling? Empirical evidence about the drivers of market sentiments', *Journal of Macroeconomics*, Vol. 42, pp. 38-51; Delatte, A., L. Fouquau and R. Portes (2017), 'Regime-dependent sovereign risk pricing during the euro crisis', *Review of Finance*, Vol. 21(1), pp. 363-385.

([10]) Salem, M. and B. Castelletti-Font (2016), 'Which combination of fiscal and external imbalances to determine the long-run dynamics of sovereign bond yields?', *Banque de France, Working Paper*, No. 606.

([11]) Afonso, op. cit.

([12]) See for example: De Santis, R. (2015), 'A measure of redenomination risk', *ECB Working Paper,* No 1785; Klose, J. and B. Weigert (2014), 'Sovereign yield spreads during the euro crisis: fundamental factors versus redenomination risk', *International Finance*, Vol. 17(1), 25-50. For a recent assessment of redenomination risk in a large euro area Member State, see Gros, D. (2018), 'Italian risk spreads: Fiscal versus redenomination risk', VoxEU.org, 29 August.

([13]) See for example: Acharya, V., I. Drechsler and P. Schnabl (2014), 'A pyrrhic victory? Bank bailouts and sovereign credit risk', *The* mutually enfeeble themselves in vulnerable countries in periods of distress, became evident in some Member States in the crisis period when bank losses led to government-sponsored recapitalisations, thereby increasing government debt and putting downward pressure on bond prices. Given banks' bias towards holding domestic sovereign bonds, this contributed to weakening their balance sheets, thereby re-starting the loop. The loop is understood to have also originated in some cases on the side of the sovereign, as when macroeconomic shocks led to increases in government debt and country risk, which transmitted to domestic banks. ([14])

There is also evidence that sovereign bond dynamics have at times been affected by **discrete events and news**. The credit rating actions represent the most prominent type of event and studies show that government bond yields respond significantly to changes in ratings and outlook, especially in the case of negative announcements. Conversely, spread dynamics are seen to have a feedback effect on sovereign rating decisions. These may affect also corporate ratings and hence have a broader impact on the economy. In addition, effects appear to be persistent, as recently-downgraded countries face higher spreads than countries with similar ratings that were not recently downgraded. ([15]) It is also documented that sovereign bond yields were affected by other, usually negative, news, especially during the euro area crisis period. ([16])

3.2. Evidence from a fixed effects panel model

In order to assess the effects of different determinants on sovereign bond yields a panel regression model with fixed effects was estimated, covering the 11 largest euro area economies. ([17]) Beyond the country-specific fixed effects, the explanatory variables in the regression include a measure of the risk-free rate and of the risk-free yield curve slope, the debt-to-GDP ratio, year-on-year GDP growth, the VIX index as a measure of global risk, the bid-ask spread as a measure of liquidity, and the amount of securities held by the Eurosystem for monetary policy purposes, to control for the effects of the asset purchase programmes. The details of the model specification and estimation results are provided in Box I.1. A country-level assessment using a time-varying parameter version of the model is provided in Subsection 3.4.

Graph 6 provides a landscape of the evolution of the average euro area yield over time, decomposed into different drivers based on the regression model and results detailed in Box I.1. As expected, monetary policy loosening in the wake of the crisis, as captured by the risk-free rate and slope variables, put strong downward pressure on sovereign bond yields across the euro area over the past decade. Debt ratios are also seen to have played a major contribution to the yield level. In fact, as of early 2018, relatively large government debts were the largest factor putting upward pressure on sovereign interest rates. GDP growth has played a moderate role, helping to bring down average yields by 30 to 60 bps during most of our sample period. During the 2008-09 financial crisis, however, average negative growth is reckoned to have contributed to increase average yields by up to 100 bps. Changes in a global risk factor have induced yield variations of at most 100 bps over our sample period. Market illiquidity played a negligible role up until 2010. However, it is seen as the major driver of the spike in average yields observed during the 2011-12 sovereign debt crisis. Quantitative easing (QE),

Journal of Finance, Vol. 69(6), pp. 2689-2739; Alter, A. and Y. Schüler (2012), 'Credit spread interdependencies of European states and banks during the financial crisis', *Journal of Banking & Finance*, Vol. 36(12), pp. 3444-3468; De Bruyckere, V., M. Gerhardt, G. Schepens and R. Vander Vennet (2013), 'Bank/sovereign risk spillovers in the European debt crisis', *Journal of Banking & Finance*, Vol. 37(12), No. 4793-4809.

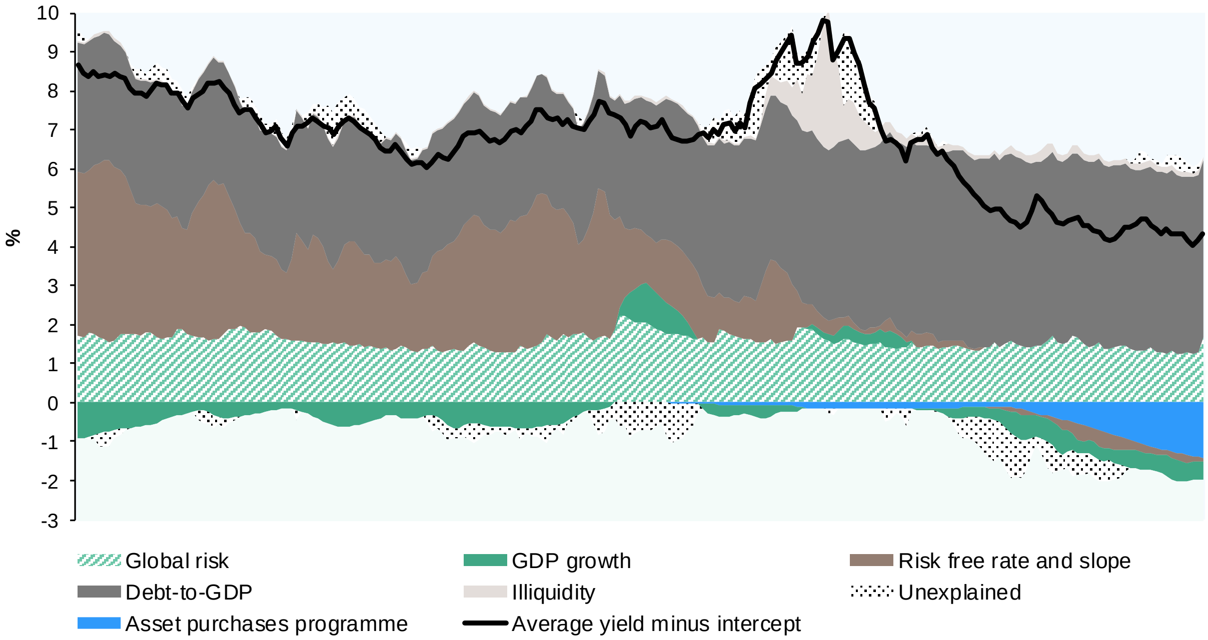
([14]) A form of the sovereign-bank loop can also emerge in the absence of government recapitalisations or of banks' bias towards holding domestic bonds, when a shock leads to reduced bank lending, thereby negatively impacting the economy, government revenues and bond prices. The government in its turn may see its debt increase, or embark on fiscal consolidation. As a result, economic activity as well as banks' balance sheets and lending capacity may be weakened.

([15]) See, for example, Afonso, A., D. Furceri, and P. Gomes (2012), 'Sovereign credit ratings and financial markets linkages: Application to European data', *Journal of International Money and Finance*, Vol. 31(3), pp. 606-638; Arezki, M., B. Candelon and M. Sy (2011), 'Sovereign rating news and financial markets spillovers: Evidence from the European debt crisis', *IMF Working Papers*, No. 11/68; De Santis, R. (2012), 'The Euro area sovereign debt crisis: safe haven, credit rating agencies and the spread of the fever from Greece, Ireland and Portugal', *ECB Working Paper Series*, No. 1419.

([16]) Beetsma, R., M. Giuliodori, F. De Jong and D. Widijanto (2013), 'Spread the news: The impact of news on the European sovereign bond markets during the crisis', *Journal of International Money and Finance*, Vol. 34, pp. 83-101.

([17]) This group of countries also offers the advantage of greater data availability given that it represents the first wave of Member States having adopted the euro. The sample thus includes Austria, Belgium, Finland, France, Germany, Greece, Italy, Ireland, the Netherlands, Portugal and Spain. Luxembourg is not included due to the small size of its sovereign bond market and attendant difficulties in terms of data availability.

Graph 6: **Mountains of debt, peaks of illiquidity and a lake of QE (decomposition of 10-year sovereign bond yields in the euro area based on a fixed effects panel model)**



(1) Summary graph based on the simple averages for AT, BE, DE, EL, ES, FI, FR, IE, IT, NL and PT. For readability, the constant (negative) contribution of the average intercept was subtracted from the average yield.
Source: Own estimations

implemented by the Eurosystem through a series of asset purchase programmes, contributed to lower interest rates across the euro area since 2012, as expected.

It may also be useful to consider the periods where the unexplained component of the average yield is largest. The first such period was during the 2008-09 financial crisis, when average yields remained lower than predicted by the panel regression model. This result is consistent with some risk under-pricing in the early stages of the recession, possibly linked to favourable expectations regarding the short-term nature of the economic troubles and the supportive role of fiscal and monetary policies. Such undershooting reversed in 2010-13, when actual average yields exceeded model-predicted yields. This was a period of asymmetric bond market dynamics in the euro area, which included panic-like yield spikes in some countries. Finally, the fact that actual yields were lower than predicted by the panel model in the 2014-16 is likely due to the frontloaded market anticipation of the effects of the Eurosystem's public sector purchase programme, which began gradually in March 2015, after having been announced in 2014.

3.3. The euro area dimension of bond price dynamics

As already hinted at in the previous subsection, the pricing of sovereign bonds can be affected by other factors beyond sovereign credit risk per se. In the euro area some of these factors carry an important cross-country dimension given the strong economic and institutional linkages between Member States.

Box I.1: Sovereign bond yield drivers in a fixed effects panel model

In order to investigate the effects of different determinants on the euro area sovereign bond yields a panel regression model was estimated for a period running from February 2000 to February 2018 and comprising the 11 largest euro area economies (i.e., Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain). The model takes the following form:

$$y_{i,t} = I_i + \beta_{rf}\, rf_t + \beta_{slope}\, slope_t + \beta_{debt}\, debt_{i,t} + \beta_{GDP}\, growth_{i,t} + \beta_{risk}\, risk_t + \beta_{liq}\, liq_{i,t-1} + \beta_{UMP}\, UMP_t + \varepsilon_{i,t}$$

where the dependent variable, $y_{i,t}$, represents the average 10-year sovereign bond yield (1) for country *i* during month *t*. The explanatory variables are as follows: *I* represents a country-specific intercept, or fixed effect; *rf* represents the short-term risk-free rate as measured by the 3-month EONIA overnight indexed swap (OIS); *slope* represents the slope of the risk-free yield curve, as measured by the spread between the 3-month and the 2-year EONIA OIS; (2) *debt* is the debt-to-GDP ratio; *growth* is the year-on-year GDP growth; *risk* represents a global risk factor as measured by the (logged) VIX index; *liq* represents market liquidity as measured by the bid-ask spread on 10-year sovereign bonds, with a higher figure therefore representing a higher degree of market illiquidity; *UMP* represents the effects of unconventional monetary policy, as measured by the value of the securities held for monetary policy purposes by the Eurosystem, in billions of euros; (3) finally, ε is an error term.

Overall, the model seeks to assess the role of fundamental factors such as monetary policy (expressed, e.g., in the risk-free rate and in the UMP), key macroeconomic variables bearing on credit risk such as the government debt ratio and economic activity, as well as global risk factors and liquidity conditions. While some of the included variables such as the slope of the risk-free rate and the risk factor have a clear forward-looking nature, the debt and growth variables are based on contemporaneous year-on-year growth rates, cubically interpolated from quarterly data. (4) Given investors' forward-looking perspective, it would be theoretically correct to use expect values for *debt*, *growth* and *UMP*. However, from an empirical viewpoint such approach is not without issues. For instance, if expected values are inferred from contemporaneous forecasts, these are typically updated at low frequency, may cover a relatively short horizon and may refer only to whole year (or end-of-year) figures. Due to the difficulties involved in accurately deriving expectations at a relatively high macroeconomic frequency some practitioners use contemporaneous outturns, which generally produce sensible results.

Another issue worth of consideration is the possible endogeneity of some of the explanatory variables. Given the financial market nature of sovereign bond yields, they should respond contemporaneously to all the explanatory variables. The risk-free rate and slope are forward looking and largely driven by inflation and monetary policy implications. As such, contemporaneous sovereign yields should play a limited causal role. Debt dynamics only respond slowly to changing yields and therefore can be assumed as essentially exogenous. Likewise, the expenditure components of GDP growth should be mostly driven, inter alia, by sustained, long-term expectations for interest rates and financing conditions, rather than react immediately to contemporaneous government rates. As regards risk perceptions and attitudes, a global, US-based risk factor was preferred as compared to an EU-specific one in order to mitigate issues of endogeneity. Liquidity conditions should, in their turn, be endogenous to bond yields in the sense that not only can bouts of illiquidity cause spikes in yields but also very high sovereign risk can cause market liquidity to dry up. To

(1) A 10-year maturity is often used in the literature on bold yield drivers, and is also the maturity of the Maastricht convergence criterion for long-term interest rates. 10-year bond yields are understood to reflect not only short-term policy developments but also longer-term economic prospects.
(2) The 2-year tenor is the longest for which data is available covering our whole sample period.
(3) The value of the securities held for monetary policy purposes reflects the Eurosystem's asset purchase programmes. It takes the value zero prior to July 2009. With the introduction of the public sector purchase programme in March 2015, its magnitude has become increasingly dominated by the latter.
(4) Using industrial production growth – a narrower measure of economic activity available at monthly frequency – instead of interpolated monthly GDP growth does not materially change the results presented in this box.

(Continued on the next page)

Box (continued)

mitigate this issue, *liq* is included with a lag in the regression. Finally, UMP comprises rules-based asset purchase programmes which were not designed to respond to particular changes in interest rates.

In line with the literature and with the results of a Hausman test, the model was estimated as a fixed effects model. Given a relatively small dimension for the cross section (11 countries) along a relatively long dimension for the time series (217 months) the fixed effects estimator can ideally be implemented by introducing 11 country-specific dummy variables *I* in the regression (and no common intercept). The results of the estimation are reported in Table 1. All the regression coefficients show the expected sign and are significant at a 1% significance level. The goodness-of-fit of the model is relatively high, with an R^2 of 79%.

Table 1: estimation results for a sovereign bond yield panel data model with fixed effects

β_{rf}	β_{slope}	β_{debt}	$\beta_{growt\ h}$	β_{risk}	β_{liq}	β_{UMP}
0.78	1.56	0.047	-0.17	0.54	5.14	-0.00058
(0.05)	(0.15)	(0.006)	(0.04)	(0.15)	(1.03)	(0.0001)

Note: HAC standard errors in parentheses.

The regression coefficients can be interpreted as follows. As must needs be the case, yields respond positively to changes in the short-term risk-free rate and the medium-term risk-free spread, loading more on the latter given the 10-year maturity of the sovereign bonds under consideration. A ten-percentage point increase in the government debt-to-GDP ratio increases sovereign yields by 47 basis points (bps) while a 1 pp increase in the annual growth rate lowers yields by 17 bps. A 10% increase in the VIX global risk factor increases yields by approximately 5 bps. An increase in the bid-ask spread of 1 bp increases yields by 5 bps. A EUR trillion of asset purchases under the asset purchase programmes of the Eurosystem can lower yields by 58 bps.

Cross-border spillovers and contagion

While the period before the Global Financial Crisis was characterized by strong convergence across sovereign bond prices, the subsequent period witnessed the emergence of significant divergence among Member States. Graph 7 shows the evolution of price-based indices of both bond market and broader financial integration. In both cases, a trend towards closer integration is clear until 2006. This trend inverted after 2007, leading to a full reversion in integration in the case of the bond market. After reaching its through during the euro area debt crisis in mid-2012, bond market integration has been increasing, which was likely supported by a broad-based economic recovery, an improvement in credit ratings and the unconventional monetary policy of the ECB.

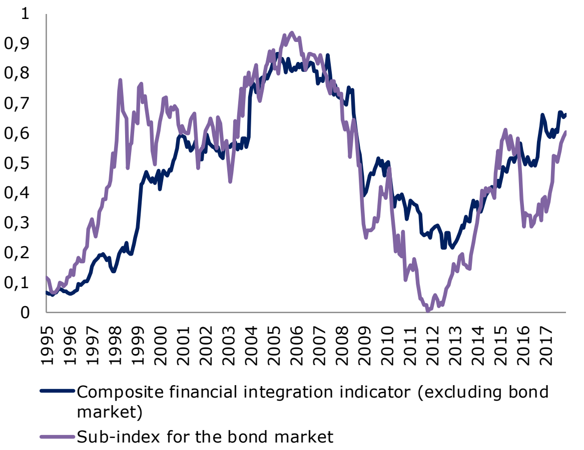
Graph 7 also suggests that convergence and divergence dynamics in bond markets have preceded similar dynamics in the broader financial market since 1995. In fact, Granger causality tests suggest that changes in bond market integration have caused changes in overall financial integration, while the reverse is not true. ([18])

Despite fragmentation at euro area level, the interdependence between bond markets of some Member States has increased since the global financial crisis. This increase in co-movements between the sovereign bond markets of some Member States has often been titled as a spillover or even contagion effect. Several studies have tried to measure such linkages and distinguish spillovers – which are usually understood as increased co-movements between sovereign bond yields – from pure contagion, which represents an intensification in the transmission of shocks from a crisis-hit country to another country that cannot be

([18]) Granger causality tests were run for the following two variables: i) changes in the bond market integration indicator (BM indicator) and ii) changes in the broader financial integration indicator, excluding the bond market (FI indicator). The sample runs from January 1995 to December 2017. The null hypothesis that BM does not Granger cause FI is rejected at a 5% confidence level, irrespective of whether the test is run with 9-month ("3-quarter"), 6-month ("2-quarter") or 3-month ("1-quarter") lags. This result is stronger when the test is run with a 9-month lag (where the p-value equals 0.013). Furthermore, the hypothesis that FI does not Granger cause BM is not rejected for the same lag lengths, even at a 10% confidence level (with p-value for the test with a 9-month lag equal to 0.26).

objectively explained by financial linkages between them. [19] These studies broadly agree that there were significant co-movements, especially within the euro area periphery, but also that pure contagion was largely limited to short-lived episodes before the announcement of the ECB's Outright Monetary Transactions programme in 2012.

Graph 7: **Indices of bond market and broader financial market integration**



(1) The financial integration index is constructed from a selection of price-based indicators that cover the money, bond, equity and banking markets. It is defined to be bounded between 0 and 1. The indicators aggregated into the bond market sub-index are the cross-country standard deviations of two and ten-year sovereign bond yields (Greece excluded), and the cross-country standard deviation of the bond yields of uncovered corporate bonds issued by non-financial corporations.
Source: ECB and own calculations

Cross-border effects have also been documented for rating actions, when a rating decision affecting lower-rated countries also affects yields of higher-rated countries, as well as for negative news, especially within the group of periphery countries. The size of cross-border spillovers also seems to be related to cross-border bank holdings. [20] As past rating announcements have seemed to have only a limited effect on the euro exchange rate, there is evidence that they have led investors to rebalance their sovereign bond portfolios within the euro area. [21]

Flight to safety and flight to liquidity

Flight to safety (FTS) is usually identified as a negative price co-movement between different asset categories (typically, stocks vs. bond returns) in periods of financial stress (e.g., when the stock market is falling), although the concept can also be applied to securities with different perceived risk levels within the same asset class. In an FTS episode, investors shed assets perceived to be riskier in favour of safer ones. [22] FTS episodes are not necessarily triggered by observed changes in fundamentals. Rather, they are often triggered by changes in risk perceptions and attitudes, which motivates the time-varying parameter analysis in the following subsection. Moreover, portfolio reallocations in connection with FTS usually reflect both safety and liquidity concerns. Therefore, flights to safety are often accompanied by flights to liquidity. In fact, market illiquidity appears to have played an important role in driving yield spikes in "periphery" countries at the height of the crisis, as documented in Graph 11 of the next subsection. In other countries, market liquidity, as measured by bid-ask spreads, has played a significant role, although with noticeable cross-country and intertemporal variations (Graph 8).

FTS has been identified as a factor affecting the pricing of sovereign bonds during the euro area debt crisis, when yields of some "core" countries moved in the opposite direction from that of the yields of vulnerable countries. Such joint dynamics confirm the increased importance of investors' risk aversion in times of uncertainty, which leads them to favour bonds of countries that are generally regarded to have a low default risk, and implies consequently a risk premium increase in other countries. [23] Some part of the yield divergence

(19) There is significant ambiguity in the literature in terms of definitions and empirical methods for testing contagion. See for example: Rigobon, R. (2016), 'Contagion, spillover and interdependence', *ECB Working Paper*, No. 1975.

(20) Böninghausen, B. and M. Zabel (2015), 'Credit ratings and cross-border bond market spillovers', *Journal of International Money and Finance*, Vol. 53, pp. 115-136.

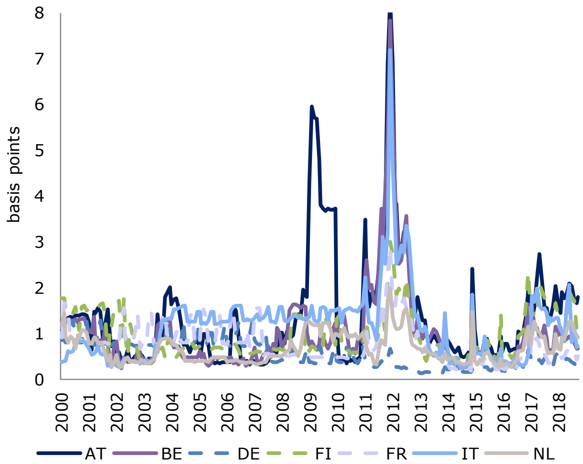
(21) Baum, C., D. Schäfer and A. Stephan (2016), 'Credit rating agency downgrades and the Eurozone sovereign debt crises', *Journal of Financial Stability*, Vol. 24, pp. 117-131.

(22) Baur, D. and B. Lucey (2009), 'Flights and contagion—An empirical analysis of stock–bond correlations', *Journal of Financial stability*, Vol. 5(4), pp. 339-352. Several papers provided stylized micro-founded models that aim to rationalize the flight to quality behaviour, e.g. Caballero, R. and A. Krishnamurthy (2008), 'Collective risk management in a flight to quality episode', *Journal of Finance*, Vol. 63(5), pp. 2195-223; Brunnermeier, M. and L. Pedersen (2009), 'Funding liquidity and market liquidity', *Review of Financial Studies*, 22, pp. 2201-2238.

(23) See for example: De Santis (2014), op. cit., Monfort, A. and J. Renne (2013), ' Decomposing euro-area sovereign spreads: credit

seems to be also driven by liquidity premia, as the liquidity of "core" bond markets increased, at the same time as it decreased for the "periphery". (24) FTS has been identified also as one of the drivers of worsening efficiency in the bond markets, and one of the reasons for the observed deviation between CDS and bond spreads. (25)

Graph 8: **Bid-ask spreads on 10-year sovereign bonds in selected euro area Member States**



Source: Bloomberg

Common monetary policy

Monetary policy in the euro area seeks to stabilise prices, typically by adjusting short-term policy interest rates. Current and expected short-term interest rates are, in turn, linked to long-term rates, with their term structure defining the slope of the yield curve and affecting the funding costs (and profitability) of banks and, consequently, of non-financial corporations and households. The Global Financial Crisis represented a major challenge both for monetary policy and financial stability, with central banks having to facilitate financial intermediation when private markets were reluctant to do so. In the following years, the need to for monetary accommodation drove short-term rates to the zero lower bound, and central banks began to use other, unconventional measures which had often direct impact on long-term interest rates.

The ECB has adopted since the global financial crisis several unconventional monetary policy measures, with some of them having a direct effect on sovereign funding costs. These include the Securities Market Programme of 2010, the Outright Monetary Transactions programme announced in 2012, the subsequent forward guidance policies, as well as the Public Sector Purchase Programme (PSPP) initiated in 2015. (26) The available empirical evidence suggests that these measures contributed to oppose disinflationary dynamics, to reduce sovereign funding costs and to ensure a more uniform transmission of monetary policy. (27) This can be attributed, inter alia, to the portfolio-rebalancing channel and to the (expected monetary policy) signalling channel. (28)

3.4. The time-varying role of sovereign yield drivers

This subsection investigates the role of country-specific dynamics in explaining observed bond yields using a time-varying parameter (TVP) panel data model. Such a model allows us to consider not only the evolution of fundamental yield drivers, but also how the importance of these drivers changes over time and across countries. In such a context, the contribution of a given driver – say, the debt ratio – can change not only because the variable itself has changed (e.g., the debt ratio has increased) but also because the TVP associated with it has evolved (e.g., markets have grown more

and liquidity risks', *Review of Finance*, Vol. 18(6), pp. 2103-2151; Ehrmann and Fratzscher (2017), op. cit.

(24) Garcia, J. and R. Gimeno (2014), 'Flight to liquidity Flows in the Euro Area Sovereign Debt Crisis', *Banco de Espana Working Paper*, No. 1429. Fontana and Scheicher (2016), op. cit.

(25) Arce, O., S. Mayordomo and J. Peña (2013), 'Credit-risk valuation in the sovereign CDS and bonds markets: Evidence from the euro area crisis', *Journal of International Money and Finance*, Vol. 35, pp. 124-145.

(26) See for example: Constâncio, V. (2017), 'Role and effects of the ECB non-standard policy measures', speech at the ECB Workshop "Monetary Policy in Non-Standard Times", September 2017, Frankfurt am Main.

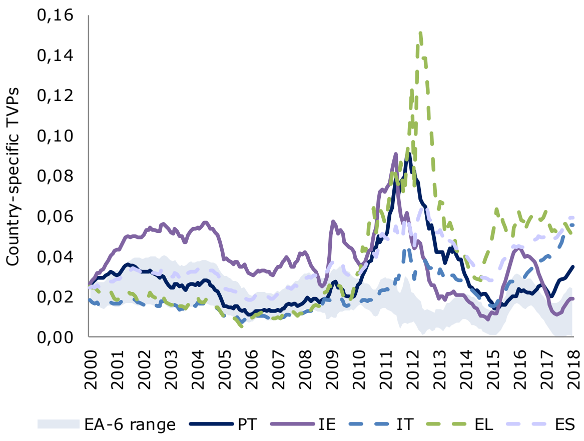
(27) See for example: Szczerbowicz, U. (2015), 'The ECB unconventional monetary policies: have they lowered market borrowing costs for banks and governments?, *International Journal of Central Banking*, Vol. 11(4), pp. 91-127; Falagiarda, M. and S. Reitz (2015), 'Announcements of ECB unconventional programs: Implications for the sovereign spreads of stressed euro area countries', *Journal of International Money and Finance*, Vol. 53, pp. 276-295; Jäger, J. and T. Grigoriadis (2017), 'The effectiveness of the ECB's unconventional monetary policy: Comparative evidence from crisis and non-crisis Euro-area countries', *Journal of International Money and Finance*, Vol. 78, pp. 21-43.

(28) Lemke, W. and T. Werner (2017), 'Dissecting long-term Bund yields in the run-up to the ECB's Public Sector Purchase Programme', *ECB Working Paper Series*, No. 2106 show using an affine term structure model that the yield declines (of the German bund at the time PSPP was announced and initiated) are almost fully attributable to a decline in the term premium as opposed to the expectations component, suggesting that the PSPP transmits to long-term yields mainly via a portfolio re-balancing channel rather than a signalling channel.

sensitive to the level of debt). The explanatory variables included in the model are the same as in the constant parameter model of Subsection 3.1 and Box I.1. For methodological details, as well as a breakdown of the contribution of the different drivers for the 11 largest euro area economies, see Box I.2. ([29])

Among the explanatory variables, the **debt-to-GDP** TVP is a key contributor ([30]) to sovereign bond yield dynamics, both in terms of the magnitude of its impact and of its variability over time and across countries. As shown in Graph 9, the cross-country variability of the debt TVP was relatively small in the pre-crisis period, with the TVP of high-debt countries such as Greece and Italy tracking the lower bound of the yield range of a set of "core" euro area Member States, denoted here and elsewhere as EA-6. This group of countries (which includes Austria, Belgium, Finland, France, Germany and the Netherlands), are represented together for readability's sake and given that they have often experienced similar dynamics. With the onset of the crisis, market sensitiveness to the debt ratio began to rapidly increase in Greece, Portugal, Ireland and Spain, even as "core" euro area countries experienced stable or decreasing sensitiveness, as shown by the evolution of the EA-6 range. A combination of increased sensitiveness and increased debt levels drove large increases in yields in "periphery" countries. Between mid-2011 and mid-2012 the contribution of debt peaked, first for Ireland, then for Portugal, Spain and Greece, possibly reflecting uncertainty on the evolution of the economy and on the implementation of financial assistance programmes. Asymmetric market sensitiveness eased considerably and continuously until year-end 2014, when it began to increase again (though in a short-lived manner in the case of Ireland). While not having experienced a marked degree of market stress, the TVP dynamics for Italy tended to track in a muted way the dynamics of the aforementioned periphery Member States until 2015.

