Eurobonds: a Path Towards Common Prosperity or a One-Way Transfer Union?

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Eurobonds: a Path Towards Common Prosperity or a One-Way Transfer Union?

A System Dynamics Approach Exploring the Possible Effects of Issuing Eurobonds on the Eurozone's Economic Growth and Stability.

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Master thesis

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Europe will be forged in crises, and will be the sum of the solutions adopted for those crises.

Memoirs of Jean Monnet, 1976

EXECUTIVE SUMMARY

Since the conception of the euro, it has often been suggested that the eurozone start a programme of jointly issuing government debt. There are many arguments for these so-called Eurobonds, and temporary issuance of them has already taken place in response to the economic impact of the recent COVID-19 pandemic. However, a permanent Eurobond programme remains a controversial topic within the EU.

Advocates claim that a Eurobond programme can facilitate economic growth and stability for the entire eurozone. It could offer much-needed fiscal space to some of the eurozone's most heavily indebted southern economies, by decreasing borrowing costs. It is assumed that the extra growth facilitated in these countries will spill over to the rest (mostly the less indebted north) of the eurozone, through increased cross-country trade and investment. Criticism mostly originates from the more financially sound eurozone member states, which fear a situation of moral hazard that leads to uncontrolled spending, and a possible deterioration of their own creditworthiness.

This research attempts to explore the economic effects of the introduction of Eurobonds on the eurozone economies. For this effort, two distinct types of Eurobonds are identified and analysed: unlimited Eurobonds and Blue Bond Eurobonds, with the former allowing unlimited issuance of mutualised debt, and the latter restricting this to 60% of a country's GDP.

The economic sub systems that are crucial for explaining the dynamics relevant to this study show a high degree of complexity and uncertainty; whether it is the dynamics of debt management (including stocks, flows, delays and feedback mechanisms), the different ways of determining bond yields (these are structural uncertainties), or the magnitude of economic elasticities/sensitivities (these are parametric uncertainties). These system characteristics stress the need for a simulation modelling approach. Because the interactions between the system's components and the relative importance of certain elements are of interest, and because the results should be insightful to non-technical policy-makers, a transparent, 'white-box' model can provide the most meaningful results. For these reasons, a system dynamics model has been developed for this study.

Specifically, an *exploratory system dynamics modelling and analysis approach* is used, due to the inherent structural and parametric uncertainties related to the system that have to be accounted for. Through exploratory experimentation with this model, the effectiveness of both Eurobond policies has been assessed based on how they affect eurozone and country-specific GDP, interest rates, and debt levels. All experimental results are robust for the different structural and parametric uncertainties identified in the system; multiple methods of determining bond yields taken have been into account, just as a large number of configurations of the parametric uncertainties.

As for the economic growth facilitated by both Eurobond policies, the country-level results are mostly insignificant (i.e., not more than 0.50% additional GDP growth after 10 years). Only slight increases in GDP are observed for both policies, with the benefits not evenly distributed amongst member states. Southern, more heavily indebted economies have more to gain, due to the larger relative decrease in their borrowing costs, assuming that the additional funding is spent productively. Furthermore, the anticipated positive economic spill-over effects caused by increased cross-country trade and investment (and not attributed decreases in interest rates) are shown to be insignificant as well.

However, the results of the analysis do indicate that both unlimited and Blue Bond Eurobonds have the potential to offer significant benefits to the eurozone's economic stability, by reducing borrowing costs for all participating countries. As anticipated, it is again mostly the heavily indebted southern economies that benefit from this. Unlimited Eurobonds offer slightly more benefits to these countries, when compared to Blue Bond Eurobonds. However, the latter is the preferred option for the less indebted north, since it restricts debt issuance and subsequently prevents Eurobond yields from surpassing their current borrowing costs; something will eventually be the case with unlimited Eurobonds.

Based on this study's results, a recommendation is made to start the implementation of (a variant of) the Blue Bond Eurobond policy. It has the potential to significantly increase the eurozone's public debt sustainability, while also offering minor (mostly insignificant) growth benefits to the heavily indebted southern member states, without deteriorating the creditworthiness and the fiscal position of the other, northern member states. Furthermore, the existing market pressure for prudent fiscal behaviour is maintained in the Blue Bond Eurobond proposal, mitigating the risks of moral hazard feared by critics of debt mutualisation.

Additionally, it is necessary to set up an adequate legal and political framework that incentivises fiscal discipline and does not allow for free-riding behaviour. A transfer of fiscal sovereignty to the EU level is to be a requirement for participation in the Eurobond programme. This is necessary to build confidence in the system, both for the eurozone member states, as for the capital markets and the general public. It is further deemed sensible to include a legal clause in the Eurobond programme that allows for the suspension of individual member states' participation. The (budgetary) conditions for such a clause to be invoked, and the potential (financial) penalties associated with this remain to be decided upon by the eurozone member states and the EU's (to-be erected) fiscal and monetary institutions.