Graph 9: **Debt-to-GDP TVP**



(1) EA-6 range is calculated based on the maximum and minimum values for AT, BE, DE, FI, FR and NL.
Source: Own estimations

Overall, the debt TVP appears to capture the panic-like effects observed during the crisis. This suggests that these effects interact with debt levels, so that the most indebted Member States were the most exposed to this type of market behaviour. It should also be noted at this point that, generally speaking, the increases in market sensitiveness to yield drivers observed in "periphery" countries can be ascribed both to factors linked to an incomplete Economic and Monetary Union (EMU) architecture, and to other factors that are less directly linked to the state of EMU completeness. Among the latter are changes in expected debt levels and growth prospects, or incomplete information regarding the true state of public finances. Among factors directly linked to EMU incompleteness are the risk of redenomination ([31]) and the risk of an aggravation of sovereign bank loops which is born of banks' home bias and the absence of proper bank resolution tools during the past crisis period.

At the same time as market responses to debt ratios were increasing in periphery countries, the debt TVPs of core euro area countries embarked on an opposite declining trend from 2009 to 2012. This suggests that markets discounted debt levels and credit risk in some countries during (and beyond) the sovereign debt crisis period, which is

([29]) The empirical framework used in this analysis is broad and seeks to track in a flexible manner the contributions of the main drivers of sovereign bond dynamics during the past two decades. However, the framework does not seek to provide definite answers to some contentious issues like the relevance of redenomination risks or the relative importance of flight-to-safety versus flight-to-liquidity phenomena, which have been the object of the specialised literature previously reviewed.

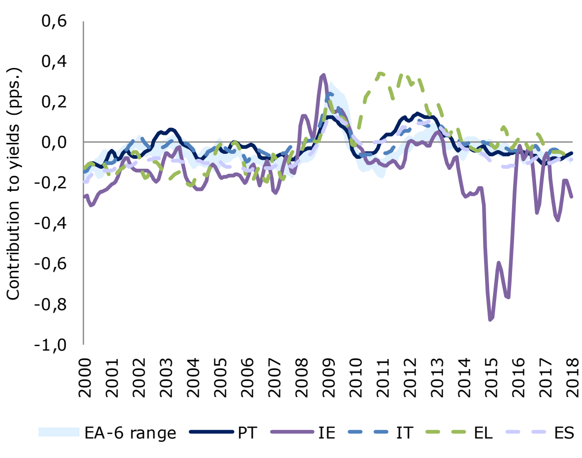
([30]) The contribution of a given determinant is calculated as the associated TVP multiplied by the associated variable. As such, the contribution of debt to sovereign yields in country i at time t is $\beta^{debt}{}_{i,t} debt_{i,t}$.

([31]) Redenomination risk can interact with debt levels and therefore be picked up by the debt ratio TVP.

consistent with the notion of flight to safety. In fact, with prospects of robust growth resuming across the euro area and unconventional monetary policy in full swing, debt levels even appear to have been momentarily written off as risk factors in the second half of 2017 in the case of Germany.

TVP estimations ascribe a modest role to contemporaneous **GDP growth**. However, inasmuch as growth can improve or aggravate debt-to-GDP ratios, its effect on yields is also captured via the debt ratio. Graph 10. plots the contribution of GDP growth to sovereign bond yields over time. As can be observed, the contributions of growth show similar magnitudes for most countries during most of the time. Pure growth effects are seen to have switched from a supportive role (i.e., a negative contribution) in the pre-crisis period to adding up to 30 basis points to yields in the 2008-09 recession. Growth effects have generally been favourable in the post-crisis period, safe for the "double dip" recession of 2012. Two notable cases are Greece and Ireland. Prolonged negative growth has put upward pressure on Greek sovereign bond yields up until 2014, while dynamic growth in Ireland has had the reverse effect during the post-crisis period.

Graph 10: **Contribution of growth to yields**

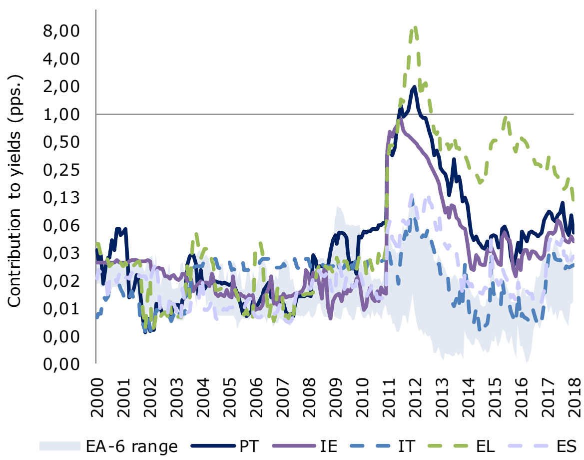


(1) EA-6 range is calculated based on the maximum and minimum values for AT, BE, DE, FI, FR and NL.
Source: Own estimations

The **global risk factor** (not shown here) has played a relevant role, having added more than 50 bps to euro area sovereign bond yields at the height of the 2008-09 crisis. The importance ascribed to the global risk factor is, nevertheless, significantly smaller in the TVP model than in the fixed effects model estimated in the previous subsection. TVP estimations suggest similar global risk sensitivities across the euro area over time, so that differences in country-specific TVPs induce only negligible differences in the contribution of global risk to yields.

Spikes in market **illiquidity** in the peak of the sovereign debt crisis had an increased, sizeable effect on the yields of Portugal and Ireland, and a major effect on the yields of Greece. While Italy and Spain do not show spikes in illiquidity, their bid-ask spreads have nevertheless tended to remain on the high side since 2011 when compared with "core" countries. Graph 11 shows the effects of illiquidity over time. (32) The observed increases in the contribution of liquidity were essentially driven by spikes in bid-ask spreads, rather than by spikes in the associated TVPs.

Graph 11: **Contribution of illiquidity to yields**

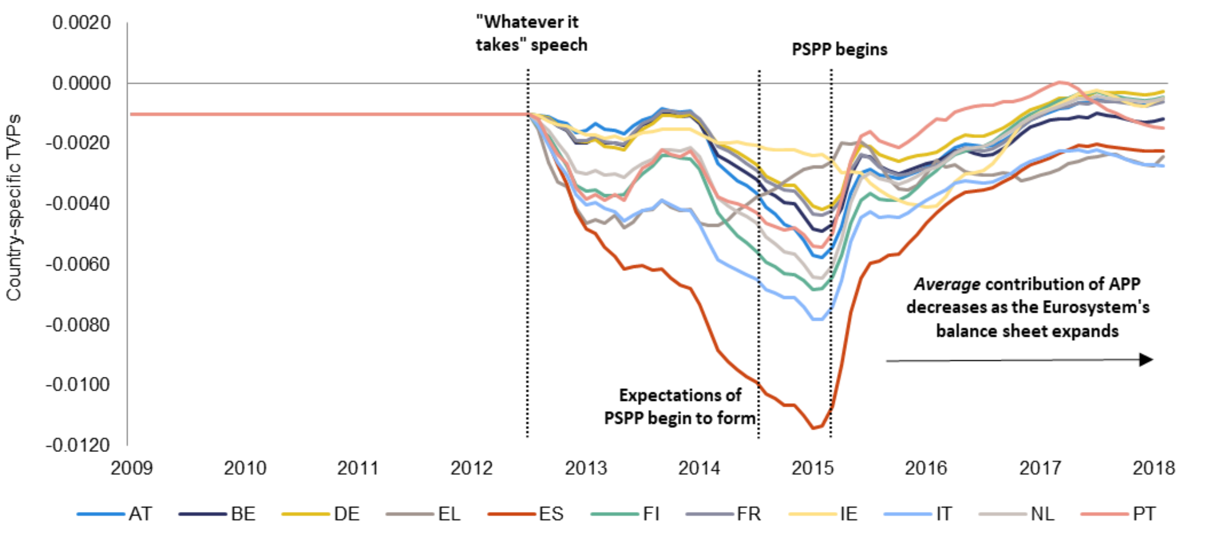


(1) Vertical axis in logarithmic scale; EA-6 range is calculated based on the maximum and minimum values for AT, BE, DE, FI, FR and NL.
Source: Own estimations

The **asset purchase programmes** (APP) of the Eurosystem have played an important role in stabilising government interest rates. Our measure of APP is the aggregate amount of securities held by the Eurosystem for monetary policy purposes. (33) This variable is zero prior to July 2009 and has grown since then in connection with the private sector asset purchase programmes of the Eurosystem. With the introduction of the

(32) The vertical axis is plotted in a non-linear (logarithmic) scale for readability purposes.
(33) I.e., the total amount on the balance sheet of the Eurosystem, summed over all participating countries. This variable is not, therefore, country-specific.

Graph 12: **Asset Purchase Programmes TVPs**



Source: Own estimations

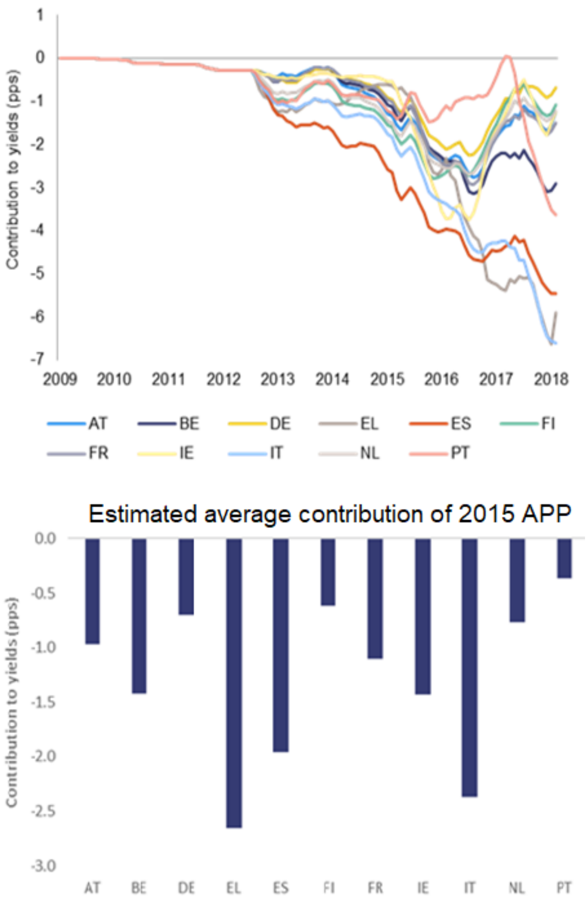
public sector purchase programme (PSPP) in March 2015 the magnitude of this asset class has become increasingly dominated by the latter. In order to identify the time-varying role of the asset purchases a common constant coefficient is assumed until July 2012. This was the month when the president of the ECB, Mario Draghi, delivered a pivotal speech to the effect that "*the ECB is ready to do whatever it takes to preserve the euro.*" This speech is widely regarded as having changed market perceptions, namely as concerns expectations of a greater role for the ECB's non-conventional monetary policy. As such, from July 2012 onwards our identification strategy allows country-specific reactions to the balance sheet size of the ECB to emerge and complement the constant, common coefficient. ([34])

Graph 12 shows the estimated TVPs for the APP variable. Following the "whatever it takes", the APP TVPs generally embark on a declining until the first quarter of 2013 signalling market's favourable assessment of the Eurosystem's balance sheet potential and its capacity to stabilise yields. This effect was more pronounced in countries experiencing market stress, or with otherwise high levels of debt (e.g., Spain, Greece, Italy and Portugal). Following some correction in 2013, TVPs embark again on a favourable downward trend in 2014. This was the year when expectations of an eventual QE programme by the ECB began to form. In March 2017, PSPP begins and the *average contribution* of APP-linked purchases begins to decrease as the balance sheet of the Eurosystem increases in size. Nevertheless, the *total contribution* of APP to lower sovereign bond yields continued to increase throughout the second half of 2017 (Graph 13). In average terms, ([35]) the APP is seen to have lowered yields the most in higher risk countries such as Spain, Italy and Greece. In "core" and lower debt euro area countries, the average contribution was lower, but still significant. Somewhat at odds with the general trend, Portugal, a high government debt country, experienced a relatively low average effect from APP (though this appeared to be in the process of correcting as of early 2018).

([34]) In the case of Greece, sovereign bonds were not eligible for the PSPP. Therefore, the bond yield effects estimated for Greece derive mainly from the existence and potential of APP as a set of policy measures, rather than from actual purchases of securities in the Greek jurisdiction.

([35]) To provide an estimate we calculate the average contribution of APP since September 2014, when news coverage of possible APPs increased sharply (see De Santis (2016), op. cit), and subtract the contribution antedating that period.

Graph 13: **Contribution of APPs to sovereign yields**



Source: Own estimations

In Box I.3 a simple counterfactual exercise is conducted whereby the actual sovereign bond yields are compared with the yields predicted by three different models capturing an "average" behaviour of parameters: a common-intercept version of fixed effects model discussed in Box I.1 (FE-CI); a "EA-6" model which is based on the average TVP values for the set of EA-6 countries; and a constant parameter model based on the FGLS-estimated coefficients in Box I.2 (CP FGLS). The objective is to assess what the yield dynamics might have looked like under a symmetric reaction to fundamental yield drivers. In order to assume cross-country symmetry, an average intercept value is taken in the fixed effects model. All three models predict much smoother profiles for Member States that underwent market stress, ([36]) reinforcing the notion that a large part of the sovereign bond dynamics observed during the 2008-09 financial crisis and the ensuing Great Recession were not driven by observed changes in country-specific fundamental determinants, but rather by differentiated and time-varying market reactions.

The models also present instances of downward price misalignment in both pre-crisis and post-crisis periods, when predicted yields are noticeably above actual yields.

4. Conclusion

When the common currency was launched in 1999, exchange rate risks had been eliminated and sovereign funding costs had almost perfectly converged for the (at the time) euro area Member States. Sovereign interest rate differences across these countries remained negligible for almost a decade, also reflecting the strong credibility of the European Monetary Union project. The subsequent fragmentation of sovereign bond markets brought to the fore the double role played by sovereign funding costs in a monetary union. While they incentivise prudent fiscal policies at Member State level, excessive differences across Member States can hamper the transmission of monetary policy. Moreover, this differentiation is typically procyclical and can exacerbate divergences in economic performance across the euro area.

While sovereign bond yields represent a prominent indicator of sovereign credit risk, it has been shown that it reflects also other factors such as market liquidity and general investor sentiment. ([37]) The empirical assessment conducted in this article confirms the role of these and other factors in driving bond yields in the euro area over time.

In particular, model-based evidence suggests that heightened market sensitiveness to debt ratios, combined with an increase in debt levels, appear to have explained a large part of the asymmetric dynamics observed during the sovereign debt crisis and the Great Recession. Changes in market sensitiveness are seen to have evolved in a divergent manner during this period, increasing for

([36]) The exception is Greece in the first quarter of 2012. This is due to an extreme spike in bid-ask spreads which more than rationalise, and possibly over-explain, the observed yields.

([37]) Garcia-de-Andoain, C. and M. Kremer (2018), 'Beyond spreads: measuring sovereign market stress in the euro area', *ECB Working Paper Series*, No. 2185 propose a composite indicator of sovereign bond market stress in the euro area. This indicator integrates measures of credit risk, volatility and liquidity at short-term and long-term government bond maturities into a broad measure of sovereign market stress.

some euro area economies, while decreasing for others, which is suggestive of flight-to-safety dynamics. At the same time, data on cross-border flows supports the notion of a flight-to-safety from “periphery” to “core” euro area economies, and also from the euro area to the US during the 2007-09 crisis period. In addition, bouts of illiquidity are seen to have driven yield peaks in periphery countries in the most acute phases of the crisis.

While increased market sensitiveness to yield drivers can reflect fundamental country-specific issues, the divergent dynamics observed in the past also appear to be linked to an incomplete EMU architecture. An institutional setup that can contain abrupt and undue shifts in investors’ perceptions in crisis periods, as well as eliminate bouts of illiquidity and remove redenomination risk, can deliver significant stability benefits for the euro area.

Over the past years, significant progress has been achieved in strengthening the EU's institutional framework, namely as regards the implementation of a banking union, the capital markets union initiative and the introduction of new monetary policy tools. A number of additional reforms are warranted as discussed in the Commission’s Reflection Paper on EMU, ([38]) which can potentially help to overcome the observed fragmentation in sovereign bond markets and address some of the issues reviewed in this article. Such issues include i) the emergence of flight-to-safety dynamics observed within the euro area and with respect to the rest of the world; ii) the risk of bond market fragmentation experienced in the euro area, which could materialise again and foment broader financial market disintegration in periods of stress; iii) the risk of illiquidity spikes in such periods, which could transmit through the credit channel to the real economy; and iv) the risk of currency redenomination. In any case, given the prominent and continued role of debt ratios in driving yield dynamics, polices that are fiscally prudent and growth friendly remain an important complement to past or prospective institutional improvements.

([38]) See Buti, M., S. Deroose, J. Leandro, and G. Giudice (2017), 'Completing EMU', VoxEU.org, 13 July.

Box I.2: **A time-varying parameter analysis of sovereign bond yields in euro area countries**

Time-varying parameter (TVP) models are particularly useful when causal relationships are unstable, or evolve, over time. They can help deal with different forms of model misspecification by allowing regression coefficients to evolve stochastically under some law of motion. The literature on TVP panel data models is limited, and this is particularly true of applications to bond yields. The author is aware of three studies that apply a TVP approach to explain sovereign bond yields in the euro area. The first, by Bernoth and Erdogan, (1) applies a semi-parametric approach to derive common (i.e., not country-specific) TVPs for a time period running from 1999 to 2010. The second, by Afonso and Jalles, (2) addresses somewhat different research questions and employs a different estimation procedure, specification and regressor choice (3) compared to the present analysis. The third, by Paniagua, Sapena and Tamarit, (4) is the closest in nature to the approach developed in this box. Like Paniagua et al, country-specific TVPs are estimated to analyse sovereign bond yields in euro area countries since the year 2000 using state-space techniques. Differently from Paniagua et al, the panel explicitly includes Germany, and the sample was prolonged to cover the 2014-18 period. A different, enlarged set of explanatory variables is also included, as well as a more flexible parameter structure.

In particular, the panel regression model described in Box I.1 was adapted and expanded to a TVP context, and a model of the following form specified:

$$y_{i,t} = \bar{I} + \left(I_{i,t} - \bar{I}\right) + \overline{\beta^{rf}}rf_t + (\beta_t^{rf} - \overline{\beta^{rf}})rf_t + \overline{\beta^{slope}}\,slope_t + (\beta^{slope}{}_t - \overline{\beta^{slope}})slope_t + \overline{\beta^{debt}}\,debt_{i,t} + \left(\beta^{debt}{}_{i,t} - \overline{\beta^{debt}}\right)debt_{i,t} + \overline{\beta^{growth}}growth_{i,t} + \left(\beta^{growth}{}_{i,t} - \overline{\beta^{growth}}\right)growth_{i,t} + \overline{\beta^{risk}}risk_t + \left(\beta^{risk}{}_{i,t} - \overline{\beta^{risk}}\right)risk_t + \overline{\beta^{liq}}liq_{i,t-1} + \left(\beta^{liq}{}_{i,t} - \overline{\beta^{liq}}\right)liq_{i,t-1} + \overline{\beta^{UMP}}UMP_t + \left(\beta^{UMP}{}_{i,t} - \overline{\beta^{UMP}}\right)UMP_t + \varepsilon_{i,t} \qquad (1)$$

An upper bar denotes a constant parameter that is common across countries. The meaning of the variables is the same as before: $y_{i,t}$, represents the 10-year sovereign bond yield for country *i* during month *t*; *I* represents an intercept; *rf* represents the short-term risk rate; *slope* represents the slope of the risk-free yield curve; *debt* is the debt-to-GDP ratio; *growth* is year-on-year GDP growth; *risk* represents a global risk factor; *liq* represents market liquidity; *UMP* represents the effects of unconventional monetary policy; and *ε* is an error term. (5)

For the *β* coefficient on variable *j* of country *i,* the specification allows for time-varying deviations from the constant parameter, $\left(\beta^j{}_{i,t} - \overline{\beta^j}\right)$, which evolve in an autoregressive manner:

$$\left(\beta^j{}_{i,t} - \overline{\beta^j}\right) = \rho_i^j\left(\beta^j{}_{i,t-t} - \overline{\beta^j}\right) + \mu_i^j\,cyas_{i,t} + u_{i,t}^j \qquad (2)$$

where *ρ* is an autoregressive parameter, *μ* is a "coefficient driver" and *u* is an error term. Like Paniagua et al (2017 the evolution of the TVPs is allowed to respond to an indicator of cyclical asymmetry in the euro area, the *cyas* variable, through the coefficient driver *μ*. (6) The rationale behind its inclusion is that macroeconomic

(1) Bernoth, K. and B. Erdogan (2012), 'Sovereign bond yield spreads: A time-varying coefficient approach', *Journal of International Money and Finance*, Vol. 31(3), pp. 639-656.
(2) Afonso, A. and J. T. Jalles (2018), 'Economic volatility and sovereign yields' determinants: a time-varying approach', *Empirical Economics*, 58, pp. 427-451.
(3) For example, Afonso and Jalles (2018) model TVPs as random walks, do not include unconventional monetary policy as an explanatory variable and seek to explain spreads with respect to Germany, meaning that the latter does not form part of the country sample.
(4) Paniagua, J., J. Sapena, J. and C. Tamarit (2016), 'Sovereign debt spreads in EMU: The time-varying role of fundamentals and market distrust', *Journal of Financial Stability*, Vol. 33, pp. 187-206. The author is grateful for the very useful exchanges with Juan Sapena on the estimation results presented in the aforementioned paper.
(5) For more details, please see Box I.1.
(6) The *cyas* variable measures, for each country, the difference between its year-on-year GDP growth and that of Germany, deemed as an "anchor country". The associated coefficients, μ_i^j, were found to be significant in most of the state equations. Nevertheless, removing *cyas* from our specification does not materially affect the results.

(Continued on the next page)

Box (continued)

divergences may influence market expectations regarding the future of a currency union. It should be noted that the time-varying coefficients on *rf* and *slope* are assumed common to all Member States and that the coefficient drivers are therefore turned off for these two variables.

The model was estimated in three stages. Firstly, the constant parameters are estimated through feasible generalised least squares (FGLS). In a constant parameter (CP) panel data context this would be equivalent to assuming a random effects model. In a FGLS estimation, observations with higher variance are given less weight. In our exercise this offers the advantage of a less erratic profile for the residuals, (7) less fit of the constant parameter model and therefore more revealing dynamics for the TVPs. The fact that the Hausman test recommends the fixed effects model need not be an obstacle as this is a test between two types of CP models rather than between different types of TVP models. In fact, as will be seen, our specification allows for permanent "country effects" irrespective of the initial FGLS estimation.

Secondly, given the CPs estimated via FGLS, the unexplained part of the $y_{i,t}$ in the set of equations (1) is taken as the "signal equations" to be explained by the set of "state equations". (2) In such a state-space setting, the time series for the TVP deviations from the CP, $\left(\beta^j{}_{i,t} - \overline{\beta^j}\right)$, can be estimated with a Kalman filter. Let *R* denote the covariance matrix of $\varepsilon_{i,t}$ and *Q* the covariance matrix of $u^j_{i,t}$. The Kalman filter estimation requires initial guesses on *R*, *Q*, the set of ρ^j_i and μ^j_i, as well as starting values for $\beta^j{}_{i,t} - \overline{\beta^j}$. An iterative procedure was followed whereby the Kalman filter is initially run by setting uninformed guesses on *R* and *Q* in the form of (scaled-down) identity matrices. Reversion of country-specific deviations to the constant parameters was assumed, and the initial ρ^j_i and μ^j_i were set to 0.9 and to zero, respectively. The exception are the TV intercepts where the ρ^I_i were set to one, thereby initially assuming a random walk, which allows country effects to be potentially permanent. Finally, the zero-period values of $\left(\beta^j{}_{i,t} - \overline{\beta^j}\right)$ were to zero.

Thirdly, an iterative procedure was run whereby the results of the Kalman filter estimation are used to formulate new initial guesses, until a good degree of convergence is achieved. All the constant parameters display the right sign and are significant at conventional significance levels. The flexibility of the TVPs allows for a near-perfect fit of the model. Approximately half of the yield variance is explained by the CPs, with the rest being explained by the TVPs, with an overall R^2 of close to 100%. (8) Table 1 summarises our estimation results.

Table 1: estimation results for a sovereign bond yield TVP panel data model

	I	β_{rf}	β_{slope}	β_{debt}	β_{growth}	β_{risk}	β_{liq}	β_{UMP}
Constant parameter	1.023	0.46	0.71	0.023	-0.03	0.13	1.7	-0.001
TVP deviations	[0.025, -0.017]	[0.005, -0.003]	[0.0007, -0.0005]	[0.128, -0.024]	[0.004, -0.007]	[0.003, -0.001]	[0.002, -0.001]	[0.001, -0.0104]

Note: the range across time and countries for the TVP deviations from the constant parameter is reported between square brackets.

A look at Table 1 shows that the TVPs exhibiting the greatest (relative) variability are those associated with *debt* and *UMP*. As in the fixed effects model estimated in Box I.1, the debt ratio is a key determinant of bond yields and asymmetric market sensitiveness to this variable is a key driver of variability along the cross-section and the time-series dimensions. It can also be observed that none of the TVP deviations are sufficient to

(7) For instance, in countries that have experienced acute market stress, spikes in illiquidity more than fully rationalise spikes in yields in the peak period of the crisis under a fixed effects CP model, so that the resulting time series of the residuals follow an M shape, with the through observed precisely during the crisis peak. This is a counter-intuitive result which is avoided by FGLS estimation, which places a lower weight on this very erratic period and produces Λ-shaped residuals. Under FGLS estimation the effect of spikes in illiquidity are not over-explained by the constant liquidity parameter but rather by changes in country-specific TVPs.

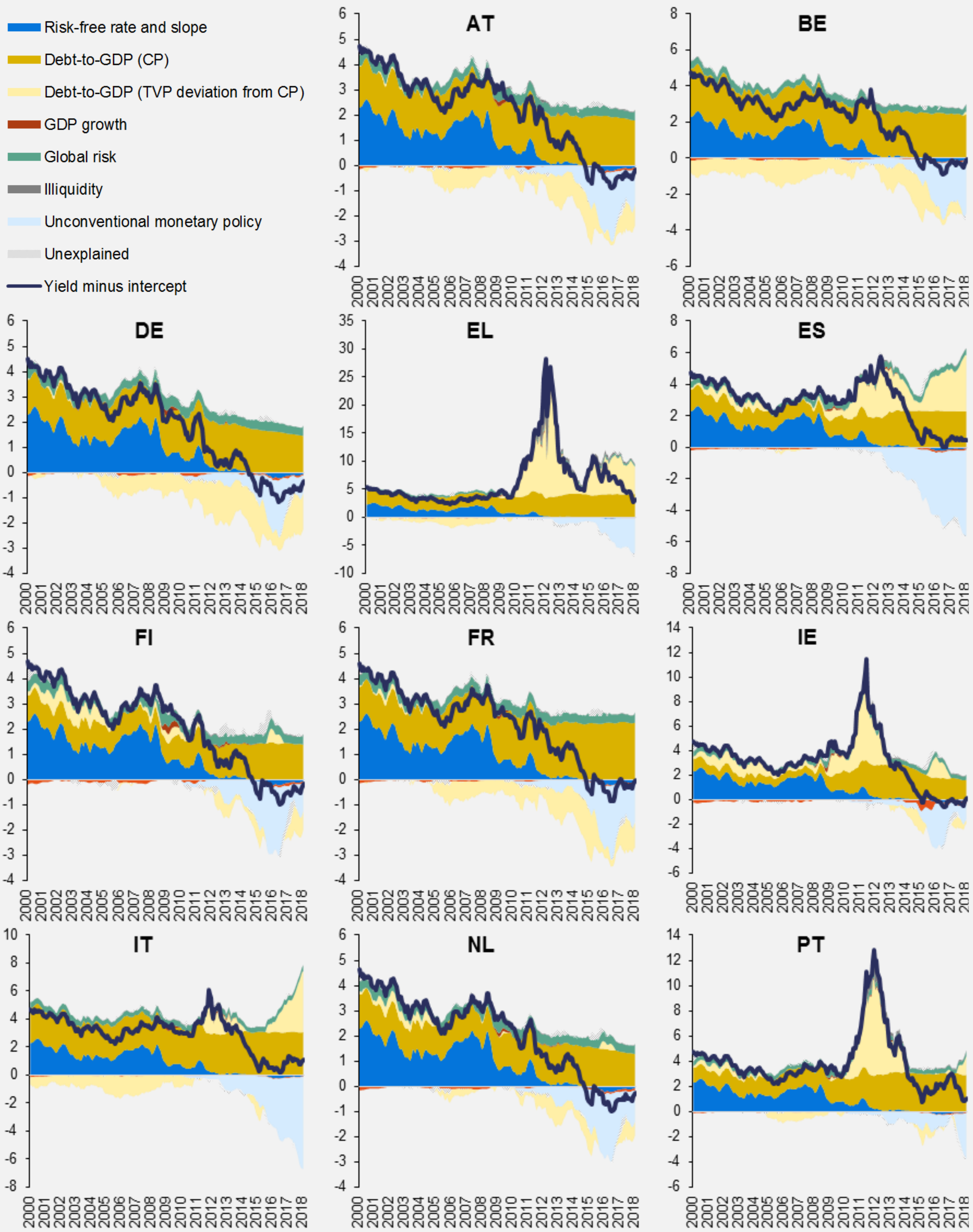
(8) An R^2 of 100% is a characteristic of the TVP approach and does not constitute, in itself, evidence in favour of our model specification.