Keywords: *Eurobonds, Bond yield determination, Debt sustainability, Macroeconomic analysis, Policy analysis, Exploratory Modelling and Analysis*

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This report marks the end of my seven and a half years as a student at the Technical University of Delft. My initial choice to study (and finish) the bachelor's degree of Industrial Design Engineering has been very helpful for establishing what I did not want to do in my future professional life; maybe the world has lost a talented drawer of vacuum cleaners though. During this time, I had always had the feeling that my curriculum was lacking certain elements that I felt especially passionate about. Since I became aware of the existence of the master's degree of Engineering and Policy Analysis, it was immediately clear to me that the focus on *societal grand challenges* that is at the core this study suited my interests a lot better. The switch of degree could not have been more fulfilling.

From my teenage years onwards, I have been interested in and engaged with national and international political affairs. In general, European politics has always been intriguing to me, perhaps not in the least because it is such a divisive topic on the national political level, especially in the Netherlands. It is my impression, that national debates about EU matters are not always fact-driven, and often guided by emotional sentiments and electoral considerations (e.g., the Dutch Ukraine referendum, or the UK Brexit vote, both in 2016). For this reason, I already knew from the start that I wanted my thesis to focus on a European policy issue, and to contribute to a fair and rational analysis. Because I hosted a discussion on the topic in 2020, I had become aware of Eurobonds and their possible implications, and since the topic became relevant again during the COVID pandemic, I knew what I wanted to work on. Using system dynamics modelling to do so made it even more exciting, because this had become my favourite modelling technique since I first followed a course on it.

It has not been hard to find a suitable pair of supervisors to guide me through the process of writing a thesis on this topic. After getting in touch with my first supervisor Willem Auping, I was happy to hear that he was also excited about the topic. Starting from that moment, our weekly meetings have been helpful and motivating for me to work in a semi-structured way, both for writing and modelling. For this, I would like to express my gratitude. These moments of feedback were always insightful, and often fun as well. I was also warned, however, that the topic might be quite complex. Luckily, that is where my second supervisor, Servaas Storm, joins the story. Being a passionate economist, he was the ideal second supervisor for my thesis project. I would like to thank him for his involvement and support. Though not weekly, we have had meetings on several occasions, and the discussions we had were always critical and insightful, providing me with much-appreciated economic context and general advise. Lastly, I would like to thank the chairman of my graduation committee, Cees van Beers. Even though we have only met during the official kick-off and green-light meetings, his feedback has been helpful overall.

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Robin Lenskens

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1. CONTENTS

1. INTRODUCTION

Eurobonds evoke both fierce support and opposition from all corners of the eurozone. For some, it is a necessity to preserve the euro and to facilitate economic growth and stability, while for others it is a sure path towards a fiscal transfer union benefiting just the heavily indebted member states.

Whatever its position on the issue, a country's stance on Eurobonds is often affected by electoral considerations. This can complicate a fact-based debate, especially as the overarching topic of economic growth is not so straightforward: it depends on an array of factors like demographics and trade (Barro 1996; Chirwa and Odhiambo 2016). The system is so complex that simple mental models often fail to address the important dynamics at play. Developing a simulation model to explore the economic effects of Eurobonds can help policy-makers better understand the issue.

Most countries in the EU have a very open economy (World Bank 2021b), and for the vast majority of these countries, other EU member states are their biggest trading partners (Trading Economics 2022). Considering the high reliance on trade and the subsequent economic interdependence of the member states, there is a clear interest in each other's economic success. Despite this, middle-sized, wealthy countries like the Netherlands and Austria mostly maintain a 'frugal' attitude towards helping other member states, forming a coalition of smaller-sized countries that mostly opposes any form of monetary integration like a Eurobond programme (Verdun 2022).

Eurobonds are a proposed instrument of issuing mutualised eurozone-backed public debt, as opposed to the current situation where every country borrows capital by itself. It is a tool meant to promote economic growth and stability. Politicians from many other (mostly southern) eurozone countries do support the idea and stress the benefits it can offer (Politico 2017; Reuters 2011a; Le Monde 2022; Reuters 2015). However, many European politicians from the north have been sceptical about such initiatives, as Eurobonds could lead to a situation of moral hazard, with reduced incentives for fiscally prudent behaviour. Furthermore, Eurobonds could create a so-called 'transfer-union' they say, only benefitting the southern member states, at the cost of the north (VVD 2019; Deutscher Bundestag 2021; CDA 2021; Wiener Zeitung 2020).

This northern restraint is rooted in the fact that a Eurobond programme would imply one interest rate for all participating governments when collectively borrowing money. This rate might be higher than the current German Bund's interest rate, and lower than e.g. current Italian rates. However, it is generally assumed that for the euro area as a whole, borrowing costs could become lower than they are now, because liquidity in the Eurobond market would be larger than that of all national bond markets combined, and the market's risk perception would be lower than the weighted average of all current bond markets combined (Delpa, J. and von Weizsäcker, J. 2010). If true, this would allow weaker eurozone economies to invest in their structural growth capabilities, at a favourable interest rate, strengthening (amongst others) northern export markets.

However, the determination of the interest rate paid over government bonds (and thus the yield received by the holders of these bonds) is partly based on non-rational, human decision-making of the capital markets. Due to this, it cannot come as a surprise that there is no exact scientific consensus on the exact determination of bond yields, and the determinants are even said to change over time (Alcidi and Gros 2019; Ardagna et al. 2007; European Commission 2018; D'Agostino and Ehrmann 2014; Grauwe and Ji 2013; Gómez-Puig 2006; Vries and Haan 2016); Kumar and Baldacci 2010; Gruber and Kamin 2012; Ardagna et al. 2007). This is a typical example of a structural uncertainty that this study takes into account. It is a crucial element for any analysis that attempts to explore the effects of introducing Eurobonds, because it is the interest rate paid over Eurobonds that determines whether the policy is perceived as a fiscal transfer union, or whether it can immediately benefit not just a few member states, but the eurozone as a whole. Considering the differences in old (sovereign) and new (Eurobond) interest rates, the question remains whether a Eurobond programme would offer northern member states positive value, and if so, under which conditions.