(Continued on the next page)

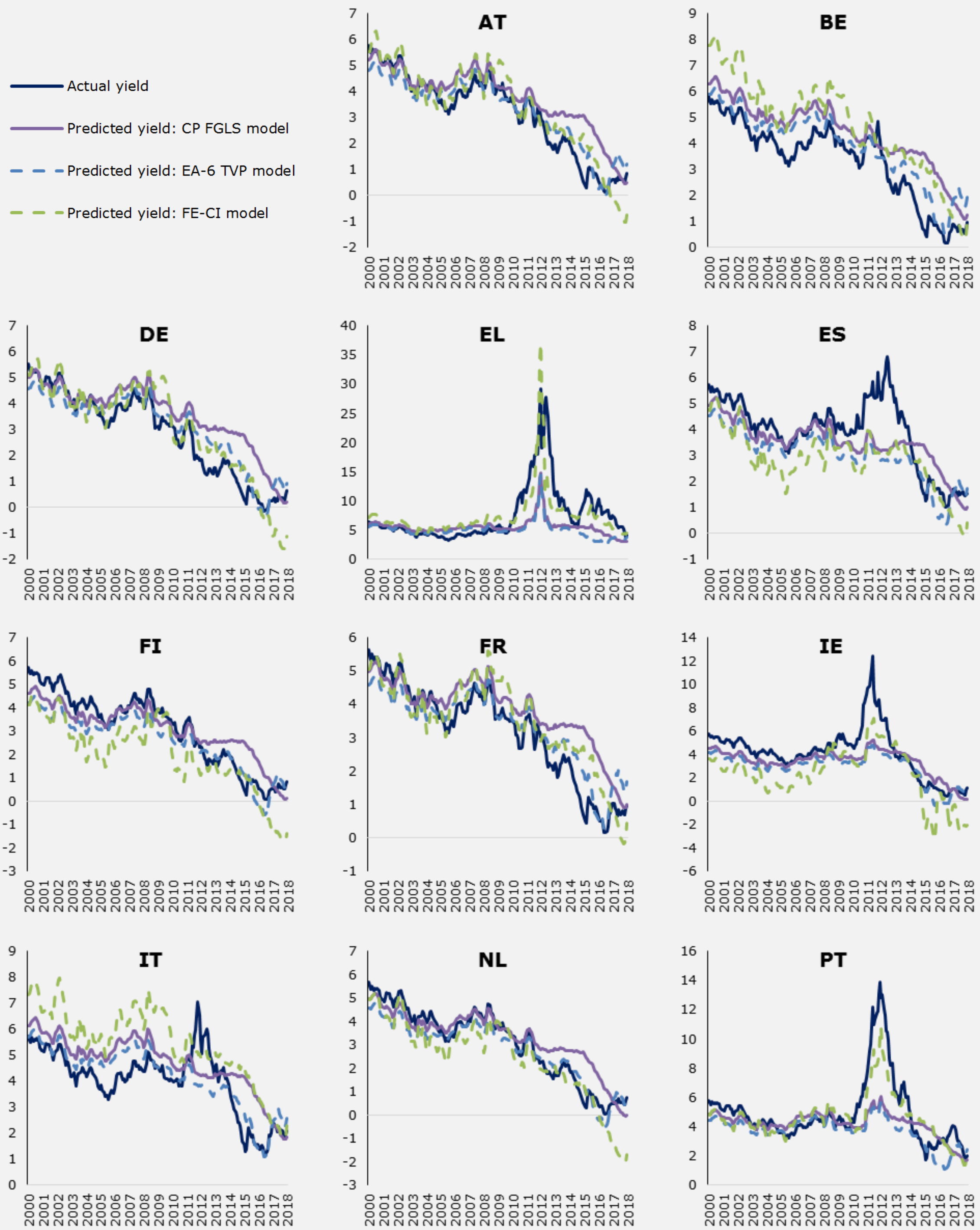
Box (continued)

change the sign of the associated coefficient, with the exception of the debt coefficient for a particular country and quarter. This exception is discussed in the main text. The chart panels below provide decompositions for the evolution of 10-year sovereign bond yields for the 11 largest euro area economies.

Decomposition of the evolution of 10-year sovereign bond yields based on a panel TVP model



Box I.3: **Actual yields vs. predicted yields from CP FGLS, FE-CI and EA-6 models**



Note: the FE-CI model is based on the constant parameters shown in Box I.1 and on an average, common intercept; the EA-6 TVP model is based on the average TVPs for AT, BE, DE, FI, FR and NL; CP FGLS model is based on the constant parameters shown in Box I.2.

Macrofinancial dynamics in a monetary union

Daniel P. Monteiro *

October 2022

Abstract

We develop a dynamic stochastic general equilibrium model of a monetary union and employ it to study in an integrated manner different macrofinancial disturbances and related policy options. The model is calibrated to the euro area, comprises two regions subject to real, nominal and financial rigidities, and features microfounded regional banking sectors and portfolio selection mechanisms allowing for empirically-consistent properties. Among the questions to which we devote our analysis are the transmission of conventional and unconventional monetary policy, the effects of private- and government-sector default risk, the implications of different macroprudential policies, the endogenous emergence of country risk premia in a context of cross-border financial flows, and the stabilising properties of joint sovereign debt issuance.

JEL classification: E32, E44, E52, F36, F45, G28, H63

Keywords: DSGE, banking, macroprudential, monetary policy, eurobonds

*Nova School of Business and Economics and European Commission. E-mail: daniel.monteiro@ec.europa.eu
The author would like to thank Francesco Franco for his very helpful comments.

1 Introduction

Spurred by the global financial crisis, the past decade brought to the forefront of the dynamic stochastic general equilibrium (DSGE) literature a closer consideration of the implications of macrofinancial disturbances and the role of financial intermediation. In the present work we investigate in an integrated manner several of the disturbances and policy responses that came to characterise the global financial crisis and the subsequent European debt crisis, that continued to evolve in connection with the covid-19 pandemic, and that may re-emerge in future contexts.

We restrict our analysis to a monetary union calibrated to the euro area. Consistently with the fact that there is neither perfect insurance between the constituent economies of the euro area, nor within those economies, our model comprises two regional blocs set to mimic a "core" and a "periphery", each home to two types of households, one of which is credit constrained. The disturbances we consider include default shocks in the different private sectors of the economy, shifts in public sector credit risk, changes to macroprudential policies and international capital flights in connection with changes in risk attitudes. We also consider the transmission and effects of two policy responses with macroeconomic stabilisation potential: unconventional monetary policy and the introduction of a common sovereign debt instrument.

The structure of our DSGE model is enriched with a number of financial frictions and mechanisms that assign a relevant macroeconomic role to credit, credit risk, financial intermediation and international capital flows. Among the more standard features of the model we have the fact that households are split into patient and impatient types, with the former owning the corporate sector and saving in the form of deposits, and the latter borrowing from domestic banks subject to a collateral constraint that is linked to their expected housing wealth. A similar collateral constraint is also included for entrepreneurs linking corporate loan amounts to the expected value of their gross operating profits and capital stock. We borrow an inertia mechanism from Iacoviello (2015) whereby outstanding household and corporate loans evolve slowly over time and introduce soft loan-in-advance constraints (LIA) for households and firms that link the use of bank loans to household and corporate investment, respectively.

The non-financial corporate sector is structured along a vertical production chain, as in Canova et al. (2015), allowing for the introduction of nominal, real and financial rigidities, as well as other relevant features, at different stages of the production process. At the first stage of production, entrepreneurs employ labour and physical capital to produce an intermediate good subject to real investment adjustment costs as in Christiano et al. (2005), as well as to the aforementioned LIA and collateral constraints. Intermediaries acquire the entrepreneurial production, differentiate it and sell the different varieties to wholesale aggregator firms subject to staggered pricing as in Calvo (1983). Product differentiation allows for the introduction of market power in a monopolistic competition setting, as well as for the existence of fixed costs that can offset intermediaries' operating margins. Final goods producers introduce international trade into the model by combining the output of wholesalers in both regions to produce a final good that is used for private and public consumption, as well as for investment purposes. Finally, housebuilders conduct housing investment by transforming a part of the final good into the economy's housing stock subject to investment adjustment costs and to decreasing returns to scale.

Among our more innovative contributions are the modeling of the banking sector and the associated mechanisms for portfolio selection and cross-border financial flows. Motivated by the experience of the 2007-08 financial crisis, there has been much progress in the past decade in rendering financial intermediation a relevant mechanism for originating, transmitting and amplifying shocks in a DSGE context. One dimension along which modeling approaches differ is as to their degree of microfoundation. On one end of the range we can find financial sectors that are described by a set of empirically-flexible reduced-form equations that are not explicitly derived from optimising agent behaviour, of which Gourinchas et al. (2016) is a relatively recent example. On the other end of the range, one can find deeply microfounded banking sectors, of which Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) are seminal examples. The latter class of models, however, typically relies on a highly stylized description of the workings of financial intermediation and often requires strong assumptions as to structure of the underlying economy, the types of shocks that originate financial disturbances or as regards agent behaviour and the timing of their decisions.

Our modeling of the banking sector is microfounded on standard firm theory whereby zero-measured bank managers maximize a discounted dividend stream on behalf of bank owners under a standard principal-agent friction that implies that the time horizon of managers is more myopic than that of owners. Banks are subject to a capital ratio constraint that is consistent with real-world regulatory requirements imposed by supervisory authorities, as well as a deviation cost built around banks' leverage ratio. The cost assumes that banks target a steady-state leverage ratio, as in Kollmann et al. (2013), thereby incorporating both the well-accepted notion that banks behave as if holding (too much) capital is costly, as well as the possibility of market pressure mechanisms for banks holding too little capital.

We opt to work with consolidated regional banking sectors rather than with different types of banks connected via the interbank market, as is for example the case of the workhorse DSGE model described in Coenen et al. (2018). This is in part motivated by Europe's tradition of universal banking and by a desire to avoid a pattern of bank specialisation that has no clear counterpart in the actual structure of the European banking industry. However, our model implementation is such that the study of interbank lending disturbances remains possible both along domestic and cross-border dimensions.

The transmission of monetary policy in our model is effected via a competitive banking sector and is modeled in an explicit manner. Banks have access to a central bank deposit facility, with the monetary authority controlling the policy rate on this facility. Banks' no-arbitrage pricing reflects changes in the policy rate, thereby transmitting conventional monetary policy to borrowers, depositors and the broader economy. As regards unconventional monetary policy, the monetary authority is empowered to purchase government bonds from banks at the market price and to swap them for reserves held at the deposit facility.

An important feature of our model is the inclusion of portfolio management mechanisms whereby (risk-adjusted) portfolio yields are maximized subject to investor preferences and the prevailing financial environment. In our setup, bank head offices decide steady-state investment amounts and define competitive interest rates for their portfolio of government bonds and interbank loans. These are communicated to portfolio managers, along with investment preferences (or guidelines). Portfolio managers are then tasked with allocating investment across regions based on the whole information set provided by head offices. In the spirit of the preferred habitat theory introduced by Modigliani and Sutch (1966), financial asset price formation is thus the result of two forces in our model: the competitive cost-based, no-arbitrage pricing of head offices, and the investor preference-influenced decisions of portfolio managers. Besides helping to determine asset prices and allocations, the interplay of portfolio managers in both regions has an important role in determining relative country risk, as this will be the relative premium demanded for cross-border interbank loans in order to ensure sufficient external funding. As such, differently from more mechanistic approaches for ensuring external balance described in Schmitt-Grohé and Uribe (2003), country risk is an implicit mechanism in our model, purely determined by the interplay of investors and other general equilibrium forces.

The previously-described model design renders it particularly suitable for the assessment of three types of policies. The first are macroprudential policies, which we translate into included model features such as capital requirements and loan-to-value ratios. The second are monetary policies, particularly as regards unconventional measures such as asset purchases. The third is the introduction of different forms of common sovereign debt instruments, a topic which has gained renewed relevance given the current initiatives for large, temporary issuance by the European Union on behalf of Member States in the wake of the recent pandemic crisis.[1] Common sovereign debt instruments have been mainly analysed from the viewpoint of their credit risk properties - see, e.g., ESRB High-Level Task Force on Safe Assets (2018), Leandro and Zettelmeyer (2019) and Monteiro (2023) - or of these properties in interaction with a banking sector, as in Brunnermeier et al. (2017). A full-blown general equilibrium analysis of common sovereign debt instruments is still missing in the literature. The first and, to our knowledge, only attempts at modeling such instruments in a DSGE framework are Badarau et al. (2021)

[1]This is namely the case of the NextGenerationEU and the SURE initiatives.

and Jarociński and Maćkowiak (2018). However, their modeling framework is significantly more stylized than what is considered here.[2]

The remainder of this paper is organised as follows: Section 2 provides a detailed model description; Section 3 discusses the calibration of the model; Section 4 simulates the model dynamics in response to standard macroeconomic shocks, different monetary and financial shocks, macroprudential policy changes and the introduction of a common debt instrument; while Section 5 concludes and provides avenues for future research.

2 The model economy

The model economy is discretised to quarterly frequency and comprises two regions in a monetary union: a "periphery" with measure $0 < n < 1$ and a "core" with measure $1 - n$. The following subsections describe the periphery bloc, which can also be understood as the "domestic" region from the viewpoint of our analysis. The description of the core region is analogous to that of the periphery.

2.1 The household sector

The economy is populated with savers, which are indexed by s and have measure $0 < \omega_s < 1$, and borrowers, which are indexed by b and have measure $1 - \omega_s$. Both household types share similar preferences but differ as to their intertemporal discount factors $0 < \beta_b < \beta_s < 1$ and asset ownership. The more patient households own the entire corporate sector and save in the form of bank deposits while the comparatively impatient households borrow in the form of bank loans.

2.1.1 Saver households

The representative saver household maximizes a discounted stream of expected utility by choosing in each period t how much to consume (C_s), how much housing capital to own (H_s), how much time to work (N_s) and how much to save (D_s):

$$\max_{\{C_{s,t},H_{s,t},N_{s,t},D_{s,t}\}} E_0 \sum_{t=0}^{\infty} \beta_s^t \left[\frac{\left(C_{s,t} - h\bar{C}_{s,t-1}\right)^{1-\chi}}{1-\chi} + \nu_s^h \frac{H_{s,t}^{1-\chi}}{1-\chi} - \nu_s^n \frac{N_{s,t}^{1+\varphi}}{1+\varphi} \right] \tag{1}$$

where $0 < h < 1$ captures external habits in consumption, $\bar{C}_s$ is the aggregate consumption of savers, $\chi > 0$ is the coefficient of relative risk aversion, $\nu^h, \nu^n > 0$ are the relative (dis)utility weights of housing services and hours worked, respectively, and $\varphi > 0$ is the inverse of the Frisch elasticity of labour supply. The budget constraint of savers is given by

$$P_t(C_{s,t} + T_{s,t} + AC_{H_s,t}) + P_t^H(H_{s,t} - (1-\delta_H)H_{s,t-1}) + D_{s,t} = R_{s,t}^D D_{s,t-1} + W_t N_{b,t} + DIV_{s,t} \tag{2}$$

where P denotes the price level of final goods, AC_{H_s} a real cost from adjusting the housing stock, $T > 0$ a lump-sum tax, P^H the price of housing, $0 < \delta_H < 1$ the depreciation rate of the housing stock, R^D the gross return rate on deposits, W the nominal wage rate and DIV the aggregate net dividends paid out by the corporate sector.

The inclusion of AC_{H_s} seeks to capture housing transaction costs, broadly defined. It reflects, inter alia, the costs associated with searching and moving into new housing, as well as possible transaction taxes. One of its implications is that, for a given total housing stock H in the economy, changes in ownership between savers and borrowers do not happen in a frictionless

[2]For instance, Badarau et al. (2021) do not include a banking sector nor other features found in fully developed models, such as capital accumulation. Jarociński and Maćkowiak (2018)) consider only an area-wide banking sector and their common debt instrument (which is akin to undefaultable central bank liabilities) is unlike the most common proposals.

manner. Housing adjustment costs are governed by intensity parameter $s_{H_s} > 0$ and take the following form:

$$AC_{H_s,t} = \frac{s_{H_s}}{2} \left(H_{s,t} - H_{s,t-1}\right)^2 \tag{3}$$

2.1.2 Borrower households

The representative borrower household faces a similar lifetime utility maximisation problem, although it optimises on loans from domestic banks (L_b) rather than on deposits:

$$\max_{\{C_{b,t},H_{b,t},N_{b,t},L_{b,t}\}} E_0 \sum_{t=0}^{\infty} \beta_b^t \left[\frac{\left(C_{b,t} - h\bar{C}_{b,t-1}\right)^{1-\chi}}{1-\chi} + \nu_b^h \frac{H_{b,t}^{1-\chi}}{1-\chi} - \nu_b^n \frac{N_{b,t}^{1+\varphi}}{1+\varphi} \right] \tag{4}$$

Borrowers are subject to an intertemporal budget constraint,

$$\begin{aligned} P_t \left(C_{b,t} + T_{b,t} + AC_{H_b,t}\right) + P_t^H \left(H_{b,t} - (1-\delta_H) H_{b,t-1}\right) + \varepsilon_t^b R_{b,t-1} L_{b,t-1} + P_t LIA_{b,t} \\ = L_{b,t} + W_t N_{b,t} \end{aligned} \tag{5}$$

where R_b represents the gross nominal interest rate on bank loans, $0 < \varepsilon^b \leq 1$ the complement of the loan default rate and LIA_b real costs from deviating from a LIA constraint. They are also subject to housing adjustment costs, as in the case of saver households:

$$AC_{H_b,t} = \frac{s_{H_b}}{2} \left(H_{b,t} - H_{b,t-1}\right)^2 \tag{6}$$

When lending to households, banks impose a collateral constraint that limits the loaned amounts to a fraction of the expected housing wealth. Thus

$$L_{b,t} \leq \rho_b \Pi_t L_{b,t-1} + (1-\rho_b) \left(\gamma_t^b E_t \frac{P_{t+1}^H (1-\delta_H) H_{b,t}}{R_{b,t}} \right) \tag{7}$$

where the $0 < \gamma_t^b < 1$ parameter governs the loan-to-value ratio and is allowed to vary as a function of exogenous shocks. In order to capture the empirical fact that loan amounts change only slowly over time, we include $0 < \rho_b < 1$ as an inertia parameter and allowing for the updating of the associated past nominal loan amounts at the inflation rate Π_t. It is worth noting that Equation 7 assumes that banks compute housing wealth in present value terms, considering the expected evolution of house prices, the size of the housing stock and the riskiness of the mortgage loan as reflected in the interest rate. A change in any of these factors implies a change in loan amounts and produces a "financial accelerator" type of mechanism.

Finally, borrower households are subject to a soft LIA constraint governed by intensity parameter s_b which makes it costly for them to deviate from the steady-state housing-wealth-to-loan ratio:[3]

$$LIA_{b,t} = \frac{s_b}{2} \left(\frac{P_t^H H_{b,t}}{L_{b,t}} - \frac{P^H H_b}{L_b} \right)^2 \tag{8}$$

According to Equation 8, a relative dearth of credit makes it more difficult for indebted households to expand or sustain their nominal housing stock. This may be because households may need to search harder for mortgage loans, face a constrained banking sector that is passing on to borrowers higher-than-usual loan appraisal and monitoring costs, or because a share of families is incurring the costs of bank repossession. Conversely, a credit boom stimulates housing demand.

Ultimately, the soft LIA constraint sharpens the specificity of bank loans as primarily funding housing rather than consumption, reflecting the empirical fact that loans to households are by and large mortgage loans.

[3]Here and elsewhere, the suppression of the t subscript from a variable in an equation denotes that we are considering the steady-state value of that variable.

2.2 The non-financial corporate sector

The non-financial corporate sector is vertically organised, comprising entrepreneurs, intermediaries, wholesalers, final goods producers and housebuilders. This structure allows to easily track the introduction of key macroeconomic features and rigidities, which are gradually integrated at different stages of the production process.

The different types of firms are deemed to behave competitively and to be price takers. This can be understood as a consequence of the assumption that, at each stage of production, there is continuum of firms, with none able to yield market power. The exception are wholesale firms who operate in a monopolistically competitive environment due to the fact that each one offers a differentiated product. In the model description below this continuum of firms is indexed in the case of wholesalers, but firm-level indices are otherwise omitted to keep the notation lighter.

2.2.1 Entrepreneurs

Entrepreneurs maximize the expected discounted value of a profit stream $\Omega_{e,t}$ where the choice variables are bank loan amounts L_e, investment levels I_e and the two production factors, capital (K_t) and labour (N_t):

$$\max_{\{L_{e,t},I_{e,t},K_t,N_t\}} E_0 \sum_{t=0}^{\infty} \beta_e^t \lambda_{s,t} \Omega_{e,t} \tag{9}$$

Entrepreneurs' stochastic discount rate incorporates that of firm-owning households, $\lambda_{s,t}$. At the same time, the constant discount factor β_e is assumed to be lower than β_s, reflecting a principal-agent friction whereby managers' time horizon with a firm is shorter than that of the (infinitely-lived dynasty of) firm owners. This relative impatience of entrepreneurs to pay out dividends ensures that they will wish to borrow to the maximum possible extent in a neighbourhood of the model's steady state.

The in-period profit is given by

$$\Omega_{e,t} = P_t^X X_t + L_{e,t} - (P_t I_{e,t} + \varepsilon_t^e R_{e,t-1} L_{e,t-1} + W_t N_t + P_t LIA_{e,t}) \tag{10}$$

where X is a real amount produced and P^X its price, P is the final goods price at which investment goods can be acquired and transformed into physical capital, R_e is the gross nominal interest rate on corporate loans, $0 < \varepsilon^e \leq 1$ is the complement of the corporate loan default rate, N is the total labour supplied by both types of households and LIA_e are the real costs from deviating from a LIA constraint.

Entrepreneurial production technology is Cobb-Douglas:

$$X_t = \varepsilon_t^z (K_{t-1})^{\alpha} (N_t)^{1-\alpha} \tag{11}$$

where ε_t^z accounts for exogenous shocks to total factor productivity (TFP) and $0 < \alpha < 1$ is the share of capital income in total entrepreneurial production.

The law of motion of physical capital is given by

$$K_t = I_{e,t} \left[\varepsilon_t^{I_k} - S^k (I_{e,t}, I_{e,t-1}) \right] + (1 - \delta_k) K_{t-1} \tag{12}$$

where $\varepsilon_t^{I_k}$ takes the value of one in the steady-state, while allowing for exogenous shocks that modify investment efficiency, $0 < \delta_k < 1$ is the capital depreciation rate and $S^k \geq 0$ is an investment adjustment cost governed by intensity parameter s_k:

$$S^k (I_{e,t}, I_{e,t-1}) = \frac{s_k}{2} \left(\frac{I_{e,t}}{I_{e,t-1}} - 1 \right)^2 \tag{13}$$

It is worth noting that the fact that entrepreneurs choose both I_e and K is a shorthand way of introducing capital goods production into the economy. This approach is equivalent to an alternative one found in the DSGE literature whereby independent capital goods producers acquire and transform final goods into physical capital.

Similarly to borrowing households, entrepreneurs face a collateral constraint linking the maximum value of their loans to the expected discounted value of their gross operating surplus ($P^X X - WN$) and capital stock:

$$L_{e,t} \leq \rho_e \Pi_t L_{e,t-1} + (1-\rho_e)\left(\gamma_t^e E_t \frac{(P_{t+1}^X X_{t+1} - W_{t+1}N_{t+1}) + (1-\delta_k)Q_{e,t+1}K_t}{R_{e,t}}\right) \tag{14}$$

In the previous inequation, $0 < \rho_e < 1$ is an inertia parameter, Q_e is the price of capital and $0 < \gamma_t^e < 1$ governs the loan-to-value ratio of entrepreneurial firms, which is allowed to vary over time in response to exogenous shocks.

Finally, entrepreneurs are subject to a soft LIA constraint of the form

$$LIA_{e,t} = \frac{s_e}{2}\left(\frac{Q_{e,t}K_t}{L_{e,t}} - \frac{Q_e K}{L_e}\right)^2 \tag{15}$$

where $s_e > 0$ governs the overall intensity of the constraint. According to Equation 15, a relative scarcity of corporate lending increases the cost of sustaining or expanding the capital stock. This may be because of increased search costs for other forms of funding (e.g., equity investment from saver households), because of the lower quality of the investment incurred by liquidity-constrained firms, or for other reasons such as those previously discussed when considering the problem of borrower households. Conversely, relatively abundant credit incentivises the expansion of the capital stock (or may otherwise prove costly if not backed by sufficient collateral).

2.2.2 Intermediary firms

Intermediary firms, together with wholesale firms discussed in the next subsection, allow for the introduction of market power, fixed costs and nominal rigidities in the model, the latter via a mechanism of staggered prices. A continuum of intermediaries indexed by $i \in [1, n]$ acquires the production X of entrepreneurs at price P^X and differentiates it into a continuum of i varieties, with each intermediary selling its variety to wholesalers at a price P_i^Y and incurring fixed costs F_i. The maximization problem of a given intermediary i is thus

$$\max_{\widetilde{P}_{i,t}^Y} E_0 \sum_{t=0}^{\infty} \beta_s^t \lambda_{s,t}\left(P_{i,t}^Y Y_{i,t} - P_t^X X_{i,t} - F_i\right) \tag{16}$$

subject to wholesalers' demand for Y_i. It can be observed that the stochastic discount rate of intermediary firms coincides with that of their owners.

What makes intermediaries' optimisation problem dynamic and allows for the introduction of price rigidities is the fact that only a randomly-determined fraction of firms $1-\phi$ is allowed to revise their prices in any given period. The remaining $0 < \phi < 1$ fraction is stuck with a price previously set, though updated at the steady-state inflation rate. Thus, $\widetilde{P}_{i,t}^Y$ denotes the optimal chosen price whenever an intermediary has the opportunity of revising it. $\widetilde{P}_{i,t}^Y$ can be shown to be

$$\widetilde{P}_{i,t}^Y = \frac{\theta}{\theta-1}\frac{E_t\sum_{l=0}^{\infty}(\phi\beta_s)^l \lambda_{s,t+l}\left(\Pi^l\right)^{-\theta} P_{t+l}^X \left(P_{t+l}^Y\right)^{\theta} Y_{t+l}}{E_t\sum_{l=0}^{\infty}(\phi\beta_s)^l \lambda_{s,t+l}\left(\Pi^l\right)^{1-\theta}\left(P_{t+l}^Y\right)^{\theta} Y_{t+l}} \tag{17}$$

where θ is a product differentiation parameter presented in the next subsection. P_t^Y can be shown to evolve as

$$P_t^Y = \left[(1-\phi)\left(\widetilde{P}_{z,t}^Y\right)^{1-\theta} + \phi\left((\Pi_t)^{-1}\Pi P_{t-1}^Y\right)^{(1-\theta)}\right]^{\frac{1}{1-\theta}} \tag{18}$$

2.2.3 Wholesalers

Wholesalers acquire the product varieties i produced by intermediaries and aggregate them into a composite good Y that can be used as an input for the production of the domestic final good (Y_D), or otherwise exported (Y_{M^*}). The wholesalers' problem is to minimize total expenditure,

$$\min_{Y_{i,t}} \int_0^n P_{i,t}^Y Y_{i,t} di \tag{19}$$

subject to a given level of output Y obtained from a Dixit-Stiglitz aggregation technology:

$$Y_t = Y_{D,t} + Y_{M^*,t} = \left[\left(\frac{1}{n} \right)^{\frac{1}{\theta}} \int_0^n \left(Y_{i,t} \right)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}} \tag{20}$$

The $\theta > 0$ parameter is the elasticity of substitution among varieties, conferring differentiation-based market power to intermediary firms.

2.2.4 Final goods producers

Firms producing final goods combine domestic wholesale production Y_D acquired at price P^Y with wholesale production imported from the foreign region, Y_M^*, which is acquired at price P^{Y^*}.[4] Final goods producers minimize total expenditure,

$$\min_{Y_{D,t}, Y_{M,t}^*} P_t^Y Y_{D,t} + P_t^{Y^*} Y_{M,t}^* \tag{21}$$

subject to a constant elasticity of substitution (CES) production technology,

$$Z_t = \left[\left(1 - \omega^M\right)^{\frac{1}{\nu}} \left(Y_{D,t}\right)^{\frac{\nu-1}{\nu}} + \left(\omega^M\right)^{\frac{1}{\nu}} \left(Y_{M,t}^*\right)^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}} \tag{22}$$

where ω_M is an input share parameter and ν the CES parameter.

2.2.5 Housebuilders

Housebuilders acquire final goods for housing investment purposes, I_h, and use them as inputs to change the overall housing stock. Their optimisation problem is to choose investment levels to maximize a stream of profits discounted at the firm owners' rate,

$$\max_{\{I_{h,t}\}} E_0 \sum_{t=0}^{\infty} \beta_s^t \lambda_{s,t} \left(P_t^H \Xi_t - P_t I_{h,t} \right) \tag{23}$$

subject to a housebuilding technology exhibiting decreasing returns to scale and investment adjustment costs:

$$\Xi_t = H_t - (1 - \delta_H) H_{t-1} = \left(s_{h_0} - S^h \left(I_{h,t}, I_{h,t-1} \right) \right) I_{h,t}^{\gamma} \tag{24}$$

$$S^h \left(I_{h,t}, I_{h,t-1} \right) = \frac{s_{h_1}}{2} \left(\frac{I_{h,t}}{I_{h,t-1}} - 1 \right)^2 \tag{25}$$

The $0 < \delta_H < 1$ parameter denotes the depreciation rate of the housing stock, $0 < \gamma < 1$ is a technological parameter governing the degree of decreasing returns to scale and $s_{h_0} > 0$ is a technological parameter calibrated in such a way as to ensure that the usual capital law of motion holds in the steady state. I.e, $H_t = (1 - \delta_H) H_{t-1} + I_{h,t}$ whenever $H_t = H_{t-1} = H$ and $I_{h,t} = I_h$. Parameter $s_{h_1} \geq 0$ governs the intensity of the investment adjustment costs.

The fact that housebuilding is subject to decreasing returns to scale can be motivated by the existence of a production factor in fixed supply, e.g. land, while investment adjustment costs is a standard feature describing real economies.

[4] Here and elsewhere, an asterisk signals a foreign economy variable, or one that is traded across borders.

2.3 Banks

Each region is home to a consolidated banking sector f that operates competitively. Banks grant loans to households (L_h), to entrepreneurs (L_e) and to domestic (IB_f) and foreign banks (IB_f^*). Banks also hold a portfolio of domestic (B_f) and foreign sovereign bonds (B_f^*) and can access a deposit facility (CB_t) with the common central bank, which completes the description of the asset side of their balance sheets. On the funding side, banks take deposits (D_h) and obtain equity financing (K_f) from saver households, while also funding themselves in the domestic and cross-border interbank market (IBF_f).

It should be noted that domestic interbank loans are necessarily in zero net supply in each region, with the gross outstanding long and short positions canceling each other out when considering the banking sector in consolidated terms. For this reason, IB_f is not taken into account when considering the consolidated assets and liabilities of the regional banking sectors. However, domestic interbank lending can still be usefully included in the model in order to study the effects of interbank default and to enable portfolio selection mechanisms, as will be presently seen. In fact, the impact of interbank default is linked to the gross outstanding amounts of interbank exposures, as are any capital requirements associated with interbank lending.

As regards the deposit facility of the central bank, it serves two important purposes. First, it is the means through which the monetary authority enacts its conventional monetary policy. By setting the policy rate R^{EA} on this facility, interest rates in the wider economy are affected via banks' no-arbitrage asset pricing conditions. Second, the presence of a deposit facility allows us to study the effect of other forms of monetary policy. For instance, reserve requirements can be modeled as mandatory amounts held by banks in the deposit facility,[5] while asset purchase programmes can be modeled as a swap of government bonds (or private-sector loans) for central bank reserves.

Another key interest rate affecting economy-wide dynamics will be the weighted average rate paid by banks on their interbank funding portfolio IBF_f, which will affect the interest rate paid on depositors (i.e., the other form of debt-based funding banks can resort to) via a no-arbitrage relationship.[6] The average rate on IBF_f will also be the means via which country risk premia can affect an economy's funding costs, as discussed in Subsection 2.3.2.

An important characteristic of the model is that bank head offices price government bonds as well as domestic and foreign interbank loans in a competitive manner taking into account i) the risk-free rate (as given by the deposit facility), ii) the credit risk of each exposure and iii) the respective capital requirements, as interacted with the general conditions of the bank, such as the tightness of the leverage ratio constraint. Bank head offices do not decide, however, the exact proportions of domestic and foreign assets to be held in each of these categories. Instead, they communicate their pricing and investment preferences (in terms of desired steady-state regional asset shares and willingness to substitute across regions) to bond and interbank portfolio managers, which can be understood as separate divisions within the bank. This approach merges the notion of risk- and cost-based, no-arbitrage pricing (conducted by head offices) with preferred habitat effects (introduced by portfolio managers), so that the resulting asset price formation reflects both forces. It allows us to pin down portfolio allocations that reflect observable data and to generate financial flows that are empirically consistent.

Banks take into account the stochastic discount factor of firm owners and maximize the expected present value of dividends, which are equal to net income ($NI_{f,t}$) minus changes in bank capital ($\Delta K_{f,t}$):

$$\max_{\left\{L_{h,t},L_{e,t},B_{f,t},B^*_{f,t},IB_{f,t},IB^*_{f,t},CB_{f,t},D_{h,t},IBF_{f,t}\right\}} E_0 \sum_{t=0}^{\infty} \beta_f^t \lambda_{s,t} \left(NI_{f,t} - \Delta K_{f,t}\right) \tag{26}$$

with

[5] This, in fact, similar to how CB_t is modeled in the present version of the model, i.e., as exogenously determined by the central bank.

[6] This is readily seen in Equation 91 in Appendix B.

$$
\begin{aligned}
NI_{f,t} = &\left(\varepsilon_t^b R_{b,t-1} - 1\right) L_{h,t-1} + \left(\varepsilon_t^e R_{e,t-1} - 1\right) L_{e,t-1} \\
&+ \left(\varepsilon_t^B R_{t-1} - 1\right) B_{f,t-1} + \left(\varepsilon_t^{B^*} R_{t-1}^* - 1\right) B_{f,t-1} + \left(\varepsilon_t^{ib} R_{f,t-1}^{IB} - 1\right) IB_{f,t-1} \\
&+ \left(\varepsilon_t^{ib^*} R_{f,t-1}^{IB^*} - 1\right) IB_{f,t-1}^* + \left(R_{t-1}^{EA} - 1\right) CB_{f,t-1} - \left(R_{s,t-1} - 1\right) D_{h,t-1} \\
&- \left(\varepsilon_t^{ib} R_{f,t-1}^{IBF} - 1\right) IBF_{f,t-1} - P_t AC_{K,t}
\end{aligned} \tag{27}
$$

and

$$
\begin{aligned}
K_{f,t} &= L_{h,t} + L_{e,t} + B_{f,t} + B_{f,t}^* + IB_{f,t} + IB_{f,t}^* + CB_{f,t} - D_{h,t} - IBF_{f,t} \\
&= L_{h,t} + L_{e,t} + B_{f,t} + B_{f,t}^* + IB_{f,t}^* + CB_{f,t} - D_{h,t} - IB_{f^*,t}
\end{aligned} \tag{28}
$$

where the second equality of Equation 28 follows from the fact that $IB_{f,t}$ is in zero net supply. In the previous equations $0 < \beta_f < \beta_s$ is the constant discount factor; R and R^* denote the gross nominal yield on domestic and foreign bonds, respectively; $0 < E_t[\varepsilon_{t+1}^B] \leq 1$ is the complement of the expected loss on sovereign bond holdings; $0 < \varepsilon^{ib} \leq 1$ is the complement of the interbank loan default rate; R_f^{IB} and R_f^{IB} are the gross interest rates charged on domestic and foreign interbank lending, respectively; R_f^{IBF} is the average gross interest rate paid on interbank borrowing; and AC_K is the real cost from deviating from a target leverage ratio.

It should be recalled that, in the absence of unexpected shocks, the expected loss rates on mortgage, corporate and interbank loans coincide with actual loss rates due to the operation of the law of large numbers in conjunction with the assumption of the existence of an infinity of private-sector agents. However, given that a government is a single entity, government default is a binomial event. As such, ε_t^B captures the underlying credit risk of the government, as given by the ex ante expected loss on the exposure, rather an actual ex post loss rate. Whether ε_t^B materialises in actual losses is dependent on the sovereign actually defaulting, a scenario which can be modeled as being governed by a “sunspot” variable, with ε_t^B taking the value 1 in the absence of default.

It should also be noted at this stage that a share $0 \leq \omega^f \leq 1$ of banks is assumed to be locked into a strategic game with their home sovereign, whereby their dominant strategy is to increase their exposure to the latter whenever domestic sovereign risk increases. This game is illustrated in Appendix A and is based on the idea that, for highly-exposed banks, increasing domestic bond holdings when confronted with higher credit risk premia is a one-way bet: while shareholder value is always fully wiped out in the event of sovereign default, the higher premia can be pocketed in as extra income in case there is no default. Therefore, such ω^f share of highly-exposed banks consider the actual costs of credit risk, as given by the associated capital requirements discussed below, but not the potential costs, as given by the actual losses in the case of a credit event. This model feature allows us to capture the empirical phenomenon whereby periphery banks reinforced their sovereign home bias during the euro area sovereign debt crisis. It carries no particular implications for the description of the banking sector laid out in this subsection, but leads to two different first order conditions for B_f depending on whether bank $f \in \omega^f$ or not.[7]

In line with the Basel III/IV provisions as set out in the Capital Requirements Regulation and Directive (CRRD) for European Union Member States, banks obey a regulatory constraint whereby their level of capital needs to be equal to or greater than their capital requirements, $KR_{f,t}$, as defined in the CRRD and assessed by bank supervisory authorities:

$$
K_{f,t} \geq KR_{f,t} \tag{29}
$$

where KR_t is defined as

$$
KR_{f,t} = \rho_f \Pi_t KR_{f,t-1} + (1 - \rho_f)\left(RWA_{f,t} + EL_{f,t}\right) \tag{30}
$$

[7]See Equations 83 and 84 of Appendix B.

and

$$RWA_{f,t} = \eta_t^{L_h} L_{h,t} + \eta_t^{L_e} L_{e,t} + \eta_t^{B}\left(B_{f,t} + B^*_{f,t}\right) + \eta_t^{IB}\left(IB_{f,t} + IB^*_{f,t}\right) \tag{31}$$

Equation 30 computes capital requirements as the sum of a banks' risk weighted assets (RWA_f) and unrecognised expected losses EL_f. RWA are, for their part, computed as bank exposures multiplied by their respective risk weights $\eta \geq 0$. The inclusion of the $0 < \rho_f < 1$ parameter allows for a degree of inertia in adjusting bank capital, which can reflect leniency or inattention on the part of the supervisory authority.

It should be noted that Equations 30 and 31 express risk weights in effective form, meaning that they already incorporate a bank's minimum regulatory capital ratio[8] as well as any other capital add-ons, including those that bank management may wish to apply as part of their internal capital adequacy assessment process. In the case of the latter add-ons, the bank may be operating discretionarily above minimum capital requirements, implying that the ρ_f parameter can then partly reflect a smoothing behaviour by bank managers.

In line with the CRRD, bank capital should also cover for unrecognised expected losses and impairments, which justifies the inclusion of the EL_f term.[9] The computation of $EL_{f,t}$ is therefore as follows:

$$\begin{aligned} EL_{f,t} = E_t\Bigg[&(1-\varepsilon^b_{t+1})(1-\eta_t^{L_h})L_{h,t} + (1-\varepsilon^e_{t+1})(1-\eta_t^{L_e})L_{e,t} \\ &+ (1-\eta_t^B)B_{f,t}\left(\omega^{HFT}\left(1-\frac{\bar{R}_t}{R_t}\right) + (1-\omega^{HFT})(1-\varepsilon^B_{t+1})\right) \\ &+ (1-\eta_t^B)B^*_{f,t}\left(\omega^{HFT}\left(1-\frac{\bar{R}^*_t}{R^*_t}\right) + (1-\omega^{HFT})(1-\varepsilon^{B^*}_{t+1})\right) \\ &+ (1-\eta_t^{IB})\left((1-\varepsilon^{ib}_{t+1})IB_{f,t} + (1-\varepsilon^{ib^*}_{t+1})IB^*_{f,t}\right)\Bigg] \end{aligned} \tag{32}$$

I.e., capital requirements due to unrecognised expected losses on a given exposure equal that part of the exposure not already covered by bank capital, $(1-\eta)$, times the expected default rate $(1-\varepsilon_{t+1})$ on any such part. In the case of government bonds a refinement is introduced. Given that bonds are tradable securities, they can either be held for trading (HFT) or held to maturity, implying different accounting treatments. In particular, the share of bonds that is HFT, ω^{HFT}, is subject to impairments whenever the yield currently demanded by market participants R_t is higher than the average promised interest rate on those bonds, $\bar{R}_t$, as set in the past when the bonds were originally issued.

Given Equations 28, 30, 31 and 32, we have that Inequation 29 is equivalent to:

[8] As such, if a bank's (core equity) tier 1 ratio is set at 10.5% and the credit risk weight on a given exposure is set at 50%, then the effective risk weight on that exposure is set at 10.5% × 50% = 5.25%.

[9] Impairments are born of the difference between the book value of exposures, as included e.g. in Equation 28, and their fair value, which needs to account for changes in the present value in the case of securities held for trading, or of expected losses in the case of debt exposures held to maturity. These expected losses and impairments, being unaccounted for elsewhere in the model, must be recognized for capital requirements purposes in Equation 30.

$$
\begin{aligned}
D_{h,t}+IB_{f^*,t} \leq \rho_f \Pi_t \big(&D_{h,t-1}+IB_{f^*,t-1}-L_{h,t-1}-L_{e,t-1}-B_{f,t-1}-B^*_{f,t-1}-IB^*_{f,t-1}-CB_{f,t-1}\big) \\
&+ L_{h,t} + L_{e,t} + B_{f,t} + B^*_{f,t} + IB^*_{f,t} + CB_{f,t} \\
- (1-\rho_f) \Bigg(&\eta_t^{L_h} L_{h,t} + \eta_t^{L_e} L_{e,t} + \eta_t^{B} \left(B_{f,t} + B^*_{f,t}\right) + \eta_t^{IB} \left(IB_{f,t} + IB^*_{f,t}\right) \\
&+ E_t \Bigg[(1-\varepsilon^b_{t+1})(1-\eta_t^{L_h}) L_{h,t} + (1-\varepsilon^e_{t+1})(1-\eta_t^{L_e}) L_{e,t} \\
&+ (1-\eta_t^B) B_{f,t} \left(\omega^{HFT}\left(1-\frac{\bar{R}_t}{R_t}\right) + (1-\omega^{HFT})(1-\varepsilon^B_{t+1})\right) \\
&+ (1-\eta_t^B) B^*_{f,t} \left(\omega^{HFT}\left(1-\frac{\bar{R}^*_t}{R^*_t}\right) + (1-\omega^{HFT})(1-\varepsilon^{B^*}_{t+1})\right) \\
&+ (1-\eta_t^{IB}) \left((1-\varepsilon^{ib}_{t+1}) IB_{f,t} + (1-\varepsilon^{ib^*}_{t+1}) IB^*_{f,t}\right) \Bigg] \Bigg)
\end{aligned} \tag{33}
$$

Besides being subject to a regulatory constraint expressed in Equation 33, banks find it costly to deviate from a target (steady-state) leverage ratio:

$$
\begin{aligned}
AC_{K,t} &= \frac{a_K}{2} \left(\frac{Assets_{f,t}}{K_{f,t}} - \frac{Assets_f}{K_f} \right)^2 \\
&= \frac{a_K}{2} \left(\frac{Liabilities_{f,t}}{K_{f,t}} - \frac{Liabilities_f}{K_f} \right)^2 \\
&= \frac{a_K}{2} \left(\frac{Liabilities_{f,t}}{KR_{f,t}} - \frac{Liabilities_f}{KR_f} \right)^2 \\
&= \frac{a_K}{2} \left(\frac{D_{h,t} + IB_{f^*,t}}{\rho_f \Pi_t KR_{f,t-1} + (1-\rho_f)(RWA_{f,t} + EL_{f,t})} - \frac{D_h + IB_{f^*}}{KR_f} \right)^2
\end{aligned} \tag{34}
$$

where the second equality follows from the fact that $Assets_{f,t} = K_{f,t} + Liabilities_{f,t}$, the third equality from the fact that β_f is calibrated in such a way that Inequation 29 holds with equality in a neighbourhood of the steady state, and the fourth equality from Equation 30.[10]

One the one hand, Equation 34 reflects banks' disinclination to hold too much capital relative to total assets. This is consistent with the well-established observation in the banking literature according to which banks behave as if capital is costly. Besides the usual corporate finance argument that debt can boost the risk-adjusted return on equity by increasing the tax shield, there are also bank-specific reasons that may render debt a cheaper funding alternative when compared with capital. These include the possibility of banks enjoying pricing power in the market for deposits, as well as that of government bail-outs, the latter (partly) protecting bank's creditors, including depositors, who may therefore accept a lower rate of remuneration.

On the other hand, too little capital relative to total assets may also prove costly for banks via the unflattering effect it may have on a bank's solvency position when compared with its peers. For these reasons, Equation 34 postulates a target steady-state leverage ratio from which banks avoid deviating according to intensity parameter $a_K > 0$.

2.3.1 Banks' bond portfolio manager

Banks' head offices communicate to bond portfolio managers i) competitively-priced bond yields $\tilde{R_f}$ and $\tilde{R^*_f}$, as given by Equations 83, 84, and 85 in Appendix B, as well as ii) their geographical

[10] The autoregressive term $\rho_f \Pi_t KR_{f,t-1}$ is assumed to be taken as given by banks in their intertemporal optimization problem. This assumption, which does not materially affect the model structure, avoids introducing unnecessary algebraic complication in banks' first order conditions.

investment preferences in terms of an investment share parameter $0 < \omega_f^B < 1$ and willingness to reallocate their bond holdings across regions in response to yield differentials, $\sigma_f^B > 0$. Portfolio managers maximize a weighted average of "excess" gross returns on domestic ($R/\tilde{R}_f$) and foreign ($R^*/\tilde{R}_f^*$) bonds under a CES framework incorporating the aforementioned preferences:

$$\max_{B_{f,t},B_{f,t}^*} \left(\left(\omega_f^B\right)^{\frac{1}{\sigma_f^B}} \left(\frac{R_t}{\tilde{R}_{f,t}} B_{f,t} \right)^{\frac{\sigma_f^B-1}{\sigma_f^B}} + \left(1-\omega_f^B\right)^{\frac{1}{\sigma_f^B}} \left(\frac{R_t^*}{\tilde{R}_{f,t}^*} B_{f,t}^* \right)^{\frac{\sigma_f^B-1}{\sigma_f^B}} \right)^{\frac{\sigma_f^B}{\sigma_f^B-1}} \tag{35}$$

subject to

$$\begin{aligned} B_{f,t} + B_{f,t}^* = BP_{f,t} \Leftrightarrow \\ P_t^B \frac{R_t}{\tilde{R}_{f,t}} B_{f,t} + P_t^{B^*} \frac{R_t^*}{\tilde{R}_{f,t}^*} B_{f,t}^* = BP_{f,t} \end{aligned} \tag{36}$$

where B_f denotes domestic government bonds held by domestic banks, B_f^* their holdings of foreign government bonds, BP_f their total sovereign bond holdings, $P_t^B = \frac{\tilde{R}_{f,t}}{R_t}$ and $P_t^{B^*} = \frac{\tilde{R}_{f,t}^*}{R_t^*}$.

It is additionally assumed that competitive pressures imply that there are no excess yields on average in the steady state:

$$\frac{\frac{R}{\tilde{R}_f} B_f + \frac{R^*}{\tilde{R}_f^*} B_f^*}{BP_{f,t}} = R^{BP} = 1 \tag{37}$$

It should be noted that, in pricing government bonds, banks' head offices and their portfolio managers help determine required quarterly returns in a market equilibrium each period. This does not mean, however, that government bonds are in general one-period securities. As discussed in Subsection 2.4, the average duration of government bonds is calibrated to available evidence. However, as bonds are tradable securities, market participants freely exchange and reprice outstanding bonds every period.

2.3.2 Banks' interbank loan portfolio manager

As in the case of government bonds, banks' head offices transmit to interbank loan portfolio managers their investment preferences in terms of geographical portfolio shares $0 < \omega^{IB} < 1$ and elasticity of substitution among regions $\sigma_f^{IB} > 0$. As regards the pricing of interbank loans to domestic (IB_f) and foreign banks ($IB_{f,t}^*$), head offices first determine the respective competitive interest rates, as per Equations 86 and 87 of Appendix B. The latter pricing equations take into account two forms of default-related costs: i) expected loss rates in the following period - which, given a continuum of banks, will be exactly realized by the law of large numbers - and ii) costs from holding capital against those expected losses. The assessment of default-related costs allows head offices to produce net, default-corrected yields for domestic ($\tilde{R}_f^{IB}$, as given by Equation 101 in Appendix B) and foreign interbank lending ($\tilde{R}_f^{IB^*}$, as given by Equation 102), which are transmitted to portfolio managers for aggregate return maximization under a CES framework:[11]

$$\max_{IB_{f,t},IB_{f,t}^*} \left(\left(\omega^{IB}\right)^{\frac{1}{\sigma_f^{IB}}} \left(\tilde{R}_{f,t}^{IB} IB_{f,t} \right)^{\frac{\sigma_f^{IB}-1}{\sigma_f^{IB}}} + \left(1-\omega^{IB}\right)^{\frac{1}{\sigma_f^{IB}}} \left(\frac{\tilde{R}_{f,t}^{IB^*}}{e_t} IB_{f,t}^* \right)^{\frac{\sigma_f^{IB}-1}{\sigma_f^{IB}}} \right)^{\frac{\sigma_f^{IB}}{\sigma_f^{IB}-1}} \tag{38}$$

subject to

[11] It is worth noting that the meaning of $\tilde{R}_f^{IB}$ and $\tilde{R}_f^{IB^*}$ is not therefore equivalent to that of $\tilde{R}_f$ and $\tilde{R}_f^*$, as the interest rates considered by interbank portfolio managers are default cost-corrected, while those considered by bond portfolio managers are not. The reason for this difference in modeling approaches is explained below.

$$
\begin{aligned}
IB_{f,t} + IB^*_{f,t} &= IBP_{f,t} \Leftrightarrow \\
P^{IB}_{f,t}\tilde{R}^{IB}_{f,t}IB_{f,t} + P^{IB^*}_{f,t}\frac{\tilde{R}^{IB^*}_{f,t}}{e_t}IB^*_{f,t} &= IBP_{f,t}
\end{aligned}
\tag{39}
$$

where $e_t > 0$ is a relative country risk premium $P^{IB}_{f,t} = \frac{1}{\tilde{R}^{IB}_{f,t}}$, $P^{IB^*}_{f,t} = \frac{e_t}{\tilde{R}^{IB^*}_{f,t}}$ and IBP_f are the total interbank lending amounts approved by head offices.

Domestic interbank loans, which are in zero net supply from the viewpoint of the consolidated domestic banking sector, are modeled as a share ib_f of domestic loans to the household and corporate sectors, and admit exogenous shocks:

$$
IB_{f,t} = ib_f \times (L_{h,t} + L_{e,t})\,\varepsilon^{IB_f}_t \tag{40}
$$

Two aspects should be discussed regarding the workings of the interbank portfolio management mechanism. The first relates to the relative country risk premium e_t. This premium is assumed not to exist in the steady state (i.e., $e = 1$), but to be otherwise priced in by portfolio managers as a market equilibrium mechanism whenever a region's demand for interbank loans exceeds the other region's willingness to supply them. As will be seen in Section 4 this will often occur when a region's net foreign asset (NFA) position increases with respect to the other region. However, differently from other devices found in the literature, the link between country risk and the NFA is not mechanistically set in a dedicated equation, but rather emerges as a pure general equilibrium phenomenon. Besides relative NFA positions, among the key drivers of country risk is the willingness of portfolio managers to reallocate interbank lending across regions in response to relative returns, as given by the CES parameter σ^{IB}_f. As such, allowing for time variation in the CES and share parameters as a function of exogenous shocks readily permits capturing the shifts in risk attitudes and flight-to-safety phenomena that characterised the 2009-14 sovereign debt crisis in the euro area.

The second aspect relates to discounting default-related costs from the competitive interest rates determined by head offices. This choice is motivated by the fact that portfolio managers would tend to otherwise naively invest in the interbank loans commanding the highest promised return, notwithstanding the fact that those returns will fail to materialise in the subsequent period. This formulation also constitutes an alternative to the "excess yield" approach seen in the previous subsection. The technical reason for the different modeling approaches lies in the fact that, while "excess yields" can be identified separately in each sovereign debt market, country risk premia can only be identified in relative terms in the model.

2.4 The government sector

The government raises lump-sum taxes T from each type of household in proportion to their size (as determined by ω_s), acquires a share of the final good to conduct government expenditure G, manages its outstanding debt amounts B on which it pays average gross interest $\bar{R}$, and receives the central bank profits DIV_{CB} (or, conversely, recapitalises central bank losses) each period. The government respects the following budget constraint each period:

$$
P_tG_t + \bar{R}_{t-1}B_{t-1} = B_t + P_tT_t + DIV_{CB,t} \tag{41}
$$

Government expenditure is constant as a fraction g of steady-state GDP, safe for exogenous expenditure shocks ε^{gy}_t:

$$
\frac{G_t}{Y} = g\varepsilon^{gy}_t \tag{42}
$$

Equation 42 assumes that government spending does not change in real terms, thus imparting a degree of countercyclicality and macroeconomic stabilisation role to fiscal policy. As regards tax policies, the government sets the tax-to-GDP ratio t_t to eventually stabilise the government debt-to-GDP ratio b, and also possibly in response to the business cycle and financial market conditions:

$$\ln\left(\frac{t_t}{t}\right) = t_1 \ln\left(\frac{b_{t-1}}{b}\right) + t_2 \ln\left(\frac{Y_t}{Y}\right) + t_3 \ln\left(\frac{R_t/R_t^{EA}}{R/R^{EA}}\right) + \varepsilon_t^{\zeta} \tag{43}$$

where $t_1 > 0$ is a parameter capturing the speed at which the government stabilises the debt ratio towards its steady-state value, t_2 is a parameter allowing for (counter)cyclical tax policies, $t_3 \geq 0$ is a parameter capturing governments' reaction to marginal funding costs and ε_t^{ζ} is a tax policy shock. The effect associated with the t_3 parameter is consistent with evidence from the literature (see, e.g., Meyermans (2019)) according to which euro area governments have tended to tighten fiscal policies when confronted with rising spreads. Its inclusion allows, in particular, to study the impact of the introduction of a common sovereign debt instrument on market discipline, as such instruments may alter a sovereign's marginal funding cost (see, e.g., Giudice et al. (2019)).

Total government debt is held by domestic and foreign banks:

$$B_t = B_{f,t} + B_{f^*,t} \tag{44}$$

Government default risk ε_t^B is linked to sovereign probabilities of default PD, which in turn are linked to the expected debt ratio:

$$\varepsilon_t^B = (1 - PD_{G,t} \times LGD_G) \tag{45}$$

$$PD_{G,t+1} = E_t \left[\exp\left(p_1 \left(\frac{B_{t+1}}{4 \times Y_{t+1}}\right)^{p_2}\right) - 1 + \varepsilon_t^{pd}\right] \tag{46}$$

where $0 < LGD \leq 1$ is a loss given default parameter capturing the percentage loss imposed on bondholders in the event of sovereign default, while p_1 and p_2 are curvature parameters describing the non-linear relationship between default risk and the government debt ratio.

Each period the government faces gross financing needs (GFN) associated with the roll-over of maturing bonds and, possibly, a fiscal deficit:

$$GFN_t = PtB_t - P_{t-1}B_{t-1} + \frac{1}{m}P_{t-1}B_{t-1} \tag{47}$$

where m is the average maturity of government bonds expressed in terms of quarters. New government debt linked to GFN is issued at prevailing market rates R_t and feeds into average rates as follows:

$$\bar{R}_t = \frac{\left(\frac{m-1}{m}P_{t-1}B_{t-1}\right)\bar{R}_{t-1} + (GFN_t)\,R_t}{\frac{m-1}{m}P_{t-1}B_{t-1} + GFN_t} \tag{48}$$

Equations 47 and 48 are based on the assumption that government bonds mature randomly with probability $1/m$ each quarter. Such a simplifying assumption, which can be found e.g. in Chatterjee and Eyigungor (2012), is a useful aggregation device allowing us to keep track of just an average and a marginal government interest rate, thus avoiding the inclusion of numerous state variables, each one linked to a particular bond issuance. At the same time, this approach allows for a gradual pass-through of marginal rates to average interest rates that is consistent with observable government bond duration. Finally, it is worth noting that exogenous term premia could be trivially included and linked to average bond duration m, although we abstract from such premia in the present version of the model.