Answering questions like these requires a clear understanding of the underlying fundamental mechanisms that affect debt management, economic growth, spill-over effects between economies, and bond yields. Next to the structural uncertainties related to the latter, scientific literature also provides varying approaches towards the exact parameterisation of all other system components. The relative importance and the absolute magnitude of many determinants, sensitivities, and elasticities remain ambiguous. Due to this overall complexity and uncertainty, this study attempts to provide insight using a simulation model.

Since the relevant economic system includes the accumulation of stocks, flows, delays and feedback mechanisms, the choice was made to develop a system dynamics (SD) model to simulate the eurozone economy for the period of 2022 to 2032. This is a white-box modelling technique that is especially well-equipped to inform policy-makers of complex dynamics. Furthermore, the structural and parametric uncertainties present in the system require an exploratory rather than a deterministic modelling approach, to account for all possible future scenarios; that is why an *Exploratory System Dynamics Modelling and Analysis* approach is used for this study (Kwakkel and Pruyt 2015).

This research attempts to explore the effects of introducing Eurobonds both on the overall eurozone economy, as on the level of individual member states. More specifically, this study's results should provide insight into the distribution of growth- and stability-related costs and benefits across the eurozone, while taking the system's structural and parametric uncertainties into account. The aim is to offer a foundation for future political debate and to provide actionable recommendations to European policy-makers. The main research question to be answered is:

What are the effects of issuing Eurobonds on the eurozone's economic growth and stability?

The sub-questions required to answer the main research question are as follows:

SQ1. What is the intended goal of introducing Eurobonds and what different types of Eurobonds can be distinguished?

SQ2. Which system elements and uncertainties need to be considered when modelling the economic effects of Eurobonds?

SQ3. Do Eurobonds facilitate economic growth and stability for the eurozone, and which countries have most to gain or lose with Eurobonds?

A necessary first step is to clearly define the characteristics of a Eurobond programme and to distinguish between different types of Eurobond proposals. Based on this, model assumptions can be made. Chapter 2 provides some economic background and will cover this issue more thoroughly to answer the first sub-question.

Sub-question 2 is addressed in chapter 3, which covers the methodology of this study. An overview of the modelling technique and the used approach are provided, along with details about the model's structure and its uncertainties, followed by a validation section.

Sub-question 3 is addressed in chapter 4 and it serves as a basis for any conclusions and recommendations. It can be answered by using the results of the modelling experiments that take the system's uncertainties into account.

2. BACKGROUND

During the European sovereign debt crisis, the issuing of eurozone-wide mutual government bonds (i.e., Eurobonds) was seriously considered as a possibility for creating financial stability and promoting European monetary integration (Reuters 2011b; Euractiv 2011). During this time, the debt-to-GDP ratios of several countries in the euro area had risen significantly, leading to a severe increase of yearly interest payments. For countries like Greece, Ireland, Portugal Spain and Cyprus, a sovereign default came very close. It was due to financial support from both the EU and the IMF that the situation had not come so far. The EU subsequently set up programmes that are funded by the member states to aid economies that are in need of support. Additionally, the ECB drastically changed its policy in this period and became one of the biggest holders of European sovereign debt, something that was even prohibited before (TFEU 2008).

Although the policy interventions of this crisis and post-crisis period do all indicate solidarity (or at least the acknowledgement of interdependence), the funding of these programmes did not involve or require the mutual issuance of any debt instruments like Eurobonds. In 2012, German chancellor Angela Merkel even said that there would be no Eurobonds as long as she is alive (Handelsblatt 2012), with the fiscally conservative FDP subsequently wishing her a long life. The fact that Eurobonds have not been introduced in some form in the aftermath of the European debt crisis can be politically explained and attributed to the dominant narrative in the public policy domain at that time, which was more oriented towards national level economic prescriptions of austerity (Matthijs and McNamara 2015).

However, the idea did surface again as a response to the impacts of the COVID-19 crisis. Although initially disputed, the situation called for drastic action and it soon lead to the (partially fulfilled) option of de facto issuing Eurobonds for the *SURE* and *Next Generation EU* programmes of up to 850 billion euros (European Commission 2021a, 2022). The funding raised by these programmes was only meant for specific purposes though, and loaned from the European Commission to the member states in need. Also, these programmes are only temporary. Permanent issuance remains controversial; even proposals for similarly raising funds for the financial assistance of Ukraine have met fierce resistance within the EU (Politico 2022).

2.1 ARGUMENTS FOR AND AGAINST EUROBONDS

Before diving deeper into the different types of permanent mutual bond issuance that have all been suggested at one point, it is insightful to first elaborate further on the main arguments for introducing Eurobonds, and to discuss the most common arguments against this. All arguments can generally be categorised as being either economic or political. For the economic arguments, there is a subdivide between growth-related and stability-related arguments, as the next sections will show.