2.5 The common monetary authority

The common monetary authority sets the policy rate R_t^{EA} on the deposit facility of the central bank in order to meet a union-wide inflation target Π^{EA} and to stabilise union-wide output Y_t^{EA} according to a Taylor rule:

$$\ln\left(\frac{R_t^{EA}}{R^{EA}}\right) = \ln\left[\left(\frac{R_{t-1}^{EA}}{R^{EA}}\right)^{\rho_R} \left(\left(\frac{\Pi_t^{EA}}{\Pi^{EA}}\right)^{\gamma_\Pi} \left(\frac{Y_t^{EA}}{Y^{EA}}\right)^{\gamma_Y}\right)^{1-\rho_R}\right] + \varepsilon_t^R \tag{49}$$

where

$$\Pi_t^{EA} = n\Pi_t + (1-n)\Pi_t^* \tag{50}$$

and

$$Y_t^{EA} = nY_t + (1-n)Y_t^* \tag{51}$$

The $0 < \rho_R < 1$ parameter captures the degree of policy rate smoothing, $\gamma_\Pi > 1$ and $\gamma_Y \geq 0$ are the weights attached by the monetary authority to price stability and output stabilisation, respectively, and ε_t^R is a monetary policy shock.

The monetary authority also has a balance sheet, with reserves as liabilities and government bonds as possible assets. This balance sheet produces a net income stream that is rebated to euro area governments every period according to a distribution key based on their relative economic size, as determined by n.

2.6 The balance of payments

The balance of payments identity equals the nominal trade balance $P_t TB_t$ to the sum of (the negative of) the income account and the financial account:

$$\begin{aligned} P_t TB_t = {} & \bar{R}_{t-1} B_{f^*,t-1} + \frac{1-n}{n} e_{t-1} R^{IB}_{f^*,t-1} \varepsilon_t^{ib} IB_{f^*,t-1} + \frac{1-n}{n} B^*_{f,t} + IB^*_{f,t} + CB_{f,t} + K_{CB,t} \\ & - \Bigg(\frac{1-n}{n} \bar{R}^*_{t-1} B^*_{f,t-1} + \frac{R^{IB^*}_{f,t-1}}{e_{t-1}} \varepsilon_t^{ib^*} IB^*_{f,t-1} + B_{f^*,t} + \frac{1-n}{n} IB_{f^*,t} \\ & + R^{EA}_{t-1} CB_{f,t-1} + K_{CB,t-1} + DIV_{CB,t} \Bigg) \end{aligned} \tag{52}$$

where K_{CB} denotes the capital position of the central bank, a "foreign" asset owned by euro area governments. The trade balance is in turn given by exports minus imports:

$$P_t TB_t = \frac{1-n}{n} P_t^Y Y_{M^*,t} - P_t^{Y^*} Y^*_{M,t} \tag{53}$$

3 Calibration

The model parameters are calibrated based on: i) observable data for the 11 largest euro area Member States; ii) standard values from the DSGE literature; and iii) results from microeconomic studies and other relevant literature. The core region captures an aggregate comprising Germany, France, the Netherlands, Belgium, Austria and Finland. The periphery region aggregate comprises Italy, Spain, Portugal, Greece and Ireland. We use region-specific values where allowed by the data sources, and keep parameters symmetric across regions otherwise. Table 2 in Appendix D lists the model parameter values.

Parameters derived from observable data generally take 2019 as the reference year.[12] This year choice is motivated by the fact that the economic turbulence caused by the covid-19 crisis (and the subsequent Russian invasion of Ukraine) render data for more recent years less representative of a possible steady state. Eurostat data has been used to calibrate: the relative size n of the periphery regional bloc; the share g of government spending; the average maturity m of government debt;[13] a corporate loan-to-GDP ratio of 78% in each region through the γ^e parameter; and a housing stock-to-GDP ratio[14] of 1.53 in the periphery and of 1.65 in the core through the ν^h parameter. Data provided by the European Banking Authority (EBA) in its Q4

[12]In some cases, parameter values are based on averages taken over 2019 and previous years, for robustness sake.

[13]For Austria, the source was the OeBFA.

[14]The value of the housing stock is net of land value.

2019 Risk Dashboard informed the expected loss rates on household (ε^b) and corporate loans (ε^e), while the steady-state loss rate on interbank loans (ε^{ib}) was set to zero by assumption. EBA data from its 2019 Transparency Exercise informed: the risk weights η^B on sovereign bonds; the portfolio share of domestic sovereign bonds (ω_f^B); the share of sovereign bonds held for trading (ω^{HFT}); the portfolio share of domestic interbank lending (ω^{IB}); and the amount of domestic interbank lending as a percentage of corporate and household loans, ib_f. European Central Bank (ECB) data was used to set: the risk weights on household (η^{L_h}), corporate (η^{L_e}) and interbank loans (η^{IB});[15] a euro area-wide household loan-to-value ratio of 81% via the γ^b parameter;[16] and the steady-state central bank reserves as a percentage of other bank assets, cb_f.[17] The share of imports in domestic demand, ω^M, is derived from bilateral trade data for 2015 available from the OECD TiVA database. We choose to rely on trade-in-value-added data, rather than on gross trade flows, as the former is more consistent with the trade specification described in Subsection 2.2.4 and, in particular, in Equation 22, where foreign exports have no import content and are thus, in effect, in foreign value added terms. The housing transaction costs parameters s_H are region-specific and derived from Global Property Guide data.[18]

A set of parameters was calibrated based on standard values found in the DSGE literature. We relied, in particular, on three institutional workhorse DSGE models of the euro area employed by the ECB and the European Commission, and described in Coenen et al. (2018), Albonico et al. (2019) and Burgert et al. (2020). The parameters calibrated based on these models are: the capital income share α; the discount factors β_b and β_s; the Taylor rule coefficients γ_Π, γ_Y and ρ_R; the capital depreciation rate δ_k; the consumption habits parameter h; the CES of intermediate good varieties θ; the CES of imports ν; the weight of hours worked in the utility function ν^n; the corporate investment adjustment costs s_k;[19] the Calvo price stickiness parameter ϕ; the inverse of the Frisch elasticity of labour supply φ; the constant relative risk aversion of households χ; and the share of saver households ω_s. Some banking and construction sector parameters were informed by specialised models. As such, the DSGE model with a banking sector of Iacoviello (2015) was used to calibrate the persistence parameters ρ_b, ρ_e and ρ_f, while the DSGE model with a housing sector of Pataracchia et al. (2013) was used to calibrate the housing depreciation rate δ_H and the construction technology parameter γ.[20] We relied on Quint and Rabanal (2014) for the housing investment adjustment costs parameter s_{h_1} and for the CES of the interbank loan portfolio σ_f^{IB}.[21]

Non-DSGE literature and microeconomic studies informed a subset of parameters, notably those influencing the financial dynamics of the model. The parameter governing the strength of the penalty from deviating from target bank capital ratios, a_K, was derived from literature on the effects of regulatory changes to bank capital requirements. In fact, the latter provide natural experiments where banks are temporarily dislodged from their target capital ratios by having to adjust to new (usually higher) target ratios.[22] In order to set the value of a_K we simulate the

[15] Equality of steady-state inflation rates across regions requires (via Equation 109 in conjunction with other steady-state equations) that η^{IB} be the same in both regions. For this reason, we use euro area-wide rather than region-specific values for η^{IB}.

[16] As per the loan-to-value ratio at origination derived from the 2019 SSM credit underwriting data collection exercise and published in Lang et al. (2020).

[17] Given that the model's steady state does not include central bank asset purchases, the calibration of reserves was based on average figures taken from 2001 to 2013 (the year preceding the introduction of the ECB's asset purchase programme).

[18] Source: `http://www.globalpropertyguide.com/transaction-costs`. Consistent with Equations 3 and 6, each s_{H_s} and s_{H_b} corresponds to half of a "round-trip", with regional figures calculated as dwelling value-weighted averages of national figures.

[19] For s_k, we rely on the original estimation of the model described in Coenen et al. (2018), i.e. the NAWM model of Christoffel et al. (2008), whose parameter value is closer to those typically found in the wider literature.

[20] The value of the γ parameter is also consistent with land representing 25% of total housing-related wealth, a figure broadly in line with empirical estimates.

[21] While Quint and Rabanal (2014) use a different approach for determining international risk premia - namely a reduced-form equation linking risk premia to the foreign debt ratio -, their estimated parameter κ_B can be mapped to σ_f^{IB} on account of the latter's role in generating country risk in our model.

[22] It is worth noting that, as mentioned in European Central Bank (2015), DSGE models with a banking sector tend to underestimate the transition costs to higher capital requirements when compared to micro studies. At the same time, such DSGE models may arguably overestimate the long-run impact of hikes in capital requirements by failing to distinguish between short-run and long-run effects. Our modeling strategy imposes consistency with

effect on loan supply of a 1 pp increase in capital requirements that is progressively incorporated by banks into a new target capital ratio. Under our calibration, such a shock reduces bank loans by 1.5% in the first 9 months, and by 2% on average during the first three years, in line with the results for European banks of Mésonnier and Monks (2015) and Maurin and Toivanen (2012).[23]

Among the parameters derived from the non-DSGE literature are also those governing the strength of the LIA constraints, s_b and s_e. As regards the corporate LIA parameter s_e, it was calibrated so that a credit supply shock reducing corporate lending by an average of 1% in the first year produces a reduction of approximately 0.8% in corporate investment and in the corporate investment ratio (I_e/K) during that period. This co-movement is consistent with the range of results found in the literature, such as those in Degryse et al. (2019) for Belgium, Cingano et al. (2016) for Italy, Amiti and Weinstein (2018) for Japan and Claessens et al. (2014) for recessions associated with credit crunches.[24] As regards the LIA parameter of households, s_b, it was calibrated by drawing on Favara and Imbs (2015), Bayoumi and Melander (2008) and Claessens et al. (2014). Under our parameter choice a 1% positive shock to household lending leads to an average increase in house prices of approximately 0.2% in the first year.[25]

The CES of bank's bond portfolio, σ_f^B, was set so that the model mimics the estimated impact of central bank asset purchases on bond prices. Under our calibration, acquiring 10% of euro area government debt lowers annual yields by 24 bps, equivalent to the value found by Altavilla et al. (2015) in their event study (one-day change) for the euro area.[26] This figure is on the lower end of available estimates for the euro area.[27] However, the particular circumstances under which asset purchases have taken place may have potentiated their effect, motivating the selection of a conservative figure.[28]

The share of banks locked in a strategic game with the domestic sovereign, ω^f, was calibrated so as to reproduce the home bias dynamics observed during the European sovereign debt crisis. As such, under our calibration a 1 pp increase in sovereign debt spreads is associated with a 3.65% increase in the relative share of domestic sovereign bond holdings.[29]

The value of the sovereign risk curvature parameters, p_1 and p_2, was adapted from the analysis in Monteiro and Vasicek (2019). The values of the tax rule parameters t_1 and t_3 were, in turn, derived from the fiscal reaction function literature. Concretely, t_1 was set so that a 1 pp increase in the government debt-to-GDP ratio elicits a 0.05 pp increase in the government's primary balance as a percentage of GDP. This sensitiveness is consistent with the average estimates

micro studies, while our simulation strategy in Subsection 4.4 purges long-run effects from short-term transition costs. We return to the discussion of the distinction between short-run and long-run effects of macroprudential policy in that subsection.

[23]Our calibrated impact sits towards the lower end of the range found in the literature. For instance, it is weaker than that estimated in Aiyar et al. (2014) and in Noss and Toffano (2016) for UK banks, or that estimated by Brun et al. (2013) for French banks. However, given that such microeconomic studies often cover periods of economic fragility that can potentiate the immediate negative effects of an increase in capital requirements, we find it preferable to focus on the lower end of available estimates.

[24]The results found in the literature need to be translated into terms that are comparable among themselves and with the model. For instance, credit shocks in Degryse et al. (2019) where translated from standard deviations to percentage changes, and the regression results of Cingano et al. (2016) were applied to the in-model K/L_e ratio. Different horizons also complicate the comparisons. As such, while we considered co-movements during the first year, the horizons considered in Cingano et al. (2016) and Claessens et al. (2014) are longer.

[25]This figure is somewhat higher than the 0.12% found in Favara and Imbs (2015) for the US, but considerably lower than the approximately one-to-one co-movement between credit and house prices found by Claessens et al. (2014) for recessions associated with credit crunches. As regards Bayoumi and Melander (2008), our calibration produces results that are: i) approximately twice the estimated long-run impact on spending in residential investment of a one monetary unit increase in lending and ii) approximately half the same estimated impact when the variable of concern is spending on durable goods.

[26]Here and elsewhere, results were made comparable by considering asset purchases in percentage of total debt.

[27]For instance, it is lower than the effect found over a two-day window in the same paper by Altavilla et al., or the results in Andrade et al. (2016), De Santis (2020) and Monteiro and Vasicek (2019).

[28]As regards estimates for US, our simulated impact is close to that of Vayanos and Vila (2021), and somewhat stronger than that implied by the results in Krishnamurthy and Vissing-Jorgensen (2012).

[29]This is the co-movement observed in the periphery region from the first quarter of 2010 to the second quarter of 2012, based on EBA data for sovereign bond holdings (with Greece excluded from the sample due to its particular circumstances involving the restructuring of sovereign debt). While there is no similar historical experience to draw from regarding the core region, we assume the same elasticity between spreads and domestic bond holdings as that of the periphery.

found in the literature review conducted by Checherita-Westphal and Žďárek (2017). As regards t_3, it was set so that a 1 pp increase in the government bond spread elicits a 0.3 pp increase in the primary balance, consistently with the results in Meyermans (2019), and in Mauro et al. (2015) for the post-World War II period.

The relative value of the discount factors β are such that all borrowing constraints bind in a neighbourhood of the steady state. In particular, the discount factor of entrepreneurs, β_e, was set below that of saver households and bankers, and has a value similar to that of Breuss et al. (2015). In addition, β_f was set so that banks earn a real return on equity of 9% in the steady state, in line with estimates for the cost of equity of euro area banks.[30]

A small number of parameters are assumed, or follow their own rationale. Quarterly steady-state government debt-to-GDP ratios b are set in line with the Maastricht Treaty reference figure of 60% in the core region, and consistently with an assumed 90% annual ratio in the periphery region.[31] Target inflation rate Π^{EA} is assumed to be 2%, in line with the ECB's monetary policy strategy announced in 2021. Fixed costs F are set so that the profits of intermediary firms are zero in equilibrium. The housing investment parameter s_{h_0} is set so that a standard law of motion, $H_t = (1 - \delta_H)\, H_{t-1} + I_{h,t}$, applies to the housing stock in the steady state. The LGD_G parameter is set at a conventional 60%, and t_2 is set to zero by assumption, so that real government expenditure does not respond to the business cycle.

4 Macrofinancial dynamics

In this section we rely on a first-order approximation of our calibrated model to study the effects of i) standard monetary, fiscal and productivity shocks, ii) credit risk shocks affecting the private and government sector, iii) changes in macroprudential policy, iv) capital flights in a recession and v) an unconventional monetary policy shock. The impact from introducing a common sovereign debt instrument is also discussed, particularly in connection with point iv).

4.1 Expansionary monetary, fiscal and productivity shocks

We begin by examining the basic properties of the model with a simulation of three standard expansionary shocks: a 10% increase in government expenditure in the domestic region, a 1 pp cut in the policy rate and a 1% increase in the TFP of the domestic region. The respective impulse response functions (IRFs) are plotted in Figure 1 of Appendix D for a selection of key economic variables covering the two regions, as well as the euro area aggregate.

All three shocks increase output in the domestic region, as well as in the euro area aggregate. Monetary policy loosening, being a symmetric shock, tends to produce similar responses in both regions. In particular, it boosts output, consumption and international trade on impact and in subsequent quarters. The associated internal demand expansion generates strong inflationary pressures which soon lead to a reversal in the policy rate.[32] Due to the forward-looking behaviour of entrepreneurs and the existence of adjustment costs, corporate investment does not react positively to the transitory interest rate cut on impact, but rather anticipates the forthcoming policy rate correction.

While the shocks to domestic government expenditure and productivity are both expansionary for the domestic economy, they carry different implications for other macroeconomic variables and for the foreign economy. Due to Ricardian behaviour, crowding out effects and a tightening reaction in monetary policy, an increase in government expenditure does not boost domestic private consumption in a sustained manner, and has an initial dampening effect on euro area corporate investment. The inflationary pressures it generates lead to an increase in

[30] See, e.g., European Banking Authority (2019).

[31] Actual government debt ratios in 2019 were 73% in the core region and 116% in the periphery region.

[32] It should be noted that, differently from the expenditure and productivity shocks which have autoregressive parameter 0.9, the policy rate shock is assumed to have zero persistence via its autoregressive parameter. While interest rate smoothing implicit in Equation 49 lends the policy rate shock a degree of persistence, this fades away fairly quickly.

the policy rate and a decrease in the real exchange rate (RER)[33] which, together with an internal demand-led increase in imports, produces a deterioration of the trade balance and of the NFA position. The increase in import demand helps, in turn, to boost output in the foreign region on impact. Overall, these offsetting effects come together to produce a government expenditure multiplier that is, as expected, below one.

As regards the productivity shock, the expansion in aggregate supply has a deflationary effect which prompts monetary policy loosening. Firms invest more to take advantage of the higher return on capital and the favourable macroeconomic environment, while the foreign economy experiences a negative competitiveness effect that modestly dents foreign output on impact. This relative competitiveness effect is reflected in an increase of the RER and in domestic exports.

In our streamlined modeling of the government sector, changes to the government debt ratio are driven by nominal growth effects, the real interest rate on government bonds and government expenditure shocks. As such, the latter has a noticeable impact on the debt ratio, bringing it from an initial 90% to approximately 92% by the end of the second year, an increase nonetheless mitigated by the strong nominal growth effect of expansionary fiscal policy. The other shocks decrease the debt ratio via positive GDP growth, an effect that is much more marked in the case of a policy rate shock which, unlike a productivity shock, has an inflationary nature.

4.2 Credit risk shocks in the private sector

Figures 2 and 3 provide an overview of the impact of an increase in the default rates of households, entrepreneurs and banks located in the domestic region in terms of the IRFs of key economic and financial variables. The increase in the default rates of households and firms is equivalent to 5% of GDP, a magnitude comparable to that observed in periphery countries during the European sovereign debt crisis. The shock to interbank default rates is also set at 5% of GDP for comparison purposes, even though such a magnitude would be unprecedented by historical standards.

Credit risk shocks have important and persistent recessionary effects in the model. Shocks to household and corporate default rates lead to a significant drop in output in the region experiencing them, with the effect being somewhat more pronounced in the case of shocks to firms. As regards interbank default shocks, the impact is shared with the foreign region, which is directly exposed to domestic banks via cross-border interbank lending. Default shocks have a net deflationary effect by impairing the functioning of the banking sector and leading to a tightening of financial conditions. In the case of interbank default shocks, the deflationary effect is particularly marked at euro area level due to the strength of its transmission to the foreign region.

Household and corporate default shocks strongly impair investment levels in the domestic region through tighter financial conditions, a drop in collateral value and weakened internal demand. However, a rebound begins to take hold in the second year following the initial shock for the cases under analysis.

Default on mortgages generates bank repossession-like phenomena whereby borrower households relinquish a large share of their housing stock, which is acquired by the bank-owning households in a context of depressed house prices and investment. Domestic consumption levels drop with the impact of corporate and interbank default, but remain robust in the case of household default. This is due to the initial positive effect that mortgage default has on the disposable income of borrowers, as well as to the latter's redirection away from housing investment towards consumption of non-durables. At the same time, while the disposable income of bank-owning lenders takes a severe hit on impact, it soon recovers as banks protect themselves against default and buttress their profitability by revising interest rates upwards.

While the foreign region weathers well household and corporate default shocks in its trading partner, and even benefits from a drop in the euro area-wide policy rate, this is not the case in the presence of interbank default, which can impair the functioning of the foreign financial sector and thus have an important negative impact on output, consumption and investment levels. In

[33] We define the RER as the price level of final goods in the foreign economy relative to that of the domestic economy. I.e., $rer_t = P_t^*/P_t$.

fact, as evidenced in comparative investment dynamics, default in the domestic banking sector can in some respects be more detrimental to the foreign region than to the domestic one, as it implies a wealth transfer from the former to the latter.

By depressing domestic demand and temporarily increasing the RER, household and corporate default shocks initially improve the trade balance, thereby lending a degree of support to the domestic economy. Interbank default shocks, however, have a more symmetric impact across economies and a weaker net impact on trade. All the default shocks increase the NFA position of the domestic economy in the first year, which in the case of household and corporate default shocks is due to the emergence of a trade surplus. Due to a sustained improvement in the NFA position, the relative country risk of the domestic economy tends to decrease when in the presence of corporate and household shocks.[34] At the same time, country risk increases with interbank default in connection with a retrenchment of cross-border interbank lending.

Focusing now on the response of interest rates, it should be noted that, given the assumed ability of banks to reprice their lending rates every period, they are able to insure themselves against loan losses stemming from heightened expected default rates in the periods following the initial shock by raising interest rates. This can be observed in Figure 3 where the interest rate on the asset class experiencing the default shock sees its nominal interest rate increase significantly, even as the monetary authority lowers the euro area-wide nominal risk-free rate in a supportive policy move. This risk premia-related increase in financial discount rates contributes, however, to lower the present value of the respective collateral, thereby having a direct effect on credit provision and inducing financial accelerator dynamics. Due to the negative impact of default on inflation and bank balance sheets, real interest rates also increase in loan classes not experiencing losses, thus contributing to tighter overall financial conditions.

It should be further noted that the ability to reprice private-sector loans does not render banks immune to the costs of default. Besides suffering unexpected losses on impact, they are further constrained to adjust their solvency and leverage positions to deal with a riskier environment that is causing valuation losses on their assets and exacting higher capital requirements. This is reflected, in particular, in the regulatory need to provision for expected losses. In practice, default losses induce banks to try and support their tier 1 ratios, which can be severely affected on impact, and to adjust leverage ratios towards target values. The speed at which tier 1 ratios are to be repaired is assumed to be essentially determined by supervisory authorities, as reflected in the ρ_f parameter of Equation 30. While tier 1 ratio repair is not instantaneous, it occurs quickly in our calibration, in the first two quarters following the default shock. At the same time, the default-induced increase in capital requirements moves the leverage ratio given by Equation 34 away from its target value. The eventual adjustment of the tier 1 and leverage ratios is achieved not only via capital injections from shareholders, but also by an asset downsizing and a tightening of credit conditions, with particular incidence in the riskier asset classes (namely, the one experiencing default, and others commanding higher risk weights). The overall persistence of credit tightening effects is partly determined by the quarterly autoregressive parameter of the default shock, which was set to 0.9.

Finally, one can observe that default shocks can significantly deteriorate the government debt ratio via their strong negative impact on real and nominal growth, with this effect reversing over time as the real government interest rate turns negative (itself a consequence of the relative safety and favourable regulatory treatment of government bonds compared to other asset classes).

4.3 Credit risk shock in the sovereign sector

After having examined the effects of credit risk shocks in the private sector, we turn now to a situation where the domestic sovereign experiences heightened credit risk. This is modeled as a 1 pp increase in the quarterly probability of default, i.e., as a shock to ε_t^{pd} in Equation 46, with autoregressive parameter equal to 0.9.

An increase in domestic sovereign risk generates losses on the balance sheets of banks in the

[34] It should be noted that country risk is strictly defined in the context of the model and does not account for any form of default risk, which is covered by dedicated variables. As such, a negative performance of the domestic economy does not necessarily generate country risk, especially if it improves the NFA position.

two regions, as evidenced by a sharp drop in tier 1 ratios on impact. These losses arise both in the case of bonds held for trading (where an increase in sovereign yields lowers their market value) as well as in bonds held to maturity (where banks need to provision for higher expected losses). As in the case of private sector default risk, the effect is contractionary and deflationary, being more marked in the domestic region (where home bias in banks' bond holdings implies a larger exposure), but also directly affecting the foreign region, which is also exposed to domestic sovereign bonds. Private consumption is affected in both regions and there is a significant contraction in investment in the domestic region in the first two years. The domestic region, being the more impacted of the two, embarks on a external trade-led recovery, supported by a favourable RER.

As regards financial variables, tighter financial conditions mean a drop in mortgage and firm loans, as well as a heightened interest rate on domestic bonds, notwithstanding a supportive decrease in the policy rate. Country risk shoots up on impact as foreign banks fly from the domestic bond market, with domestic banks compensating for these dynamics by increasing their exposure to the domestic sovereign. Because of the home bias effect discussed in Appendix A, a share of domestic banks takes advantage of the high-yield environment by significantly increasing their demand for domestic sovereign bonds, meaning that government interest rates rise less than might be expected from a pure risk-return perspective. Notwithstanding this effect, the domestic government debt ratio is durably affected by a lower real and nominal growth path, as well as by higher interest rates.

While the existence of a common European safe asset is only explicitly simulated below, in Subsection 4.5, it is worth nothing at this point that one of its effects would arguably be to prevent sudden, sharp and asymmetric increases in sovereign risk. Thus, the simulation discussed in the present subsection can also be understood as highlighting possible benefits from introducing a common safe asset, at least as regards its canonical form as a "Eurobond", where research suggests that credit risk would remain contained, even in peak crisis periods.[35]

4.4 Permanent shocks to macroprudential policy

Figures 5 and 6 depict the effects of two forms of macroprudential policy tightening: a permanent increase in tier 1 ratios and a permanent decrease in the maximum loan-to-value ratios of households and firms.

In a simulation of this nature, it is important to consider whether there are transition frictions or not. In Figure 5 the macroprudential shocks are applied to the euro area aggregate and no transition frictions are assumed, meaning that banks and borrowers internalise the new regulatory environment by updating their target capital and borrowing ratios along the transition path.[36] On the contrary, Figure 6 (which depicts macroprudential shocks in the domestic economy) assumes the existence of transition frictions, so that agents feel the full brunt of deviating from their target financial ratios on impact. After the initial shock, domestic banks and borrowers start updating these targets, so that 80% of the new capital ratios, and 20% of the new LTV ratios, are internalised by the end of the first year. The new targets are assumed to be fully internalised eventually, so that the economy converges to the same steady state as that of the frictionless transition in the long run.[37,38]

[35] See Monteiro (2023).

[36] This is implemented by effectively turning off the leverage and LIA constraints, so that banks and borrowers perceive to be meeting their financial targets at all times as they settle into the new steady state.

[37] The simulation is implemented in an approximate manner by assuming temporary shocks to capital requirements and LTV ratios under the usual capital ratio and LIA constraints. This approach is made possible by the fact that, as will be seen, the long-run effects of the macroprudential shocks are quite small under a frictionless transition, a situation that is thus approximately equal to having only temporary shocks.

[38] It is worth noting in this connection that one could also simulate the effects of permanent macroprudential shocks assuming that the original leverage and LIA constraints remain fully active throughout the transition *and in the new steady state*. This, however, would be theoretically inconsistent, in effect transforming business-cycle frictions into a permanent feature of the new steady state. In other words, it would imply accepting that the initial steady-state ratios used in the leverage and LIA equations are the only frictionless ones (a kind of "divine coincidence" governing the initial calibration of the model), and that any other steady state would generate a permanent drag on the economy. For this reason, we do not consider this type of simulation.

The stricter macroprudential policies under consideration generally lead to lower output, consumption, capital and investment levels in the long run. At the same time, they produce short- to medium-run deflationary dynamics, that eventually turn inflationary in the case of a negative LTV shock, as the capital stock dwindles and the supply side of the economy is affected. On the financial side, tighter macroprudential policies depress steady-state loans to households and firms, while tending to increase nominal and real lending rates for the riskiest asset class (corporate loans). However, the effects are very mild in the case of a frictionless transition, and in any case in the long run: for a 1 pp increase in euro area-wide tier 1 ratios, the long-run contraction in output is 0.04% to 0.05%, depending on the concerned region. In this case, the main long-run effect of an increase in tier 1 ratios stems from the need to fund a slightly higher share of lending with bank capital (which is relatively expensive, as it needs to be remunerated at a return on equity determined by β_f), instead of with cheaply-available deposits. Effects are comparatively stronger in the case of a permanent 1% decrease in loan-to-value ratios. This is particularly true of the housing market, which experiences a negative feedback loop whereby a lack of credit depresses housing investment, and a lack of housing investment depresses mortgage lending by eroding the value of the housing collateral. The existence of this feedback loop means that the "multiplier" on LTV ratios is greater than one, i.e., a 1% reduction in LTV ratios leads to more than a 1% reduction in mortgage lending. On a more positive note, the redirection of household budgets away from housing supports consumption in the short to medium-run.

While the effects of macroprudential policy shifts are seen to be relatively mild in the long run, they can be potent in the short run in the presence of transition frictions. This is shown in Figure 6, where a bank capital requirements shock requiring the immediate increase of the periphery's tier 1 ratio to meet that of the core's produces a decline in the periphery's GDP of up to 0.5% in the first year. The effects of a 1% decrease in LTV ratios are less sharp on impact, but more protracted, eventually leading to a trough of -0.5% in the periphery's GDP. Both types of shock have strong negative impact on corporate investment, which is larger and more persistent in the case of an LTV shock. In the presence of transition frictions, capital ratio shocks strongly impact the interest rate and loan amounts of the riskiest asset class (i.e., firm lending), while a reduction in LTV ratios is particularly detrimental for housing investment and long-term mortgage lending (though supportive of consumption in the short term).

While the assessment in this subsection focus on the costs of macroprudential policies, it does not contradict their overall net benefit. Gauging the latter would, however, require dedicated analysis capturing, inter alia, the positive effects of macroprudential policies on prevention, absorption and recovery from adverse shocks.

4.5 Capital flights in a recession, with and without a common sovereign debt instrument

Figures 7 and 8 depict the effects of a severe recession where the domestic economy suffers a 5% fall in TFP and the government responds immediately by raising expenditure by 25%. Three scenarios are plotted: in the first one, international financial market participants respond according to their baseline investor preferences; in the second one, there is a panicked response by foreign investors, who retrench into their home markets in a capital flight; in the third scenario, there is also a capital flight by foreign investors, but the euro area is endowed with a common sovereign debt instrument, in the form of a "Eurobond".

Capital flights are modeled as a 10 pp increase in the home bias parameter ω^{IB^*} of foreign interbank lenders, together with a sharp 99% reduction in the elasticity of substitution of interbank loans in both regions (i.e., a 99% reduction in σ^{IB} and σ^{IB^*}). Shocks to TFP, government spending and ω^{IB^*} are assumed to have a quarterly persistence of 90%.

The common sovereign debt instrument is introduced as a "canonical" Eurobond, i.e., a financial instrument that fully replaces existing national debt and is largely risk-insensitive. In practice, the Eurobond is modeled by assuming a very large elasticity of substitution between government bonds[39] and by setting portfolio investment shares equal to the shares of national

[39]This elasticity is infinite in theory, although setting it to a very high level produces equivalent results, while allowing the model to solve numerically without further modifications to its structural equations.

debt outstanding. This modeling strategy implies that investors cannot distinguish between issuing regions, and that sovereign bond markets are fully integrated under one price. Furthermore, the periphery's probability of default, as given by Equation 46, is set so as to be insensitive to domestic debt levels, consistently with the results in Monteiro (2023).

In the baseline scenario, the support offered by an increase in government expenditure is short-lived and eventually outweighed by the severity of the productivity shock, with the domestic economy experiencing a recession as a result. However, the expenditure shock boosts imports, which provide a growth impulse to the foreign economy, and even to the euro area aggregate in the first year following the shock. A combination of a sharply negative supply shock and a strongly positive demand shock produces acute inflationary pressures, which lead to an increase in the policy rate.

When a capital flight is added to the baseline scenario, the drop in output in the domestic economy sharpens even further. Given foreign investors' unwillingness to fund the domestic economy, country risk shoots up, tightening financing conditions. Consumption and investment drop more markedly than before, and the economy is forced to embark on an external trade-led recovery characterised by internal devaluation, a curtailment of imports and an expansion of exports. A capital flight also leads, by its very nature, to a strong retrenchment in interbank lending to the domestic economy. This forces domestic banks to also withdraw from foreign debt markets, so as to refinance the domestic economy and absorb the expansion in domestic government debt. Nominal interest rates on government bonds and interbank loans largely co-move with the policy rate, but are also driven by widening spreads between the two regions.[40] As regards the foreign economy, the sudden repatriation of capital has a overheating effect that stimulates output, consumption and inflation in the short term.

A euro area endowed with Eurobonds approximates in several respects the no capital-flight outcome explored in the first scenario, even when the interbank market is assumed to be characterized by the same level of panic seen in the second scenario. The stabilising effect of Eurobonds in a capital flight context means i) that the combined TFP and government expenditure shock remains inflationary; ii) that the drop in private consumption and housing investment is not as sharp, thus supporting welfare; and iii) that external funding remains available via the government bond market, preventing country risk from shooting up and imports from collapsing. At the same time, the presence of Eurobonds implies that the domestic region is not forced to embark on an export-led recovery, a situation which ultimately prolongs the negative effect of the crisis on output via protractedly low levels of net trade and corporate investment. Conversely, the foreign region benefits from the periphery's continued access to external funding, which props up the core's exports and output. It is also worth noting that, because of the very nature of common debt issuance, investors cannot discriminate between domestic and foreign bonds. As such, the share of periphery debt held by banks increases equally in both regions, mirroring the increasing share of periphery debt in total euro area debt brought about by the periphery's expansionary fiscal policies.

4.6 An unconventional monetary policy shock

We conclude our investigation of macrofinancial dynamics in the euro area by looking at the effects of an unconventional monetary policy (UMP) shock whereby the monetary authority acquires 10% of the outstanding government debt of each region on impact, and gradually unwinds these asset purchases thereafter at a rate of 5% per quarter.

When studying the effects of asset purchases, it is important to consider how UMP interacts with conventional Taylor rule-based monetary policy. If fact, if the purpose of UMP is to boost inflation, then policy rates cannot abide by the standard Taylor rule described in Equation 49, as monetary policy would be incongruous otherwise. I.e., it would be trying to boost inflation through asset purchases, only to see these efforts thwarted by a reactive increase in policy rates. For this reason, we combine asset purchases with forward guidance, just as the two UMP measures have been combined in advanced economies over the past decade. Concretely, we

[40] This effect is only observable in the interbank market once we take into account that the effective cross-border lending rate of the foreign economy is $e_t \times R^{IB}_{f*,t}$, i.e., a rate that includes the country risk premium e_t.

assume that the monetary authority credibly announces that the policy rate R^{EA} will remain frozen for one or two years, depending on the simulation concerned.[41,42]

Figure 9 shows the result of these simulations. Government bond purchases appreciate bond prices, lower yields and de-risk bank balance sheets, as bonds are exchanged for risk-free central bank reserves. The latter are seen to jump on impact, and to gradually decrease thereafter as asset purchases unwind. Bank balance sheets are thus strengthened through lower expected losses and valuation gains on bond holdings, which makes them pursue more expansionary credit policies, as reflected in increased lending and lower interest rates. Looser financial conditions provide, in turn, a boost to euro area inflation, consumption and output. At the same time, higher nominal growth and lower interest rates improve government debt ratios. All these effects are augmented when policy rates are frozen for two years, rather than one. In such a case, however, policy rates need to react more strongly once they are allowed to rise again in order to maintain inflation expectations anchored.[43] This results in a stronger correction, with a spike in lending rates and a dimple in output observable in the second and third years.

5 Conclusion

We have looked at the macrofinancial dynamics of a monetary union such as the euro area through the lens of a general equilibrium model enriched with financial frictions, portfolio selection mechanisms, endogenous country risk premia, relevant and regulatory-consistent financial intermediators and a detailed modeling of government bond markets and monetary policy transmission. The characteristics of our model allow for empirically-consistent properties, and we have so calibrated it and employed it to conduct a number of experiments relating to macrofinancial shocks and policy innovations.

We have seen, in particular, how household and corporate default shocks can have a lasting depressing effect on economic activity in the region experiencing them, and be of a deflationary nature by leading to a tightening of financial conditions. They can also carry specific economic implications, with mortgage defaults leading to an eventual dislocation of the housing stock from borrowers to creditors, and with lending and interest rates reacting particularly strongly in the sector directly concerned by the loan losses. While household and corporate default shocks may have only a comparatively modest effect on the trading partner economy (which sees a drop in export demand, but benefits from a cut in the policy rate), the same is not true of interbank default and of heightened sovereign risk. The latter are seen to be recessionary and deflationary forms of financial disturbance that affect financial intermediation and the real economy in both regions of the monetary union irrespective of their origin, a result that can be understood as the consequence of the direct cross-border exposures in sovereign and interbank debt markets.

We then considered the effects of macroprudential policy by simulating two types of permanent policy changes. An increase in banks' capital requirements is seen to permanently shift economies to lower output, consumption and investment paths. At the same time, it shifts loan levels downwards and the interest rate of the riskiest asset class upwards. While these effects can be potent in short run in the presence of transition frictions, they are minor in the long run and need to be weighed against the financial stability benefits that an increase in capital requirements may produce. A decrease in the maximum allowed loan-to-value ratios similarly depresses output, investment and, eventually, consumption. Its effects can be more marked in the long run than those of a capital ratio hike, particularly as regards the housing market, which can experience significant drops in investment and mortgage lending due to a negative feedback loop between housing collateral availability and lending for housing investment. As before, while long-run effects remain contained, the short term impact of tightening loan-to-value ratios can

[41] To ensure model stability and a re-anchoring of inflation expectations, agents also expect the Taylor rule to kick in with a one-off positive shock of 1 pp after it has been frozen for two years.

[42] Contrary to the previous subsections, the model is simulated in fully non-linear form and in a deterministic framework in order to handle the policy rate commitment.

[43] It should be noted that asset purchases are simulated as a shock from the steady state, when inflation is already on target. This differs from the real world application of UMP, which has typically been introduced in periods of low or negative inflation.

be potent in the presence of transition frictions.

As regards cross-border capital flights in a recession, we have seen how a panicked response of foreign investors can significantly sharpen the drop in output, consumption and investment in the economy experiencing the recession-inducing total factor productivity (TFP) shock. The financial intermediation disruption produced by a capital flight also tends to reverse the strong inflationary pressures from a negative TFP shock coupled with a positive government expenditure shock. Other phenomena produced by a capital flight are the forcing of the afflicted economy onto an external trade-led recovery path and a sharp increase in country risk, both of which act as external equilibrium mechanisms in a context of bilateral retrenchment in cross-border financial flows. The presence of a common sovereign debt instrument in the form of a fully-fledged "Eurobond" helps to approximates the no-capital flight outcome in some respects by facilitating the afflicted economy's access to external funding. This moderates the drop in domestic consumption, prevents deflationary dynamics from setting in and contains the increase in country risk. At the same time, the common debt instrument delays an external trade-led adjustment and prolongs the weakness in output.

Finally, we turned our attention to an unconventional monetary policy (UMP) shock whereby the monetary authority acquires sovereign bonds in the market and commits to keeping policy rates unchanged for a period of time. UMP is seen to be a powerful tool for temporarily boosting inflation and output. Eased financial conditions result in increased lending and consumption, as well as lower lending rates. The policy is more potent the longer policy rates stay frozen, although inflation expectations management may require a stronger offsetting monetary policy impulse as UMP is discontinued, which can then lead to a macroeconomic correction.

As regards future avenues for model improvement and research, a less stylized representation of the government sector could be usefully developed, particularly to explore its interaction with the macrofinancial disturbances analyzed in this paper. In particular, the model could profit from features such as distortionary taxation and the possibility of governments conducting investment. The inclusion of a rest of the world bloc could likewise prove useful by expanding the model's analytical scope as regards cross-border spill-overs and external stabilisation mechanisms. Finally, the empirical relevance of the model could be further improved by estimating some of the parameters with Bayesian methods applied to our calibrated "priors".

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Appendix A Heightened home bias as a strategic outcome

One of the empirical observations resulting from the European sovereign debt crisis was the increase in the home bias of the sovereign debt portfolios of banks located in "periphery" euro area countries. As documented in Horvath et al. (2015), Saka (2018) and Andreeva and Vlassopoulos (2019), periphery countries increased their exposure to domestic sovereigns as the spreads of the latter began to rise in 2010. This behaviour can be understood as the rational result of a non-cooperative strategic game between banks and the domestic sovereign, where the weakly dominant strategy of banks is to increase exposure amounts.

Table 1: Payoff matrix of a game between a bank and its domestic sovereign

		Government	
		Default	Not default
Bank	Increase exposure	$(max(-100,0) = \underline{0},\ -1200)$	**($\underline{\mathbf{10}}$, $\underline{\mathbf{-900}}$)**
	Not increase exposure	$(max(-50,0) = \underline{0},\ -1000)$	$(5,\ \underline{-900})$

Note: The underlined payoffs indicate the optimal strategic responses; the payoff in bold type indicates the Nash equilibrium

To see this, consider the stylized payoff matrix in Table 1 of a bank that is already highly exposed and does consider decreasing its level of exposure. As the sovereign probability of default (and therefore bond yields) increase, the bank can opt to maintain its exposure or increase it. Because the initial exposure level is already very high, it will go bankrupt in the event of sovereign default, whatever it chooses to do. While bank losses are larger for a highly exposed bank, the payoff of shareholders is always zero in the event of sovereign default due to their limited liability. However, if the bank increases its exposure and the government does not default, then it can pocket bigger profits from the higher yields applied to a larger asset base. This makes increasing its exposure a one-way bet or, in game-theoretic terms, a weakly dominant strategy.

At the same time, the government faces a higher economic and social cost of default if its domestic banks have increased their exposure, as it may need to bail them out at larger recapitalisation needs, or otherwise face a highly impaired banking system.[44]

[44]This effect may even tip the government towards the decision of not defaulting, although the payoffs in Table 1 were set so that not defaulting is already the government's dominant strategy.

Appendix B Dynamic conditions of the model

This appendix presents the dynamic conditions of the model as derived from agents' optimisation problems. All variables are expressed in real terms. As such, nominal variables which appear in upper case in the main text are here expressed in lower case to denote that they have been deflated by the final goods price level of the respective region (e.g., $d_{s,t} \equiv \frac{D_{s,t}}{P_t}$, $d^*_{s,t} \equiv \frac{D^*_{s,t}}{P^*_t}$, $p^Y_t \equiv \frac{P^Y_t}{P_t}$ and $p^{Y^*}_t \equiv \frac{P^{Y^*}_t}{P^*_t}$). Likewise, lower case interest rates are expressed in real terms (e.g., $r^D_{s,t} \equiv \frac{R^D_{s,t}}{\Pi_t}$). The real exchange rate is defined as $rer_t \equiv \frac{P^*_t}{P_t}$ and therefore evolves as $rer_{t+1} = \frac{\Pi^*_t}{\Pi_t} rer_t$. The stochastic discount factor is expressed in real terms as $\Lambda_{s,t} \equiv P_t \lambda_{s,t}$. Lagrange multipliers ξ have been normalised by dividing by λ_s. The different β discount factors have been calibrated in such a way that all constraints bind in a neighbourhood of the steady state. The conditions presented hereunder focus on the domestic economy, with those for the foreign economy following by analogy.

The first order conditions of **saver households** are:

$$\Lambda_{s,t} = \left(C_{s,t} - hC_{s,t-1}\right)^{-\chi} \tag{54}$$

$$\frac{\nu^h_s H^{-\chi}_{s,t}}{\Lambda_{s,t}} + \beta_s E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} \left(\left(1-\delta_H\right) p^H_{t+1} + s_{H_s}\left(H_{s,t+1} - H_{s,t}\right)\right)\right] = p^H_t + s_{H_s}\left(H_{s,t} - H_{s,t-1}\right) \tag{55}$$

$$w_t = \frac{\nu^n_s N^{\varphi}_{s,t}}{\Lambda_{s,t}} \tag{56}$$

$$\beta_s E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} r^D_{s,t}\right] = 1 \tag{57}$$

$$C_{s,t} + t_t Y_t + AC_{H_s,t} + p^H_t \left(H_{s,t} - (1-\delta_H) H_{s,t-1}\right) + d_{s,t} = r^D_{s,t-1} d_{s,t-1} + w_t N_{b,t} + div_{s,t} \tag{58}$$

where t_t denotes the tax-to-GDP ratio.
The first order conditions of **borrower households** are:

$$\Lambda_{b,t} = \left(C_{b,t} - hC_{b,t-1}\right)^{-\chi} \tag{59}$$

$$\begin{aligned} \frac{\nu^h_b H^{-\chi}_{b,t}}{\Lambda_{b,t}} &+ \left(1-\delta_H\right)\left(1-\rho_f\right)\left(\gamma^b_0 \epsilon^{\iota b}_t\right) \xi_{b,t} E_t \left[\frac{p^H_{t+1}}{r_{b,t}}\right] \\ &+ \beta_b E_t \left[\frac{\Lambda_{b,t+1}}{\Lambda_{b,t}} \left(\left(1-\delta_H\right) p^H_{t+1} + s_{H_b}\left(H_{b,t+1} - H_{b,t}\right)\right)\right] \\ &= p^H_t + s_{H_b}\left(H_{b,t} - H_{b,t-1}\right) + s_b p^H_t \left(\frac{p^H_t H_{b,t}}{l_{b,t}} - \frac{p^H H_b}{l_b}\right) \end{aligned} \tag{60}$$

$$w_t = \frac{\nu^n_b N^{\varphi}_{b,t}}{\Lambda_{b,t}} \tag{61}$$

$$1 - \xi_{b,t} = \beta_b E_t \left[\frac{\Lambda_{b,t+1}}{\Lambda_{b,t}} \left(\varepsilon^b_{t+1} r_{b,t} - \rho_f \xi_{b,t+1}\right)\right] \tag{62}$$

$$l_{b,t} = \rho_f l_{b,t-1} + \left(1-\rho_f\right)\left(\left(\gamma^b_0 \epsilon^{\iota b}_t\right) E_t \frac{p^H_{t+1}\left(1-\delta_H\right) H_{b,t}}{r_{b,t}}\right) \tag{63}$$

$$C_{b,t}+t_tY_t+AC_{H_b,t}+p_t^H\left(H_{b,t}-\left(1-\delta_H\right)H_{b,t-1}\right)+\varepsilon_t^b r_{b,t-1}l_{b,t-1}+LIA_{b,t}=l_{b,t}+w_tN_{b,t} \quad (64)$$

where $\xi_{b,t}$ denotes the Lagrange multiplier associated with the collateral constraint.
The first order conditions of **entrepreneurs** are:

$$1=q_{e,t}\left(\varepsilon_t^{I_k}-\frac{s_k}{2}\left(\frac{I_{e,t}}{I_{e,t-1}}-1\right)^2-s_k\left(\frac{I_{e,t}}{I_{e,t-1}}-1\right)\frac{I_{e,t}}{I_{e,t-1}}\right) \\ +\beta_eE_t\left[q_{e,t+1}\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}s_k\left(\frac{I_{e,t+1}}{I_{e,t}}-1\right)\left(\frac{I_{e,t+1}}{I_{e,t}}\right)^2\right] \quad (65)$$

$$q_{e,t}=\beta_eE_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\alpha p_{t+1}^X\left(Y_{t+1}+\frac{1}{\theta-1}Y\right)K_t^{-1}+q_{e,t+1}\left(1-\delta_k\right)\right)\right] \\ +\left(1-\rho_e\right)\epsilon_t^{\iota e}\gamma_0^e\frac{\xi_{e,t}}{r_{e,t}}E_t\left[\alpha p_{t+1}^X\left(Y_{t+1}+\frac{1}{\theta-1}Y\right)K_t^{-1}+q_{e,t+1}(1-\delta_k)\right] \\ +s_e\left(\frac{q_{e,t}K_t}{l_{e,t}}-\frac{q_eK}{l_e}\right)\frac{q_{e,t}}{l_{e,t}} \quad (66)$$

$$w_t=p_t^X(1-\alpha)\frac{Y_t+\frac{1}{\theta-1}Y}{N_t} \quad (67)$$

$$1-\xi_{e,t}+s_e\left(\frac{q_{e,t}K_t}{l_{e,t}}-\frac{q_eK}{l_e}\right)\frac{q_{e,t}}{l_{e,t}^2}=\beta_eE_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon_{t+1}^e r_{e,t}-\rho_e\xi_{e,t+1}\right)\right] \quad (68)$$

$$K_t=I_{e,t}\left[\varepsilon_t^{I_k}-\frac{s_k}{2}\left(\frac{I_{e,t}}{I_{e,t-1}}-1\right)^2\right]+\left(1-\delta_k\right)K_{t-1} \quad (69)$$

$$l_{e,t}=\rho_el_{e,t-1}+\left(1-\rho_e\right)\times \\ \left(\epsilon_t^{\iota e}\gamma_0^eE_t\frac{\left(p_{t+1}^X\left(Y_{t+1}+\frac{1}{\theta-1}Y\right)-w_{t+1}N_{t+1}\right)+q_{e,t+1}(1-\delta_k)K_t}{r_{e,t}}\right) \quad (70)$$

where q_e denotes the Lagrange multiplier associated with Equation 12,[45] and X_t has been substituted by the following intermediate goods condition:

$$Y_t+\frac{1}{\theta-1}Y=\varepsilon_t^z\left(K_{t-1}\right)^\alpha\left(N_t\right)^{1-\alpha}=X_t \quad (71)$$

Condition 71 is, in turn, based on calibrating the level of fixed costs F so that the profits of monopolistically competitive wholesalers are zero in the steady-state equilibrium. Thus

$$F=\frac{1}{\theta-1}Y \quad (72)$$

The first order conditions of **intermediaries**, **wholesalers** and **final goods firms** yield:

$$\varpi_t\equiv\phi\beta_s(\Pi)^{-\theta}E_t\left[\Pi_{t+1}^\theta\varpi_{t+1}\right]+\Lambda_{s,t}p_t^X\left(p_t^Y\right)^\theta Y_t \quad (73)$$

$$\psi_t\equiv\phi\beta_s(\Pi)^{1-\theta}E_t\left[\Pi_{t+1}^{\theta-1}\psi_{t+1}\right]+\Lambda_{s,t}\left(p_t^Y\right)^\theta Y_t \quad (74)$$

[45] q_e can thus be interpreted as the shadow price of capital (normalised by the price of the final good).

$$p_t^Y = \left[(1-\phi) \left(\frac{\theta}{\theta-1} \frac{\varpi_t}{\psi_t} \right)^{1-\theta} + \phi \left((\Pi_t)^{-1} \Pi p_{t-1}^Y \right)^{(1-\theta)} \right]^{\frac{1}{1-\theta}} \tag{75}$$

$$Y_{M,t}^* = \omega_M \left(rer_t \, p_t^{Y^*} \right)^{-\nu} Z_t \tag{76}$$

$$1 = (1-\omega_F) \left(p_t^Y \right)^{1-\nu} + \omega_F \left(rer_t \, p_t^{Y^*} \right)^{1-\nu} \tag{77}$$

The first order conditions of **housebuilders** are:

$$H_t = (1-\delta_H) H_{t-1} + \left(s_{h_0} - S^h \left(I_{h,t}, I_{h,t-1} \right) \right) I_{h,t}^{\gamma} \tag{78}$$

$$p_t^H \gamma \left(s_{h_0} - \frac{s_{h_1}}{2} \left(\frac{I_{h,t}}{I_{h,t-1}} - 1 \right)^2 \right) I_{h,t}^{\gamma-1} - p_t^H s_{h_1} \left(\frac{I_{h,t}}{I_{h,t-1}} - 1 \right) \frac{I_{h,t}^{\gamma}}{I_{h,t-1}} + \beta_s E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} p_{t+1}^H s_{h_1} \left(\frac{I_{h,t+1}}{I_{h,t}} - 1 \right) \frac{I_{h,t+1}^{\gamma+1}}{I_{h,t}^2} \right] = 1 \tag{79}$$

As regards the dynamic conditions of **banks**, first define

$$AC'_{K,t} = a_K \left(\frac{d_{h,t} + ib_{f^*,t}}{\rho_f kr_{f,t-1} + (1-\rho_f)(rwa_{f,t} + el_{f,t})} - \frac{d_h + ib_{f^*}}{kr_f} \right) \tag{80}$$

First order conditions are then:

$$1 - \xi_{f,t} \left(1 - (1-\rho_f) \left(\eta_t^{L_h} + E_t \left[1 - \varepsilon_{t+1}^b \right] (1 - \eta_t^{L_h}) \right) \right) - AC'_{K,t} \frac{(d_{h,t} + ib_{f^*,t})(1-\rho_f) \left(\eta_t^{L_h} + E_t \left[1 - \varepsilon_{t+1}^b \right] (1 - \eta_t^{L_h}) \right)}{(kr_{f,t})^2} = \beta_f E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} \left(\varepsilon_{t+1}^b r_{b,t} - \rho_f \xi_{f,t+1} \right) \right] \tag{81}$$

$$1 - \xi_{f,t} \left(1 - (1-\rho_f) \left(\eta_t^{L_e} + E_t \left[1 - \varepsilon_{t+1}^e \right] (1 - \eta_t^{L_e}) \right) \right) - AC'_{K,t} \frac{(d_{h,t} + ib_{f^*,t})(1-\rho_f) \left(\eta_t^{L_e} + E_t \left[1 - \varepsilon_{t+1}^e \right] (1 - \eta_t^{L_e}) \right)}{(kr_{f,t})^2} = \beta_f E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} \left(\varepsilon_{t+1}^e r_{e,t} - \rho_f \xi_{f,t+1} \right) \right] \tag{82}$$

For the $(1-\omega^f)$ share of banks that are not locked in a strategic game with their sovereigns (see Appendix A) the first order condition with respect to B_f is:

$$1 - \xi_{f,t} \left(1 - (1-\rho_f) \left(\eta_t^B + E_t \left[1 - \varepsilon_{t+1}^B \right] (1 - \eta_t^B) \right) \right) - AC'_{K,t} \frac{(d_{h,t} + ib_{f^*,t})(1-\rho_f) \left(\eta_t^B + E_t \left[1 - \varepsilon_{t+1}^B \right] (1 - \eta_t^B) \right)}{(kr_{f,t})^2} = \beta_f E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} \left(\varepsilon_{t+1}^B \tilde{r}_{f,t}^B - \rho_f \xi_{f,t+1} \right) \right] \tag{83}$$

For the ω^f share of banks that are locked in a strategic game with their sovereigns, changes in the potential cost of sovereign default losses (as captured by time variation in the ε^B_{t+1} factor in Equation 27) are ignored and the first order condition is:

$$\begin{aligned} 1 - \xi_{f,t}\left(1 - (1-\rho_f)\left(\eta^B_t + E_t\left[1-\varepsilon^B_{t+1}\right](1-\eta^B_t)\right)\right) \\ - AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta^B_t + E_t\left[1-\varepsilon^B_{t+1}\right](1-\eta^B_t)\right)}{(kr_{f,t})^2} \\ = \beta_f \varepsilon^B E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\tilde{r}^B_{f,t} - \rho_f\xi_{f,t+1}\right)\right] \end{aligned} \tag{84}$$

The first order condition with respect to B^*_f is the same in either case:

$$\begin{aligned} 1 - \xi_{f,t}\left(1 - (1-\rho_f)\left(\eta^B_t + E_t\left[1-\varepsilon^{B^*}_{t+1}\right](1-\eta^B_t)\right)\right) \\ - AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta^B_t + E_t\left[1-\varepsilon^{B^*}_{t+1}\right](1-\eta^B_t)\right)}{(kr_{f,t})^2} \\ = \beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon^{B^*}_{t+1}\tilde{r}^{B^*}_{f,t} - \rho_f\xi_{f,t+1}\right)\right] \end{aligned} \tag{85}$$

The remaining first order conditions of banks are:

$$\begin{aligned} 1 - \xi_{f,t}\left(1 - (1-\rho_f)\left(\eta^{IB}_t + E_t\left[1-\varepsilon^{ib}_{t+1}\right](1-\eta^{IB}_t)\right)\right) \\ - AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta^{IB}_t + E_t\left[1-\varepsilon^{ib}_{t+1}\right](1-\eta^{IB}_t)\right)}{(kr_{f,t})^2} \\ = \beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon^{ib}_{t+1}r^{IB}_{f,t} - \rho_f\xi_{f,t+1}\right)\right] \end{aligned} \tag{86}$$

$$\begin{aligned} 1 - \xi_{f,t}\left(1 - (1-\rho_f)\left(\eta^{IB}_t + E_t\left[1-\varepsilon^{ib^*}_{t+1}\right](1-\eta^{IB}_t)\right)\right) \\ - AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta^{IB}_t + E_t\left[1-\varepsilon^{ib^*}_{t+1}\right](1-\eta^{IB}_t)\right)}{(kr_{f,t})^2} \\ = \beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon^{ib^*}_{t+1}r^{IB^*}_{f,t} - \rho_f\xi_{f,t+1}\right)\right] \end{aligned} \tag{87}$$

$$1 - \xi_{f,t} = \beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(r^{EA}_t - \rho_f\xi_{f,t+1}\right)\right] \tag{88}$$

$$1 - \xi_{f,t} + \rho_f\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\xi_{f,t+1}\right] - \frac{AC'_{K,t}}{kr_t} = \beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}r_{s,t}\right] \tag{89}$$

$$1 - \xi_{f,t} + \rho_f\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\xi_{f,t+1}\right] - AC'_{K,t}\frac{\left(1-\omega^{IB}_t\right)}{kr_t} = \beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\varepsilon^{ib}_{t+1}r^{IBF}_{f,t}\right] \tag{90}$$

where Equations 89 and 90 are combined so that

$$\frac{1 - \xi_{f,t} + \rho_f\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\xi_{f,t+1}\right] - \frac{AC'_{K,t}}{kr_t}}{1 - \xi_{f,t} + \rho_f\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\xi_{f,t+1}\right] - AC'_{K,t}\frac{\left(1-\omega^{IB}_t\right)}{kr_t}} = \frac{E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}r_{s,t}\right]}{E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\varepsilon^{ib}_{t+1}r^{IBF}_{f,t}\right]} \tag{91}$$

$$
\begin{aligned}
\omega_s d_{s,t} + rer_t \frac{1-n}{n} ib_{f^*,t} \leq\ & \rho_f \big(\omega_s d_{s,t-1} + rer_{t-1} \frac{1-n}{n} ib_{f^*,t-1} - (1-\omega_s) l_{b,t-1} - l_{e,t-1} \\
& - bp_{f,t-1} - ib^*_{f,t-1} - cb_{f,t-1}\big) + (1-\omega_s) l_{b,t} + l_{e,t} + bp_{f,t} + ib^*_{f,t} + cb_{f,t} \\
& - (1-\rho_f) \Bigg(\eta_t^{L_h} (1-\omega_s) l_{b,t} + \eta_t^{L_e} l_{e,t} + \eta_t^{B} bp_{f,t} + \eta_t^{IB} \left(ib_{f,t} + ib^*_{f,t} \right) \\
& + E_t \Bigg[(1-\varepsilon^b_{t+1})(1-\eta_t^{L_h})(1-\omega_s) l_{b,t} + (1-\varepsilon^e_{t+1})(1-\eta_t^{L_e}) l_{e,t} \\
& + (1-\eta_t^B) b_{f,t} \left(\omega^{HFT} \left(1 - \frac{\bar{r}_t}{r_t} \right) + (1-\omega^{HFT})(1-\varepsilon^B_{t+1}) \right) \\
& + (1-\eta_t^B) rer_t \frac{1-n}{n} b^*_{f,t} \left(\omega^{HFT} \left(1 - \frac{\bar{r}^*_t}{r^*_t} \right) + (1-\omega^{HFT})(1-\varepsilon^{B^*}_{t+1}) \right) \\
& + (1-\eta_t^{IB}) \left((1-\varepsilon^{ib}_{t+1}) ib_{f,t} + (1-\varepsilon^{ib^*}_{t+1}) ib^*_{f,t} \right) \Bigg] \Bigg)
\end{aligned} \tag{92}
$$

Risk weights are allowed to vary in response to exogenous shocks:

$$\eta_t^{L_h} = \left(\eta_0^{L_h} \varepsilon_t^{\iota L_h} \right) \tag{93}$$

$$\eta_t^{L_e} = \left(\eta_0^{L_e} \varepsilon_t^{\iota L_f} \right) \tag{94}$$

$$\eta_t^{B} = \left(\eta_0^{B} \varepsilon_t^{\iota B} \right) \tag{95}$$

$$\eta_t^{IB} = \left(\eta_0^{IB} \varepsilon_t^{\iota IB} \right) \tag{96}$$

The relation between $D_{h,t}$ and $D_{s,t}$ is

$$D_{h,t} = \omega_s D_{s,t} \tag{97}$$

The relation between $L_{h,t}$ and $L_{b,t}$ is

$$L_{h,t} = (1-\omega_s) L_{b,t} \tag{98}$$

As regards the first order conditions of **banks' bond portfolio managers**, it is assumed that they are instructed by head offices to consider the steady state values of total bond holdings (bp_f) and average excess returns (R_f^{BP}) as given, and to respond only to the prevailing excess returns for each bond ($\frac{R_t}{\tilde{R}_{f,t}}$ and of $\frac{R^*_t}{\tilde{R}^*_{f,t}}$).[46] As such

$$b_{f,t} = \omega_f^B bp_f \left(\frac{\frac{R_t}{\tilde{R}_{f,t}}}{R_f^{BP}} \right)^{\sigma_f^B} \tag{99}$$

where $\tilde{R}$ is given by Equation 83 for a mass ω^f of banks and by Equation 84 for a mass $(1-\omega^f)$ of banks.

$$rer_t \frac{1-n}{n} b^*_{f,t} = \left(1-\omega_f^B\right) bp_f \left(\frac{\frac{R^*_t}{\tilde{R}^*_{f,t}}}{R_f^{BP}} \right)^{\sigma_f^B} \tag{100}$$

[46]This assumption implies that an increase in excess returns on a given bond tends to increase not only the relative portfolio weight of that bond, but also the absolute exposure to it. Otherwise, an increase in the relative portfolio weight of a bond experiencing heightened excess returns could be achieved in a context of reduced total sovereign exposures, which would imply poor empirical properties, namely as regards the home bias effect discussed in Appendix A.