2.1.1 Stability

It is not hard to imagine that a more evenly spread sovereign bond interest rate burden over all member states (i.e., a smaller spread) would soften any macro economic blow. The so-called flight-to-safety phenomenon (i.e., avoiding risky investment options in times of crisis) that was very visible during the European sovereign debt crisis tends to reinforce any existing interest rate spreads and worsen the inequal distribution of the crisis' costs.

It is often stated that the worst effects of the most recent financial crisis would have been significantly reduced if there had been a Eurobond programme in place in the eurozone at that time, especially because such a programme would mitigate any self-fulfilling market dynamics, moving liquidity away from weaker member states' bond markets. This is also the conclusion of two quantitative research papers (Gilbert et al. 2013; van den Noord and Codogno 2021). However, in both cases the authors do acknowledge that Eurobonds could create a situation of *moral hazard* that would encourage fiscally weaker participants to be less disciplined, budgetary speaking, because the market's incentivising function is reduced. This remains a substantial fear amongst the mostly northern eurozone member states. In the end, many Eurobond proposals represent some sort of balance between stability and moral hazard (Gilbert et al. 2013).

2.1.2 Growth

Apart from the increased resistance to any external shocks like we have seen in recent crises, implementing Eurobonds can also offer overall growth benefits on the long term because of the lowered total interest rate pressure (Grauwe and Moesen 2009). Becoming an attractive safe asset for international investors will offer the euro a similar position to the dollar, with high liquidity and a low market risk perception, possibly reducing the interest rate to even lower levels than the German Bund's (Matziorinis 2012). If the interest rate is lowered, more investment opportunities become worthwhile, further stimulating the economy. Additionally, this lower rate creates extra fiscal space (at least in weaker member states), that can be used to invest into their respective structural growth capacities, leading to increased economic growth.

However, not everyone expects Eurobond interest rates to be lower than the current weighted average of all eurozone interest rates. The influential German IFO Institut has published that it expected Eurobonds to cost the German state an additional 47 billion euros per year (Berg et al. 2011). One year earlier, the German Minister of Finance stated that Eurobonds could cost the country between 2 and 17 billion euros annually (Frankfurter Allgemeine 2011). If true, this would come at the cost of German public investment, considering the country's constitutionally embedded *debt brake* which prevents it from running structural budget deficits. However, these cost estimations have all been made before the *SURE* and *Next Generation EU* programmes, which have both shown considerable investor interest in the instruments, and subsequently negative yields (European Commission 2021b).

Apart from the discussion about the potential costs of Eurobonds, the potential benefits are also subjected to certain conditions. The raised funding has to be spent productively, in order to facilitate any economic growth. The government spending categories that have the largest positive effect on long-term economic growth have been identified in academic literature (Gemmell et al. 2016; Fouladi 2010). In practice, for EU countries, the assumption that government expenditure has a significant influence on economic growth holds. Evidence of this has been found for eight out of eight EU countries analysed (Dudzevičiūtė et al. 2018), but an explicit guarantee to put the funding to productive use would be much-appreciated by the north. The question whether the increased economic growth also creates a spill-over towards other eurozone economies requires additional dynamics to be addressed.

Additionally, Eurobonds are well-suited for the funding of large pan-European (infrastructural) projects that could help the eurozone's economic recovery, while stabilising current account balances (Duwicquet et al. 2015). However, in its current form, the EU's annual budget can be vetoed by any member state, often leading to less ambitious investment programmes.

2.1.3 Political

Finally, there are quite some political arguments in favour of issuing Eurobonds. First and foremost, a rise in the euro's use as a world reserve currency that is used for all sorts of trade, would offer the EU a larger degree of geopolitical independence (e.g., maintaining an independent sanction policy).

Already since shortly after its conception, economists have speculated that the euro could (partially) take over the dollar's role as the world's reserve currency, or at least share this position (Eichengreen 2005), but its rise in this respect has stagnated and remains at a level similar to when the euro was first issued (ECB 2021). The euro is still 'punching below its weight' due to the fact that there are no eurozone-wide safe and liquid assets (Ilzetzki et al. 2021), something that could be provided by introducing Eurobonds. A stronger international role for the euro, achieved through strengthening and deepening the Economic and Monetary Union (EMU) (i.e., mutualising debt), is one of the key pillars for the EU's strategy to reach economic and financial strategic autonomy, while also maintaining an open economy (Council of the European Union 2022).

The political arguments against Eurobonds can seem partially electorally motivated, like in Germany, where 80% of the population was against the idea of Eurobonds at the time of the European sovereign debt crisis (Howarth and Schild 2021). It is common in northern Europe to perceive southerners as lazy (Zeit 2020), and the fact that e.g. the Italian shadow economy's fraction of GDP is twice as big as for Germany (Medina and Schneider 2018) does not increase the north's trust in the south's financial management. In situations like this, advocating for any form of increased European fiscal integration can come at a cost of votes, as has happened to the social-democrat SPD in the 2017 election, after participating in a governing coalition. Furthermore, it is possible that some national constitutional courts would deem Eurobonds and the national guarantees they require to be unconstitutional, at least within the current EU legal framework, similar to what has happened in the recent past (Bundesverfassungsgericht 2020). Next to that, the European political landscape contains many eurosceptical elements – be it politically, economically or culturally motivated - that are against any form of sovereignty transfer to the European level (Usherwood and Startin 2013). Any serious Eurobond programme should account for all of this.