As regards **banks' interbank loan portfolio managers**, they maximize returns under a CES framework taking into account default risk-adjusted yields required by head offices. These are obtained from Equations 86 and 87 by discounting all default risk-related costs:

$$\tilde{r}_f^{IB} = E_t\Bigg[\varepsilon_{t+1}^{ib} r_{f,t}^{IB} - \xi_{f,t}\,(1-\rho_f)\,(1-\varepsilon_{t+1}^{ib})(1-\eta_t^{IB}) + AC'_{K,t}(d_{h,t}+ib_{f^*,t})(1-\rho_f)\frac{\left(1-\varepsilon_{t+1}^{ib}\right)(1-\eta_t^{IB})}{(kr_{f,t})^2}\Bigg] \tag{101}$$

$$\tilde{r}_f^{IB^*} = E_t\Bigg[\varepsilon_{t+1}^{ib^*} r_{f,t}^{IB^*} - \xi_{f,t}\,(1-\rho_f)\,(1-\varepsilon_{t+1}^{ib^*})(1-\eta_t^{IB}) + AC'_{K,t}(d_{h,t}+ib_{f^*,t})(1-\rho_f)\frac{\left(1-\varepsilon_{t+1}^{ib^*}\right)(1-\eta_t^{IB})}{(kr_{f,t})^2}\Bigg] \tag{102}$$

A first order condition is:

$$ib_{f,t}^{*} = (1-\omega^{IB})ibp_{f,t}\left(\frac{\tilde{R}_{f,t}^{IB^*}}{e_t R_{f,t}^{IBP}}\right)^{\sigma_{IB}} \tag{103}$$

where

$$R_{f,t}^{IBP} = \frac{1}{\left(\omega_f^{IB}\left(\frac{1}{\tilde{R}_{f,t}^{IB}}\right)^{1-\sigma^{IB}} + \left(1-\omega_f^{IB}\right)\left(\frac{e_t}{\tilde{R}_{f,t}^{IB^*}}\right)^{1-\sigma^{IB}}\right)^{\frac{1}{1-\sigma^{IB}}}} \tag{104}$$

Equivalently for the interbank portfolio managers of the foreign economy, a first order condition is:

$$ib_{f^*,t} = (1-\omega^{IB^*})ibp_{f^*,t}\left(\frac{e_t\tilde{R}_{f^*,t}^{IB}}{R_{f^*,t}^{IBP}}\right)^{\sigma_{IB^*}} \tag{105}$$

Appendix C Selected steady-state equations

This appendix presents some of the main steady-state conditions of the model.

From Equation 57 we obtain

$$R_s = \frac{\Pi}{\beta_s} \tag{106}$$

From Equation 88:

$$\xi_f = \frac{1 - \beta_f \frac{R^{EA}}{\Pi}}{1 - \rho_f \beta_f} \tag{107}$$

From Equations 86 and 88:

$$R_f^{IB} = sp_{ib}^{EA} R^{EA} \tag{108}$$

where

$$sp_{ib}^{EA} = \frac{1 - \xi_f \left(1 - \rho_f \beta_f - (1 - \rho_f)\eta_0^{IB}\right)}{\left(1 - \xi_f \left(1 - \rho_f \beta_f\right)\right)} \tag{109}$$

From Equations 91 and 109, we have that

$$R_s = sp_s^{EA} R^{EA} \tag{110}$$

where

$$sp_s^{EA} = sp_{ib}^{EA} \tag{111}$$

From the Equations 106 and 110 we have that

$$\frac{R^{EA}}{\Pi} = \frac{1}{\beta_s sp_s^{EA}} \tag{112}$$

$$\frac{R^{EA}}{\Pi^*} = \frac{1}{\beta_s^* sp_s^{EA*}} \tag{113}$$

and therefore

$$\frac{\Pi^*}{\Pi} = \frac{\beta_s^* sp_s^{EA*}}{\beta_s sp_s^{EA}} \tag{114}$$

Note that, given a steady-state inflation rate Π, Equations 107 and 112 jointly determine ξ_f and R^{EA}.

From Equations 81 and 88:

$$R_b = sp_b^{EA} R^{EA} \tag{115}$$

where

$$sp_b^{EA} = \frac{\left(1 - \xi_f \left(1 - \rho_f \beta_f - (1 - \rho_f)\left(\eta_0^{L_h} + (1 - \varepsilon_0^b)(1 - \eta_0^{L_h})\right)\right)\right)}{\left(1 - \xi_f \left(1 - \rho_f \beta_f\right)\right) \varepsilon_0^b} \tag{116}$$

From Equations 82 and 88:

$$R_e = sp_e^{EA} R^{EA} \tag{117}$$

where

$$sp_e^{EA} = \frac{\left(1 - \xi_f \left(1 - \rho_f \beta_f - (1-\rho_f) \left(\eta_0^{L_e} + (1-\varepsilon_0^e)(1-\eta_0^{L_e})\right)\right)\right)}{\left(1 - \xi_f \left(1 - \rho_f \beta_f\right)\right) \varepsilon_0^e} \tag{118}$$

From Equations 83 and 88:

$$\tilde{R}_f = sp_{B_f}^{EA} R^{EA} \tag{119}$$

where

$$sp_{B_f}^{EA} = \frac{\left(1 - \xi_f \left(1 - \rho_f \beta_f - (1-\rho_f) \left(\eta_0^{B} + (1-\varepsilon_0^B)(1-\eta_0^{B})\right)\right)\right)}{\left(1 - \xi_f \left(1 - \rho_f \beta_f\right)\right) \varepsilon_0^B} \tag{120}$$

From Equation 92:

$$\begin{aligned} \omega_s d_s + rer \frac{1-n}{n} ib_{f^*} = &+ \varepsilon_0^b \left(1 - \eta_0^{L_h}\right)(1-\omega_s) l_b + \varepsilon_0^e \left(1 - \eta_0^{L_e}\right) l_e \\ &+ \left(\omega^{HFT} + \varepsilon_0^{BP}\left(1 - \omega^{HFT}\right)\right)\left(1 - \eta_0^B\right) bp_f + cb_f + \varepsilon_0^{ib^*}\left(1 - \eta_0^{IB}\right) ib_f^* \\ &- \left(\eta_t^{IB} + (1-\eta_t^{IB})(1-\varepsilon_0^{ib})\right) ib_f \end{aligned} \tag{121}$$

where ε_0^{BP} is the steady state of the complement of the expected loss on the bond portfolio, which is given by

$$E_t\left[\varepsilon_{t+1}^{BP}\right] = \frac{b_{f,t}}{bp_{f,t}} E_t\left[\varepsilon_{t+1}^B\right] + rer_t \frac{1-n}{n} \frac{b_{f,t}^*}{bp_{f,t}} E_t\left[\varepsilon_{t+1}^{B^*}\right] \tag{122}$$

From Equation 7 we have that

$$l_b = \gamma_0^b \frac{p^H (1-\delta_H) H_b}{r_b} \tag{123}$$

Likewise, from Equation 14 we obtain

$$\frac{l_e}{Y} = \gamma_0^e \frac{\alpha p^Y + (1-\delta_k) q_e \frac{K}{Y}}{r_e} \tag{124}$$

From Equation 62 we obtain

$$\xi_b = \frac{1 - \frac{\varepsilon_0^b sp_b^{EA} \beta_b}{sp_s^{EA} \beta_s}}{1 - \rho_b \beta_b} \tag{125}$$

From Equation 68 we obtain

$$\xi_e = \frac{1 - \frac{\varepsilon_0^e sp_e^{EA} \beta_e}{sp_s^{EA} \beta_s}}{1 - \rho_e \beta_e} \tag{126}$$

From Equation 65 we have

$$q_e = 1 \tag{127}$$

Differentiation-based market power of branding firms yields the following markup condition:

$$p^Y = \frac{\theta}{\theta - 1} p^X \tag{128}$$

Taking into account Equation 72 and the production function of wholesalers, we have

$$Y = \frac{\theta - 1}{\theta} X \tag{129}$$

From Equation 66 we have

$$\frac{K}{Y} = \frac{\alpha p^Y}{r^K} \tag{130}$$

Where r^K is defined as

$$r^K = \frac{q_e\left(1-\beta_e(1-\delta_k)\right) - (1-\rho_e)\frac{\xi_e}{r_e}\gamma_0^e(1-\delta_k)}{\beta_e + (1-\rho_e)\gamma_0^e\frac{\xi_e}{r_e}} \tag{131}$$

From Equation 12 we have

$$\frac{I_e}{Y} = \delta_k \frac{K}{Y} \tag{132}$$

From Equation 67 we have

$$\frac{N}{Y} = \frac{(1-\alpha)}{w} p^Y \tag{133}$$

From the Equations 11, 129 and 133 we have

$$w = (1-\alpha) p^Y \frac{\theta-1}{\theta}\left(\frac{K}{N}\right)^{\alpha} \tag{134}$$

Given that

$$\frac{K}{N} = \frac{\frac{K}{Y}}{\frac{N}{Y}} = \frac{\alpha w}{(1-\alpha) r^K} \tag{135}$$

We have that

$$w = \left(\frac{1-\alpha}{\alpha}\right)\frac{\left(\frac{\theta-1}{\theta}\alpha p^Y\right)^{\frac{1}{1-\alpha}}}{\left(r^K\right)^{\frac{\alpha}{1-\alpha}}} \tag{136}$$

From Equation 61 we have

$$N_b = \left(\frac{w}{\nu_b^n\left((1-h)C_b\right)^{\chi}}\right)^{\frac{1}{\varphi}} \tag{137}$$

From Equations 54 and 55 we have

$$H_s = \left(\frac{\nu_s^h}{\left(1-\beta_s\left(1-\delta_H\right)\right)p_t^H}\right)^{\frac{1}{\chi}}(1-h)C_s \tag{138}$$

Likewise, from Equations 59 and 60 we have

$$H_b = \left(\frac{\nu_b^h}{\left(1-\beta_b\left(1-\delta_H\right)\left(1+\gamma_0^b\left(1-\rho_b\right)\frac{\xi_f}{\beta_b r_b}\right)\right)p_t^H}\right)^{\frac{1}{\chi}}(1-h)C_b \tag{139}$$

From Equation 79 we have

$$p^H = \frac{1}{\gamma s_{h_0} I_h^{\gamma-1}} \tag{140}$$

From Equation 67 together with Equations 56 and 61 we have

$$\frac{(1-\alpha)p^Y}{w}Y^{1+\frac{\chi}{\varphi}} = \omega_s\left(\frac{w}{\nu_s}\right)^{\frac{1}{\varphi}}\left(\frac{(1-h)C_s}{Y}\right)^{-\frac{\chi}{\varphi}} + (1-\omega_s)\left(\frac{w}{\nu_b}\right)^{\frac{1}{\varphi}}\left(\frac{(1-h)C_b}{Y}\right)^{-\frac{\chi}{\varphi}} \tag{141}$$

The trade balance is obtained by subtracting imports from exports:

$$\frac{TB}{Y} = \frac{1-n}{n}\omega_M^* rer^v \left(p^Y\right)^{1-\nu}\left(\frac{C^*}{Y^*}+\frac{I^*}{Y^*}+g^*\right)\frac{Y^*}{Y}$$
$$-\,\omega_M\left(rer^* p^{Y^*}\right)^{1-\nu}\left(\frac{C}{Y}+\frac{I}{Y}+g\right) \quad (142)$$

Let $\bar{\omega}_f^B$ and $\bar{\omega}_f^{B^*}$ denote the steady-state bond portfolio shares of banks. From Equation 44 and the steady-state bond portfolio weights of banks, we have

$$\frac{1-n}{n}rer\,\frac{b_f^*}{Y} = \frac{\left(1-\bar{\omega}_f^{B^*}\right)\left(1-\bar{\omega}_f^B\right)}{\bar{\omega}_f^B-(1-\bar{\omega}_f^{B^*})}\left(\frac{\bar{\omega}_f^{B^*}}{1-\bar{\omega}_f^{B^*}}b-\frac{1-n}{n}rer\,b^*\frac{Y^*}{Y}\right) \quad (143)$$

$$\frac{b_{f^*}}{Y} = \frac{\left(1-\bar{\omega}_f^{B^*}\right)\left(1-\bar{\omega}_f^B\right)}{\bar{\omega}_f^B-(1-\bar{\omega}_f^{B^*})}\left(\frac{\bar{\omega}_f^B}{1-\bar{\omega}_f^B}\frac{1-n}{n}rer\,b^*\frac{Y^*}{Y}-b\right) \quad (144)$$

From the previous two equations, and taking into account the steady-state bond portfolio shares, we have

$$\frac{b_f}{Y} = \frac{\bar{\omega}_f^B}{1-\bar{\omega}_f^B}\frac{1-n}{n}rer\,\frac{b_f^*}{Y} \quad (145)$$

$$\frac{b_{f^*}^*}{Y} = \frac{\bar{\omega}_f^{B^*}}{1-\bar{\omega}_f^{B^*}}rer^{-1}\frac{n}{1-n}\frac{b_{f^*}}{Y} \quad (146)$$

From Equation 52 we obtain the balance of payments identity in the steady state:

$$\frac{TB}{Y} = \frac{1-n}{n}\left(1-r^*\right)rer\,\frac{b_f^*}{Y}+\left(1-r_f^{IB^*}\right)\frac{ib_f^*}{Y}++\left(1-r^{EA}\right)\frac{cb_f}{Y}+\left(1-\frac{1}{\Pi}\right)\frac{k_{CB}}{Y}$$
$$-\left(\left(1-r\right)\frac{b_{f^*}}{Y}+\frac{1-n}{n}\left(1-r_{f^*}^{IB}\right)rer\,\frac{ib_{f^*}}{Y}+\frac{div_{cb}}{Y}\right) \quad (147)$$

Appendix D Figures and tables

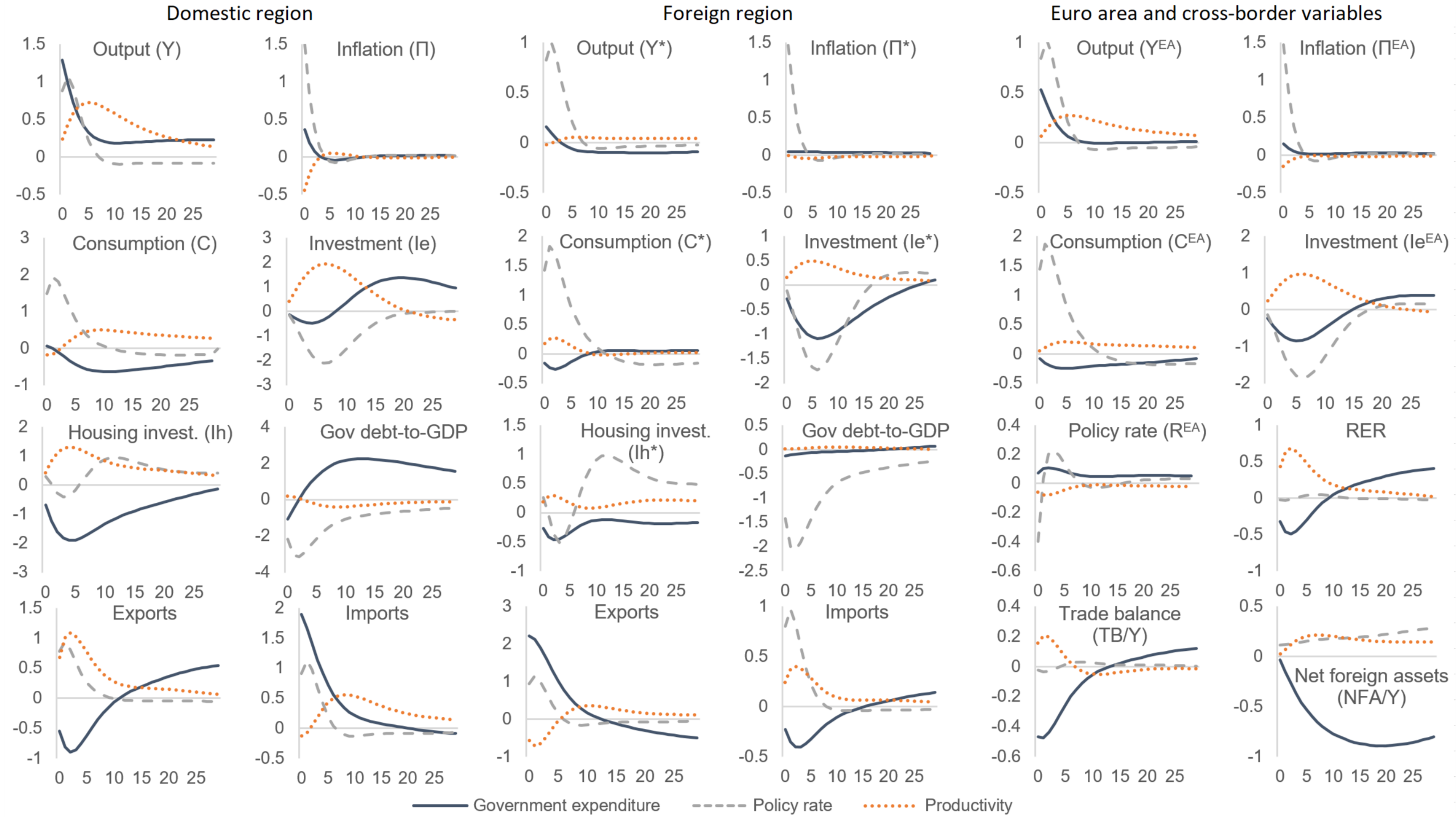
Table 2: Model parameter values

Parameter	Meaning	Value
	Size parameters	
n	Size of domestic region	0.33
ω_s	Share of saver households	0.6
	Preferences	
β_b	Discount factor of borrower households	0.967
β_e	Discount factor of entrepreneurs	0.97
β_f	Discount factor of bankers	0.977
β_s	Discount factor of saver households	0.997
h	Habits in consumption	0.8
ν^h	Weight of housing in utility function	0.94, 1.15
ν^n	Weight of hours worked in utility function	1
φ	Inverse of Frisch elasticity of labour supply	2
χ	Constant relative risk aversion	1
	Technology	
α	Capital income share	0.35
δ_k	Capital depreciation rate	0.015
F	Fixed production costs of intermediary firms	1.268, 1.276
θ	CES of intermediate good varieties	4
ν	CES of imports	1.2
s_k	Corporate investment adjustment costs	5
ω^M	Share of imports in domestic demand (in value added)	0.18, 0.11
	Housing	
δ_H	Housing depreciation rate	0.01
γ	Decreasing returns to scale in construction	0.75
s_H	Housing transaction costs	0.069, 0.073
s_{h_0}	Housing production scale parameter	0.6948, 0.7097
s_{h_1}	Housing investment adjustment costs	1.75
	Banking sector	
a_K	Bank capital ratio deviation costs	0.012
cb_f	Reserves with the central bank (as % of other bank assets)	0.008, 0.013
γ^b	Household loan-to-value ratio	0.82
γ^e	Corporate loan-to-value ratio	0.32, 0.33
ε^b	Complement of steady-state loss rate on household loans	0.9988, 0.9996
ε^e	Complement of steady-state loss rate on corporate loans	0.9959, 0.9989
ε^{ib}	Complement of steady-state loss rate on interbank loans	1
η^B	Effective risk weight on sovereign bonds	0.009
η^{IB}	Effective risk weight on interbank loans	0.029
η^{L_e}	Effective risk weight on corporate loans	0.097, 0.085
η^{L_h}	Effective risk weight on household loans	0.039, 0.033
ρ_b	Autoregressive parameter of household loans	0.7
ρ_e	Autoregressive parameter of corporate loans	0.65
ρ_f	Autoregressive parameter of bank capital requirements	0.24
s_b	Soft loan-in-advance constraint of households	1
s_e	Soft loan-in-advance constraint of firms	9
ω^f	Share of banks locked in a strategic game with sovereign	0.154, 0.290
ω^{HFT}	Share of sovereign bonds held for trading	0.51, 0.29

Parameter	Meaning	Value
	Portfolio managers	
ib_f	Domestic interbank loans (in % of corporate and HH loans)	0.07, 0.15
σ_f^B	CES of sovereign bond holdings	164
σ_f^{IB}	CES of interbank lending	1.281, 1.767
ω_f^B	Portfolio share of domestic bonds	0.91, 0.85
ω^{IB}	Portfolio share of domestic interbank lending	0.26, 0.66
	Government	
b	Steady-state government debt (in % of quarterly GDP)	3.6, 2.4
g	Steady-state government expenditure (in % of GDP)	0.19, 0.22
LGD_G	Loss given default on government bonds (in %)	0.6
m	Average sovereign bond maturity (in quarters)	34, 32
p_1	Sovereign default probability curvature parameter 1	0.0045
p_2	Sovereign default probability curvature parameter 2	3.8
t_1	Tax elasticity with respect to the government debt ratio	1.045, 0.711
t_2	Tax elasticity with respect to the output gap	0
t_3	Tax elasticity with respect to interest rate spreads	1.466, 1.327
	Monetary policy and prices	
ϕ	Calvo pricing parameter	0.8
γ_Y	Weight of output gap in Taylor rule	0.1
γ_Π	Weight of inflation in Taylor rule	2
Π^{EA}	Steady-state quarterly gross inflation rate in the euro area	1.00496
ρ_R	Policy rate smoothing	0.8

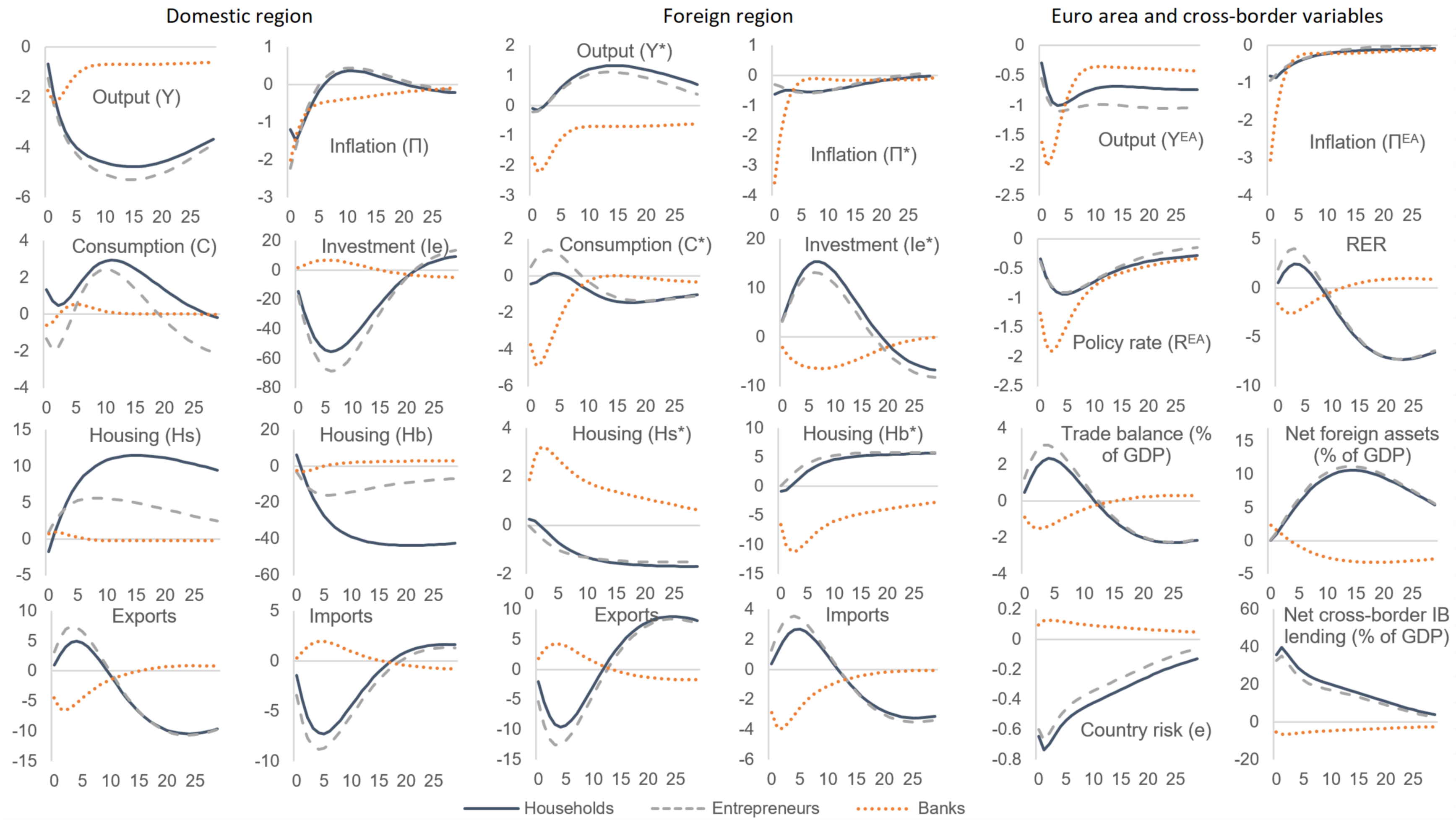
Note: When two values are shown, the first refers to the periphery (or domestic) region and the second to the core (or foreign) region