2.2 SOURCES OF ECONOMIC SPILL-OVER EFFECTS

European debt mutualisation could provide economic growth in all participating member states, especially if the new interest rates are lower than the current ones. However, if this condition is not met for all countries, would Eurobonds still provide economic benefits? To judge that, a deeper understanding of the economic dynamics between eurozone economies is required.

This section dives into the topics of European trade and investment flows and assesses their determinants. These are two important components of cross-country flows of capital that are required to determine spill-over GDP growth effects within the eurozone.

2.3.1 Trade

Easier and cheaper trade within the EU is one of the biggest benefits that the internal market offers, positively affecting all EU member states' GDP growth (CPB 2022). These benefits can be explained by the removal of many trade barriers (i.e., the creation of a single market and an economic union). The positive effects are found to be strongest in open economies, like the Netherlands. For almost all member states (except Cyprus, Malta and Ireland), intra-EU trade accounts for more than 50% of total international trade (Eurostat 2021). These numbers indicate a high degree of economic interdependence withing the EU; an increase in one country's imports stimulates another country's exports and vice versa.

In order to determine the positive effects of economic growth on other economies, a relationship between exports and economic growth has to be established. There is an abundance of scientific literature about this topic that has proven the existence of (in some cases bi-directional) Granger causality between the two in advanced economies (Kónya 2006; Michelis and Zestos 2004; Guan and

Hong 2012). These findings are in line with the export-led growth theory that has served as a guideline for many economic policy-makers in their goal of stimulating economic growth.

At the same time, higher productivity in one country (due to increased investments and GDP growth) should make its exports more attractive and competitive because of a decrease in its relative price. The degree to which trade flows respond to changes in relative prices can be expressed as import or export elasticities. Not all international trade can be explained by these elasticity factors and they differ per sector. However, there is broad economic consensus over this mechanism, although the estimates and measuring techniques of the elasticities tend to differ (Simonovska and Waugh 2014; Yilmazkuday 2019; Raimondi and Olper 2011).

2.3.2 Foreign Direct Investment

Another factor that is frequently linked to GDP growth is foreign direct investment (FDI); FDI-led growth and growth-led FDI are two theories that explain the relationship between the two variables. It is especially important for developing countries though, where FDI's relative contribution to the national capital stock is significant (UNCTAD 2016).

In a paper that looked at the ASEAN countries, a bi-directional causality between FDI and GDP, as well as a unidirectional causal relationship between FDI and exports were found (Ahmad et al. 2018). The researchers noted that FDI is an important contributor to creating a competitive environment and it helps to exploit the competitive advantages of a country. Another study has analysed the same set of countries and found similar results (Vogiatzoglou and Thi 2016).

A lot of research has been conducted that attempts to identify the factors that predict FDI itself. This has been done for specific countries (Birsan and Buiga 2009; Kinuthia and Murshed 2015; Shaukat Ali and Wei Guo 2005) and for general types of countries (Oladipo 2010; Saini and Singhania 2018). These studies assume that determinants like market size, labour costs, trade barriers, growth rate, openness, trade deficit, exchange rates, and taxes all play a role.

Although many cross-country FDI regression analyses have found causal links between these factors and FDI, an influential article published in Kyklos (Chakrabarti 2001) that assessed most serious studies about the topic thus far, had found these studies not to be robust (i.e., they are very sensitive to only minor changes in the underlying information sets). This conclusion has been confirmed by later literature reviews (Blonigen 2005). The extreme bound analysis technique that had been applied in the original study only found the correlation between market size and FDI to be robust.

These ambiguities can be explained by the heterogeneity of FDI inflows. In a working paper for the IMF (Walsh and Jiangyan 2010), it has been pointed out that the significance of several FDI determinants is sector- dependent. The IMF researchers found that openness, the real exchange rate, GDP growth, and the existing FDI stock are significant determinants for inwards FDI flows, especially for developed economies. Despite its relatively minor importance for the euro area economies, FDI is a clearly distinguishable component of cross-country investment flows and it is well-suited to be included in this study because of its characteristics.

2.3 DIFFERENT EUROBOND CHARACTERISTICS

There is a wide array of Eurobond flavours to pick from, and like some model-based studies point out (Beetsma and Mavromatis 2014; Badarau et al. 2021), the degree to which Eurobonds can provide any of the previously addressed positive effects depends on the characteristics of the suggested monetary reform. It is out of the scope of this research to quantitatively compare all Eurobonds proposals that have been made. However, understanding the core elements and similarities of these proposals is crucial for the right parametric configuration when developing a simulation model.

The most common Eurobond proposals can be differentiated along a few lines. They either suggest full or partial liability, and they differ in their restriction of the maximum amount of Eurobonds to be issued. Finally, multiple Eurobond proposals require different political and institutional conditions. The next sub-sections elaborate on each of these characteristics.

Pure and simple full Eurobonds that come in the place of national government bonds all together might not offer the best balance. The European Commission had this to say about it: "This would have strong potential positive effects on stability and integration. But at the same time, it would, by abolishing all market or interest rate pressure on Member States, pose a relatively high risk of moral hazard and it might need significant treaty changes." (European Commission 2011).

2.2.1 Full or limited joint liability

Full joint liability pertains to the repayment guarantee of all participating nations of all outstanding Eurobond debt. If a country cannot repay its sovereign debt, it normally defaults and has to restructure its debt or devalue its currency. With full joint liability Eurobonds in place, all participating countries are responsible for debt repayment and a default of a single country is impossible. This is exactly what gives Eurobonds its high level of credibility that leads to lower overall borrowing costs. At the same time, this issue is the most politically controversial element of this proposal.

For this reason, some economists call for a partial sovereign bond (Bauer and Adolph 2021, 2021, 2021). They suggest to issue bonds that are all partially insured by all eurozone members. A joint liability level of 10% seems optimal according to them. The paper also takes political feasibility into consideration and states that this solution is easily fit in current European legislature. Partial liability could be reached by pooling sovereign bonds into an asset-backed security (ABS) with several tranches, with losses covered by a trust fund that is financed by participating countries (Hild et al. 2014).

However, most Eurobond proposals suggest full joint liability. The most called-for option is the so-called *Blue bond proposal* (Delpla and Weizsäcker 2011). This concept would mean that each nation's sovereign debt be split up in a 'blue' and a 'red' part. The blue part consists of jointly issued and jointly guaranteed Eurobonds whereas the red bonds represent conventional (sovereign) bonds that have a junior status when it comes to repayment priority.

2.2.2 Maximum issuance

The first serious Eurobond proposal suggested a full switch to Eurobonds, abolishing the option to issue sovereign bonds (Boonstra 2005). The plan included a suggestion to establish an EMU fund to issue up to an unlimited amount of Eurobonds. These would be lent to the participating countries at a premium, on top of the Eurobond rate. To counter any free-riding, this premium would be based on the country's deficit and its deviation from the debt level of Germany and France. Despite the positive incentivising elements, this proposal had been tough to sell politically, and the need for such a proposal was not felt at that time.

Instead of adding a calculated premium, many Eurobond proposals suggest a maximum issuance of Eurobonds to counter any possible free rider behaviour. The Blue Bond plan includes a proposal to cap the amount of (blue) Eurobond debt to be issued to 60% of the participating nation's GDP. With the remaining red bonds, a good behaviour incentive from the market still exists and might even be exaggerated (due to the junior repayment status of the red tranche). Many other Eurobond proposals also suggest a maximum issuance of 60% of GDP (equal to the current Maastricht norms).

Several variants to the Blue Bond proposal have been suggested, like one limited to short-term mutualised debt (i.e., Eurobills instead of Eurobonds). The proposal pools all national borrowings, backed up by a joint guarantee which lowers the overall interest rate. The benefit of issuing Eurobills over Eurobonds is that it imposes continuous discipline, because there is no certainty that the guarantors renew their guarantees. The plan suggests a maximum Eurobill issuance equal to 10% of GDP for each participating nation, based on the US Treasury Bills market size (Philippon and Hellwig 2011).

2.2.3 Political and institutional requirements

Next to the free-riders problem, the main disadvantages related to Eurobonds are tensions with the no-bailout clause, credibility and political viability (Eijfinger 2011).

The no-bailout clause is part of the Maastricht Treaty (Article 125 of the Treaty on the Functioning of the European Union) and de facto prohibits countries from taking over each others' debt. At first sight, many Eurobond proposals seems to go against this clause. However, the clause does not rule out member states 'bailing out' other countries by lending to them. Neither is there any prohibition on restructuring loans. It has been established that the European Stabilisation Mechanism (ESM) for example, is consistent with the clause. To be compliant with this, any Eurobond proposal has to rule out direct bail-outs. A high level of credibility is necessary for such proposals.

In order to maintain credibility for any Eurobond programme, multiple prerequisites have to be met. First of all, the higher the participation degree, the more credible a Eurobond scheme is. Some proposals suggest a voluntary basis (and assume participating is worth it for any country), whereas others require all eurozone countries to join. An important condition is that participants cannot borrow 'on the side'. Second, the payment guarantee of all participating countries has to be binding and unconditional. However, e.g. for the Blue Bond proposal, there still needs to be an orderly procedure for filing for national bankruptcy (for the sovereign (red) debt part).

Finally, all the previously discussed Eurobond proposals include a need to establish a European Debt Agency (EDA), be it to judge the budgetary prudence, manage the distribution of gains and costs, or to issue Eurobonds itself. Whatever the final function of the EDA, it should have a mandate from all participating countries for collecting liquid funding, which the national debt agencies have to partially (depending on the proposal) cease to do. Furthermore, the institution should be completely independent, have full insight into all national budgets and be able to suggest required amendments to this budget, as to prevent any free-riding fiscal behaviour. The possibility of penalising non-compliance could further stimulate good behaviour. Because this implies a transfer of national fiscal sovereignty towards the EU level, political backlash is to be expected, especially from the countries that believe to have the least to gain from Eurobonds.

SQ1. What is the intended goal of introducing Eurobonds and what different types of Eurobonds can be distinguished?

In this chapter, it has been shown that Eurobonds' main purpose is to facilitate economic growth and stability for the eurozone. They can also contribute to euro's role as an international reserve currency and accelerate the European goal of achieving strategic autonomy. Opponents of Eurobonds fear increased interest rate pressure for financially sound member states, and a lack of fiscal discipline for more heavily indebted member states.