Figure 1: Impulse response functions for expansionary shocks (10% increase in domestic government expenditure, 1 pp cut in the policy rate and 1% increase in domestic productivity)



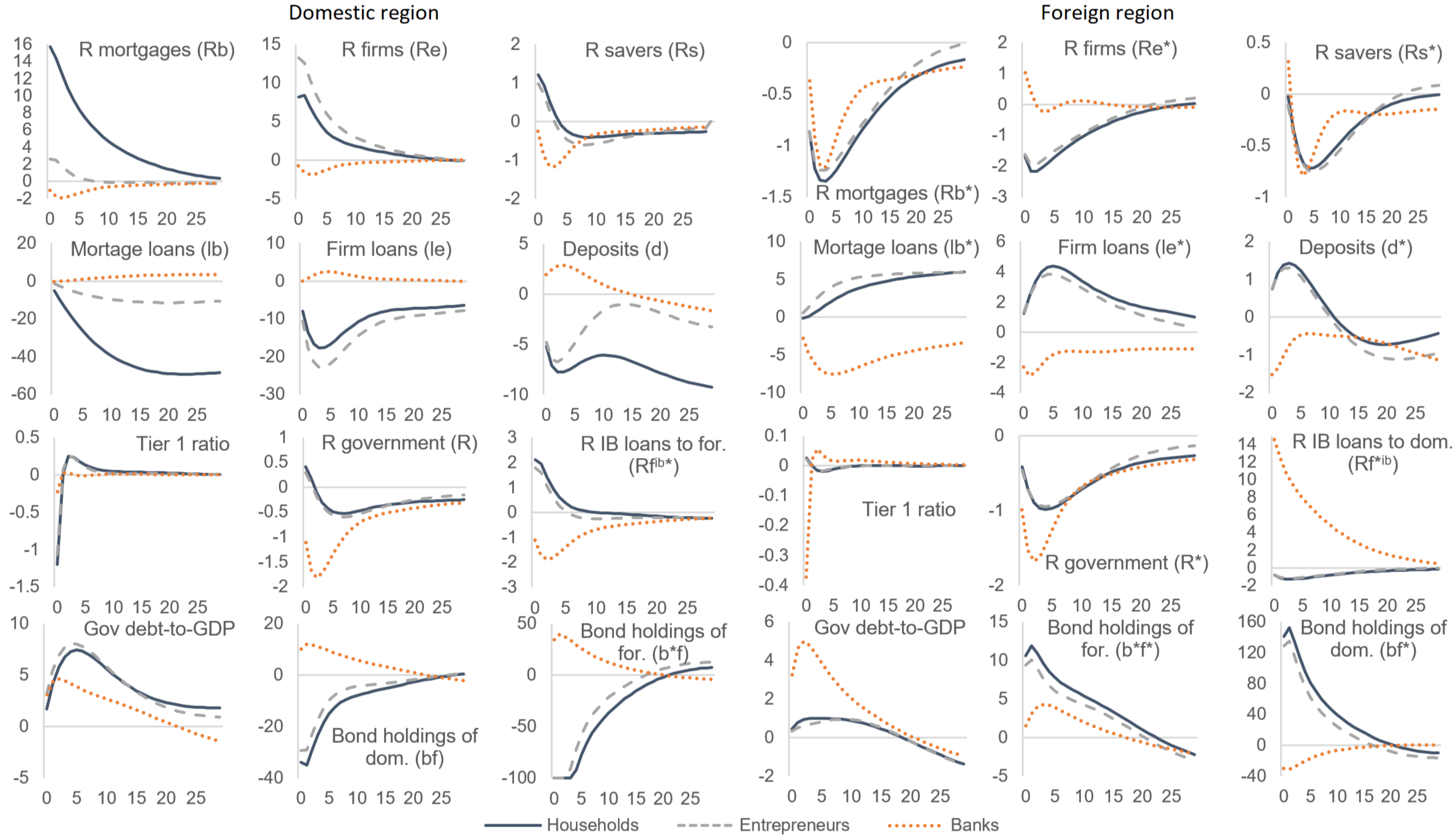
Note: interest rates, inflation, country risk and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Exports and imports in nominal terms. Shocks are assumed to have autoregressive parameter 0.9, except in the case of a monetary policy shock, which has autoregressive parameter 0.

Figure 2: Impulse response functions for credit risk shocks in the domestic private sector (default levels of households, entrepreneurs and banks increase by 5% of GDP)



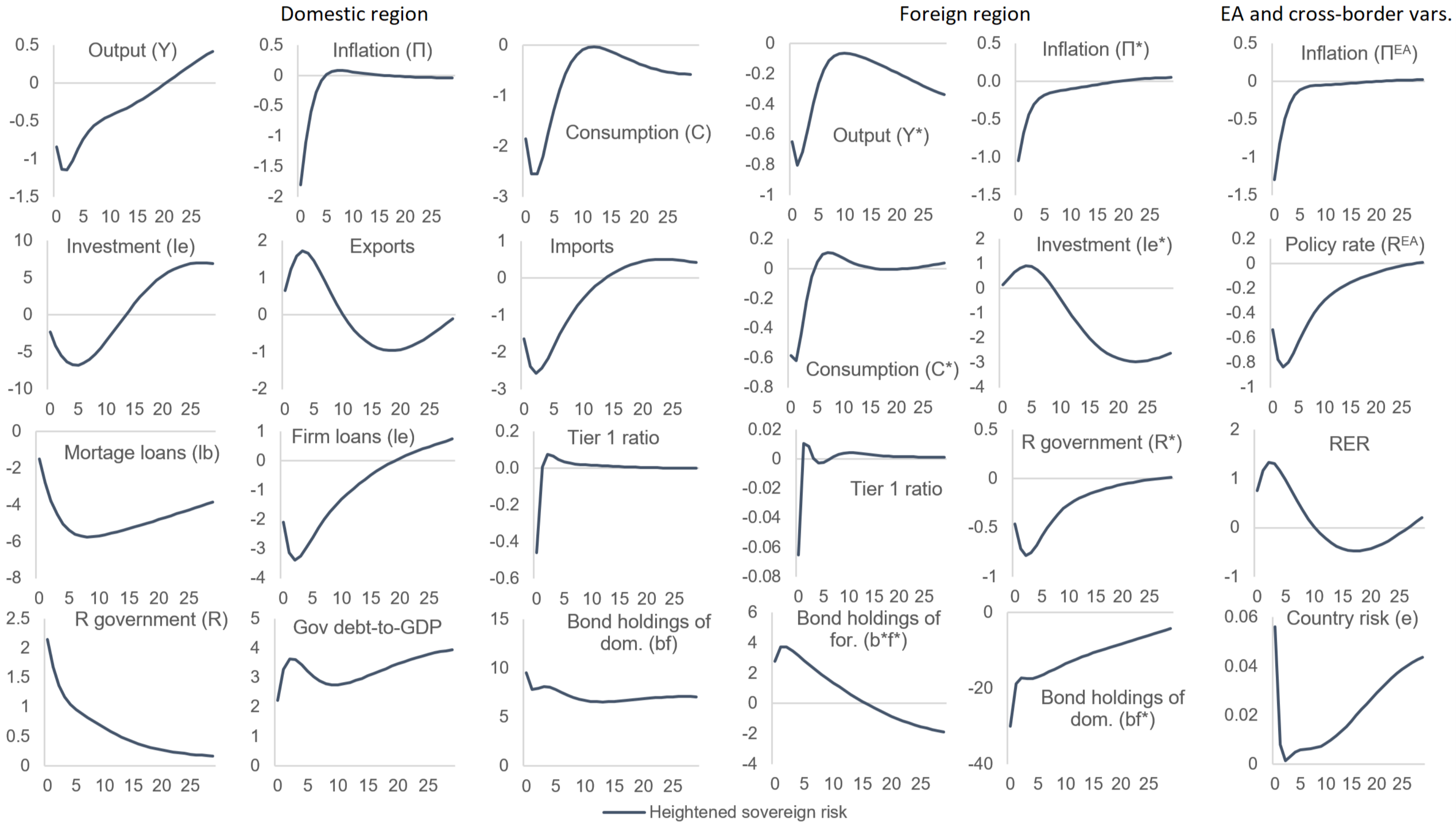
Note: interest rates, inflation, country risk and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Exports and imports in nominal terms. Shocks are assumed to have autoregressive parameter 0.9.

Figure 3: Impulse response functions for credit risk shocks in the domestic private sector (default levels of households, entrepreneurs and banks increase by 5% of GDP)



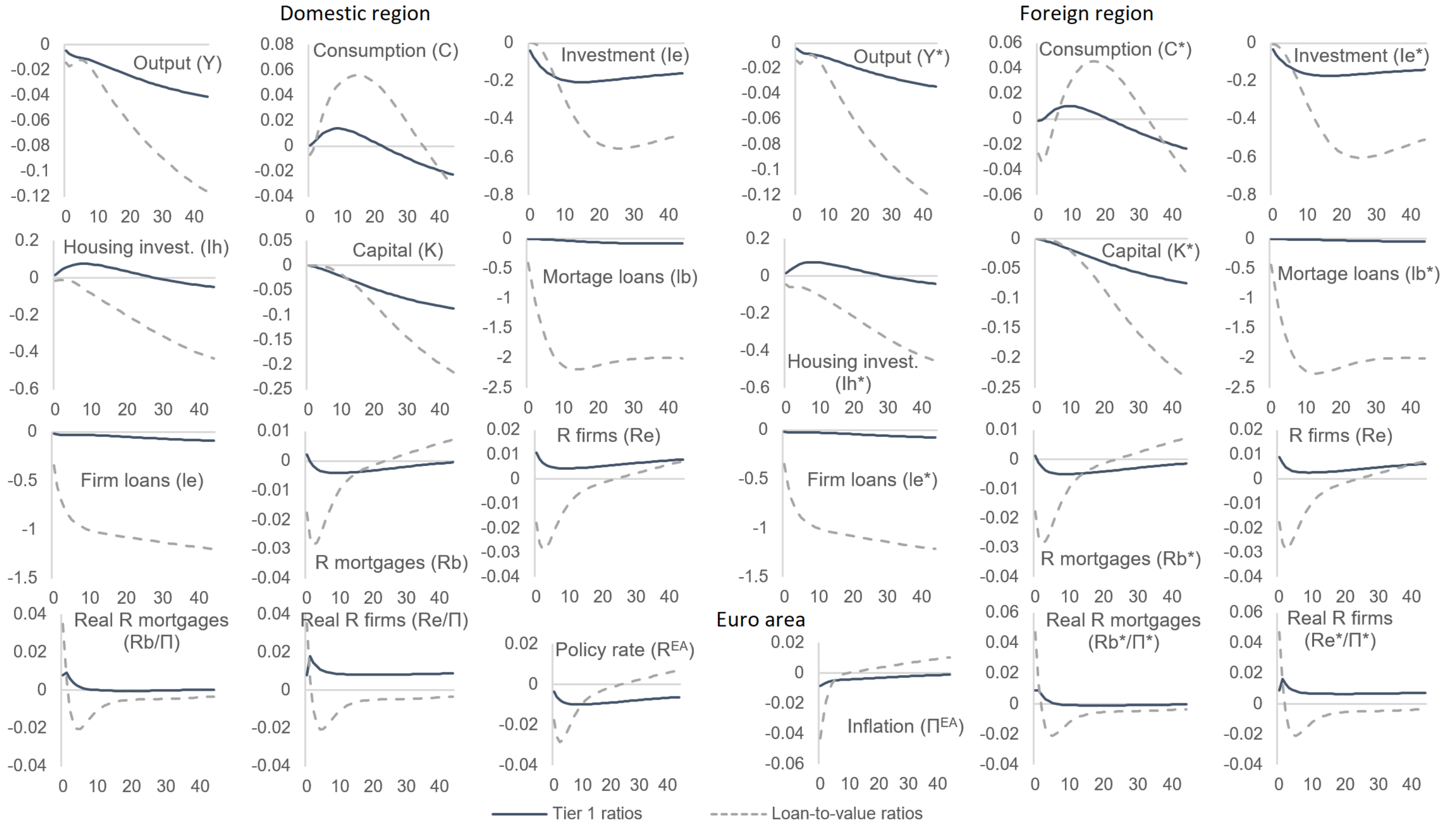
Note: interest rates and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Shocks are assumed to have autoregressive parameter 0.9.

Figure 4: Impulse response functions for a domestic sovereign risk shock (1 pp increase in quarterly probability of default)



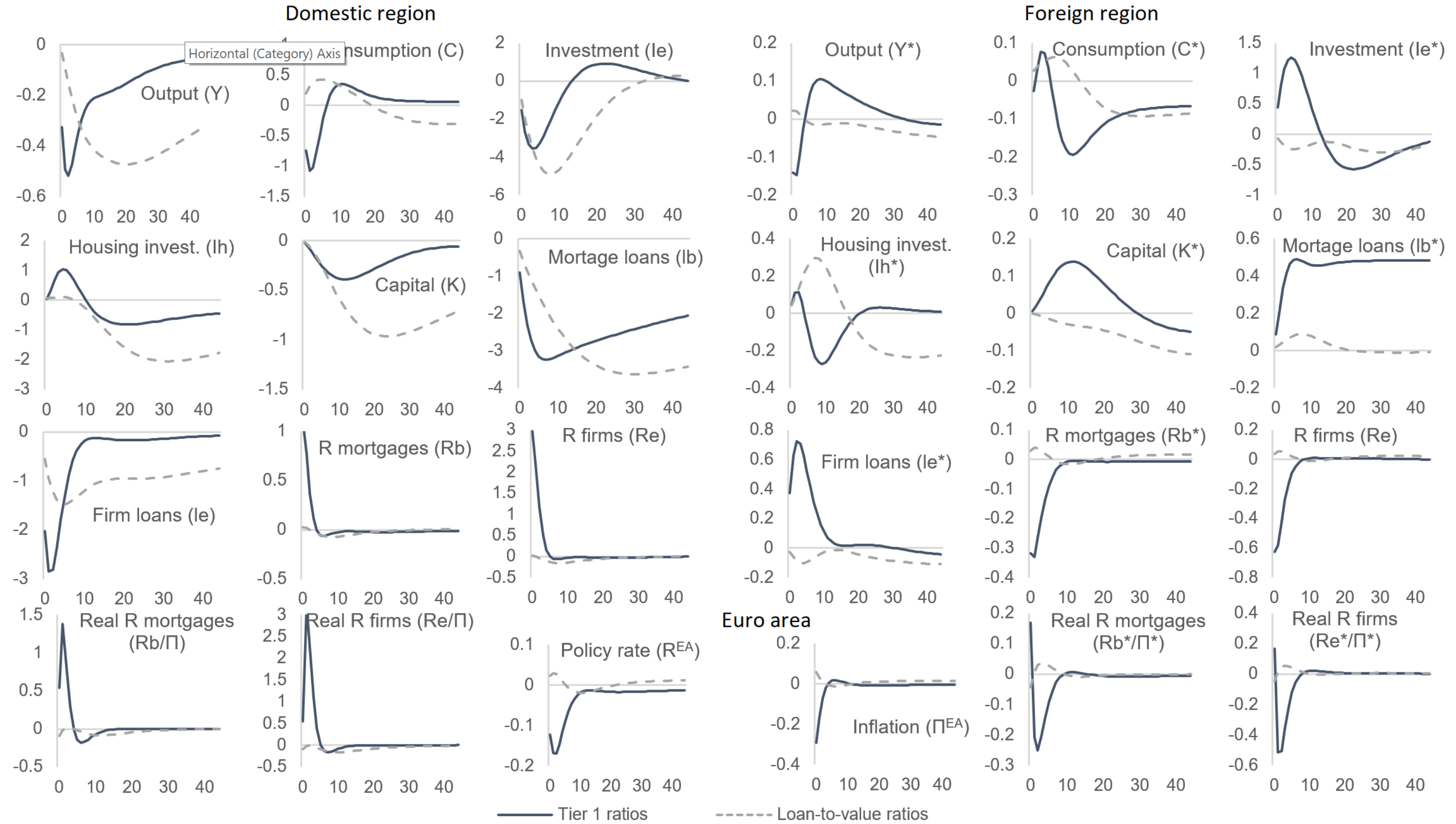
Note: interest rates and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Shocks are assumed to have autoregressive parameter 0.9.

Figure 5: Transition paths for permanent shocks to macroprudential policies in the euro area without transition frictions (1 pp increase in tier 1 ratios and 1% decrease in loan-to-value ratios)



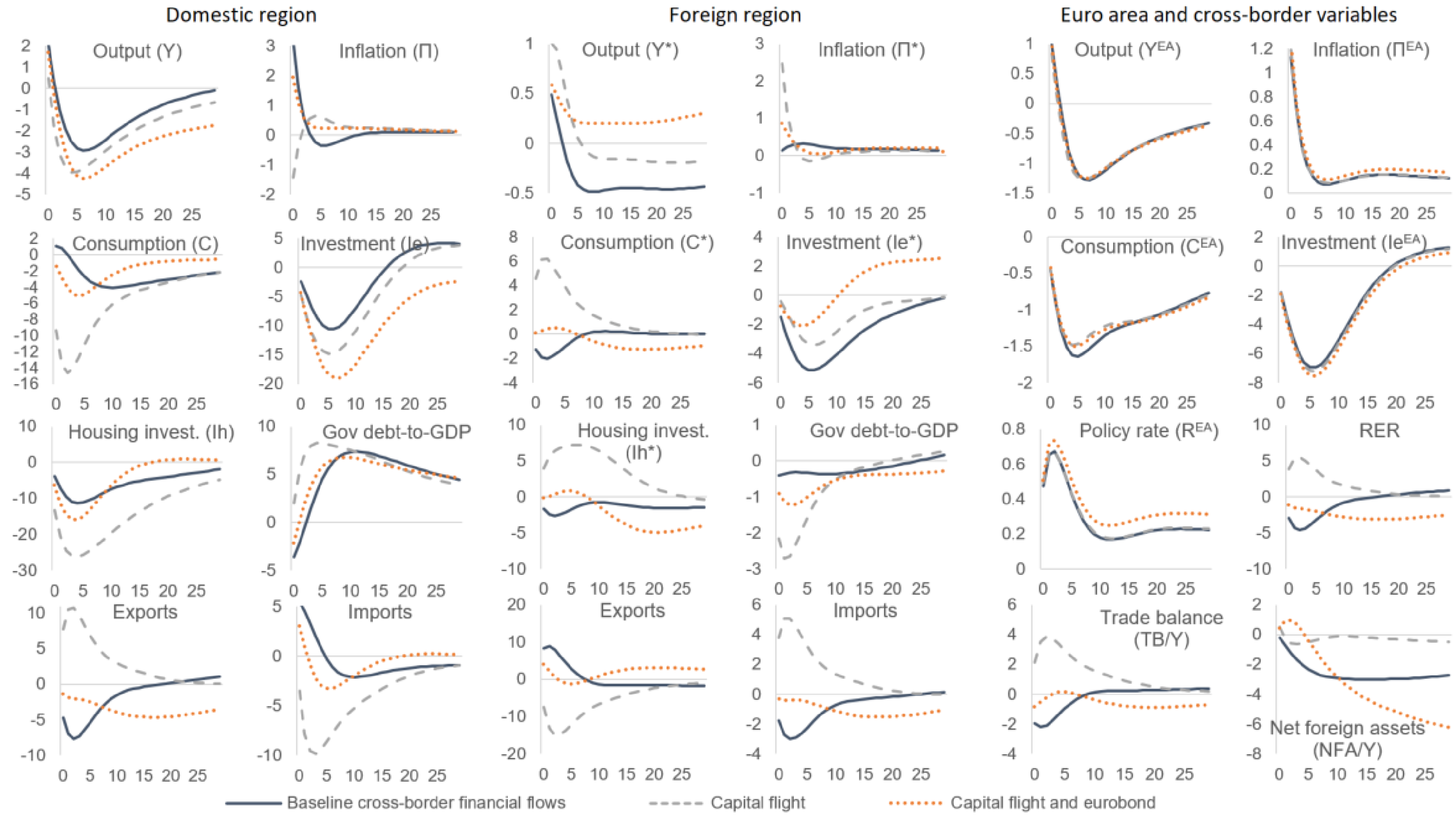
Note: interest rates and inflation expressed in percentage point change from initial steady state. All other variables expressed in percentage change from initial steady state.

Figure 6: Transition paths for permanent shocks to macroprudential policies in the domestic region, subject to transition frictions (convergence to the tier 1 ratio of core region and 1% decrease in loan-to-value ratios)



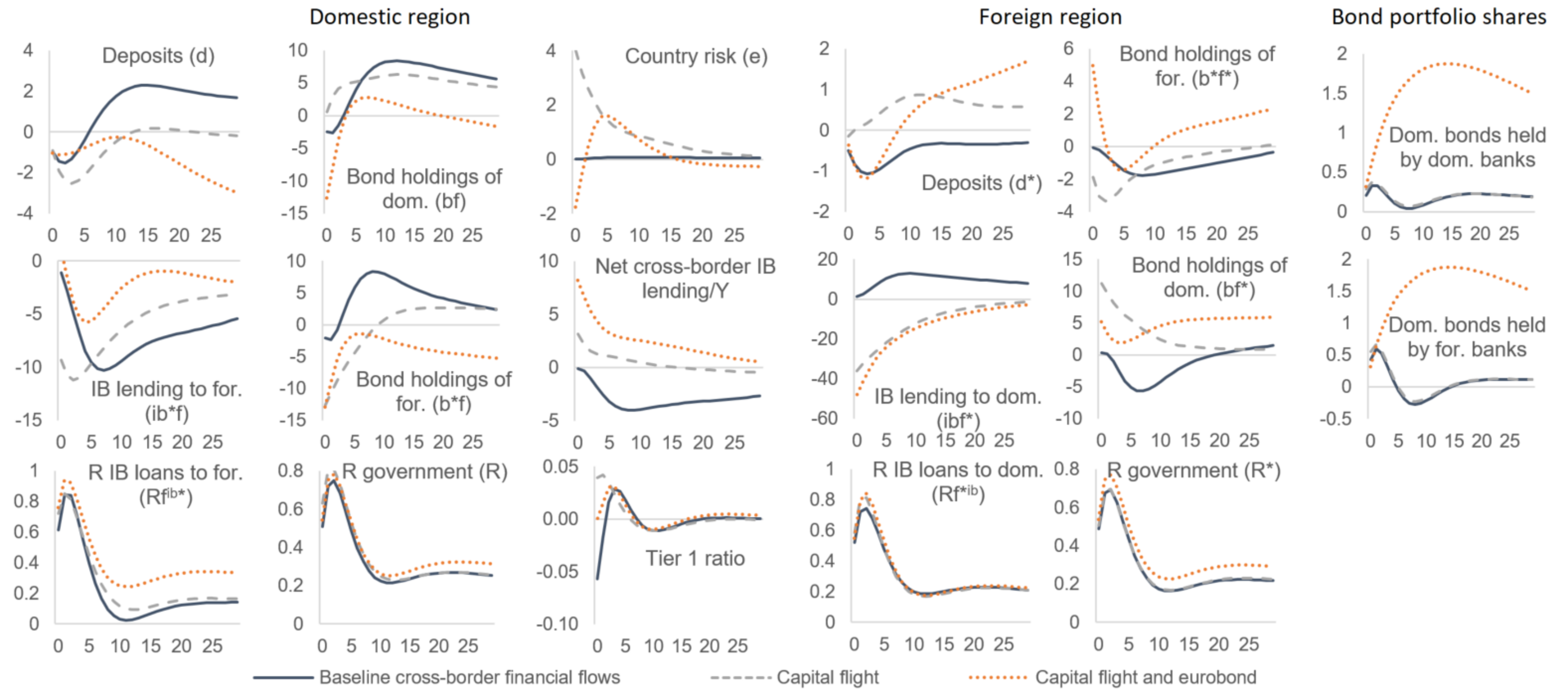
Note: interest rates and inflation expressed in percentage point change from initial steady state. All other variables expressed in percentage change from initial steady state.

Figure 7: Impulse response functions for a joint shock to domestic productivity (5% decrease) and government expenditure (25% increase), with and without international capital flights



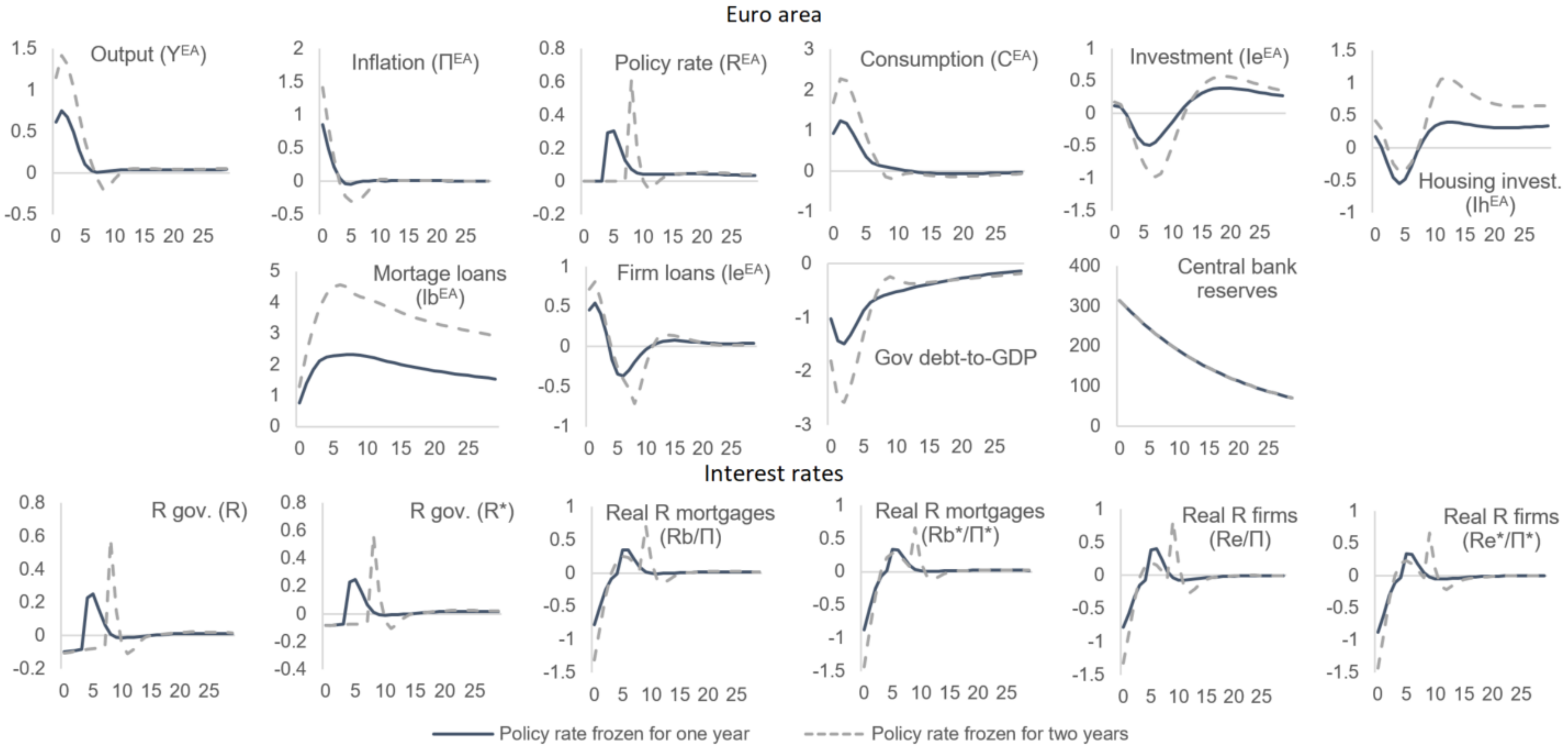
Note: interest rates, inflation and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Exports and imports in nominal terms. Capital flight is modeled as a 10 pp increase in ω^{IB^*}, together with a 99% decrease in σ^{IB} in both regions. Shocks are assumed to have autoregressive parameter 0.9, including the capital flight shocks.

Figure 8: Impulse response functions for a joint shock to domestic productivity (5% decrease) and government expenditure (25% increase), with and without international capital flights



Note: interest rates, country risk and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Capital flight is modeled as a 10 pp increase in ω^{IB^*}, together with a 99% decrease in σ^{IB} in both regions. Shocks are assumed to have autoregressive parameter 0.9, including the capital flight shocks.

Figure 9: Impulse response functions for an unconventional monetary policy shock (central bank purchase of 10% of outstanding government debt of both regions together with commitment to keep policy rate unchanged)



Note: interest rates and inflation expressed in percentage point change from steady state. All other variables expressed in percentage change form steady state. Bond purchases are assumed to have autoregressive parameter 0.95.