There have been several serious suggestions for Eurobond programmes, each with its own distinct characteristics. First of all, the proposals are divided on the question of the distribution of liability; either full or limited joint liability is considered optimal, with the former being the most called-for option.

A second dispute is about a maximum issuance of Eurobonds. Some proposals suggest unlimited Eurobonds, whereas the most politically feasible proposals include an issuance limit of up to 60% of GDP.

Finally, there are multiple flavours possible as to the institutional basis of a Eurobond programme. The possibility of a bail-out is important for the credibility of Eurobonds, but this remains one of the most controversial elements of the proposals. Furthermore, participation can be either voluntary or mandatory and the issuance of the new Eurobond debt has to be either regulated by or also executed by a European Debt Agency. This institution has to be given a eurozone-wide mandate for assessing national budgets.

For the purpose of this study, it is the difference in maximum issuance that is most interesting. In the next chapters, unlimited Eurobonds and Blue Bond Eurobonds will be analysed. Blue Bond Eurobonds are most feasible politically, and unlimited Eurobonds are included as a reference policy to be compared to.

3. METHODOLOGY

The multi-country economic system of study is dynamic and complex in nature. This makes it troublesome to form mental models to help understand a system (Sterman 2006), indicating the need for simulation modelling. Such a system model is an abstraction of the system of interest, used for the purpose of evaluating policies in different contexts (Walker et al. 2003). Because the studied system contains many feedback loops, delays and accumulation, *system dynamics* (SD) modelling is deemed the most suitable modelling technique for this study, as this chapter will further elaborate. To account for the uncertainties present in the system, an *exploratory modelling and analysis* (EMA) approach is used.

Next to the modelling technique and approach used in this study, this chapter will provide details on the model's structure. It describes the details of the Eurobond model: from the restructuring of the initial debt management model (Sorci 2011) into an extensive multi-country model that is divided into five sub-models. The most important elements of all sub-models are addressed, followed by a model validation section.

The last sections of this chapter will elaborate on the experimental set-up used to conduct experiments with the model. It includes an overview of the uncertainties and output metrics relevant to the model. The chapter concludes by providing an answer to sub-question 2.

3.1 SYSTEM DYNAMICS

For this study, an SD model has been developed *(from* now on: *Eurobond model*). SD is a computer simulation modelling technique that is used to provide insight into-, and analyse complex non-linear dynamic feedback systems in order to design policies that improve system performance (Radzicki 2009). The technique was first developed by J.W. Forrester in the 1950's at MIT to serve as a tool to help managers better understand and control corporate systems (System Dynamics Society n.d.). Today it is applied to problems in many academic disciplines, including economics and policy analysis. When studying the dynamic behaviour of public debt management and cross-country trade and investment flows, it becomes clear that such a system contains the elements that are at the core of any SD model: Accumulation of stocks, feedback loops, and delays.

First of all, the accumulation of (national and/or mutualised) public debt has to be modelled as a stock that has in- and outflows respectively representing the acquisition and redemption of debt. The same can be said for stocks of national capital, that can be increased by investment flows and decreased by depreciation, represented as an outflow.

The system also contains a significant amount of feedback loops that drive non-linear dynamic behaviour even if all constitutive causal relations making up this structure are linear (Pruyt 2013). Using the debt stock as an example and considering that the level of debt has an influence on the average interest rate paid over this debt, but that it also affects the investment decisions by the public and private sector, it becomes clear that both balancing and reinforcing feedback loop exist in the system.

Thirdly, many of the system's dynamic behaviour occurs with a delay. If we take the cost competitiveness of an exporting country, or the increase in average wage for a specific country, it is intuitively clear that its effects on total exports or labour force participation do not happen immediately. Rather, these effects occur with a delay that represents the reaction time of trading firms and the labour market.

Of course, there are other modelling techniques available that could also represent all the mentioned system elements. The possibility to conduct the experiments in this study with a more commonly used model type, like a typical accounting model, an agent-based model or a general equilibrium model, is not ruled out at all. However, what differentiates SD from these techniques and what makes it especially useful for the purpose of this study, is that it is a so-called white box modelling method (i.e., it allows the modeller to observe and understand the internal dynamics of the model). In this regard, SD is a very intuitive modelling technique that is easy to interpret, especially for non-technical political decision-makers.

3.2 EXPLORATORY MODELLING AND ANALYSIS

Uncertainty always plays a big role in the field of economic decision-making, because the entire system depends on human factors and world-wide developments. The system of study contains many irreducible parametric (and structural) uncertainties, all of them defined by an uncertainty range. Think of the magnitude of certain elasticities that determine the degree to which variables respond to changes in underlying factors (e.g., trade elasticities or investment's sensitivity to interest rate changes). Different combinations of these uncertainties could lead to different outcomes. Uncertainties like these cannot be described by probability distributions, and combinations of them should be thought of as sets of possible future scenarios. The level of uncertainty attributed to the probability of these scenarios and to the system itself can be categorised as *deep uncertainty* (Walker et al. 2012).

Despite all the partially irreducible uncertainties that exist in the system, policy decisions still have to be made. For these cases of model-based decision support under deep uncertainty, a practical open-source, python-based modelling approach has been developed that is called *Exploratory Modelling and Analysis (EMA)* (Kwakkel 2017). It should be seen as a particular way of using models for this purpose, and not as a modelling technique in itself (Kwakkel and Pruyt 2013). EMA is an approach that is used to explore the implications of varying assumptions and hypotheses, when experimenting with a predictive model is not possible due to a lack of precise system knowledge, but when there is enough information to support decision-making (Bankes 1993). It provides tools to assess the relative importance of different factors of the system and to test the robustness of policy interventions.

EMA allows for two basic search strategies to be applied: *open exploration* and *directed search*. The first is aimed at generating a set of experiments that covers the entire space of plausible futures. It can be used to answer questions like '*under what circumstances would this policy do well?*', '*under what circumstances would it likely fail?*', and '*what kinds of dynamics can this system exhibit?*'. This methodology is useful for testing the possible behaviour of the system and of the policies to be tested. A second EMA methods is *directed search*, which only covers cases of interest and is used to answer questions like *'what is the worst that could happen?'* and '*how big is the difference in performance between rival policies?*'. Both methods can be used to complement each other (Kwakkel and Pruyt 2015). Combining EMA and SD is common practice and it is called ESDMA, i.e. *Exploratory System Dynamics Modelling and Analysis* (Kwakkel and Pruyt 2015).

3.3 DATA GATHERING

Developing a useful SD model for the purpose of this study requires access to reliable sources of both qualitative and quantitative data. The former is necessary to determine the structural relations between different elements of the system. Relevant scientific literature from a broad range of economic studies has been consulted for this purpose.

For the quantitative data requirements of the Eurobond model, the preferred data sources are internationally recognised institutions like the International Monetary Fund, the World Bank, the Organisation for Economic Co-operation and Development, the European Commission and reliable platforms for economic data like Trading Economics and Our World in Data.

For an overview of the country-specific input data used in the Eurobond model, see appendix A.1 to A.3.

3.4 SORCI'S MODEL

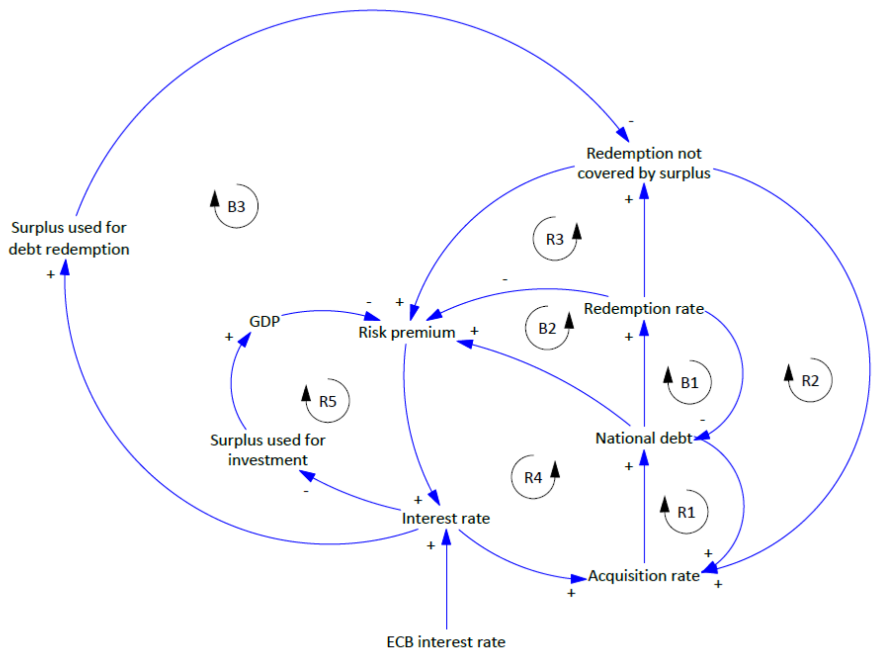

Figure 1. Causal loop diagram of Italian public debt dynamics

This model (figure 1) has been validated (Sorci 2011) to be suitable for simulating sovereign debt management dynamics and is used as a basis for a more comprehensive model that simulates multiple economies and their interactions with each other. It is retrieved from the work of an Italian MSc. thesis (Sorci 2011). One of this model's key insights is that a budget surplus can either be used to pay off existing debt, or to be invested in the national economy, leading to an increase in GDP. Since it is mostly the debt-to-GDP ratio that is crucial, this choice is made by comparing the interest rate on outstanding debt with investment productivity. At the same time, the interest rate is negatively affected by this ratio, stabilising the system by shifting the focus from investment to debt repayment and vice versa if the situation calls for this. At some point, the debt level could become so hight, that it becomes self-reinforcing (the 'doom loop'). This is because once the interest rate is much higher than the productivity of investments, the debt management system fails to balance itself. For a detailed description of the feedback loops of this model, see appendix B.1.

3.5 MODEL OVERVIEW

The initial Sorci model can be interpreted as a combination of two components: a debt management part (feedback loops R1, R2, R3, R4, B1 and B2 in figure 1) and an investment part (feedback loops R5 and B3). Figure 2 is a visual representation of this, including the sub-models that are added to the existing structure. The arrows represent interaction between different sub-models.

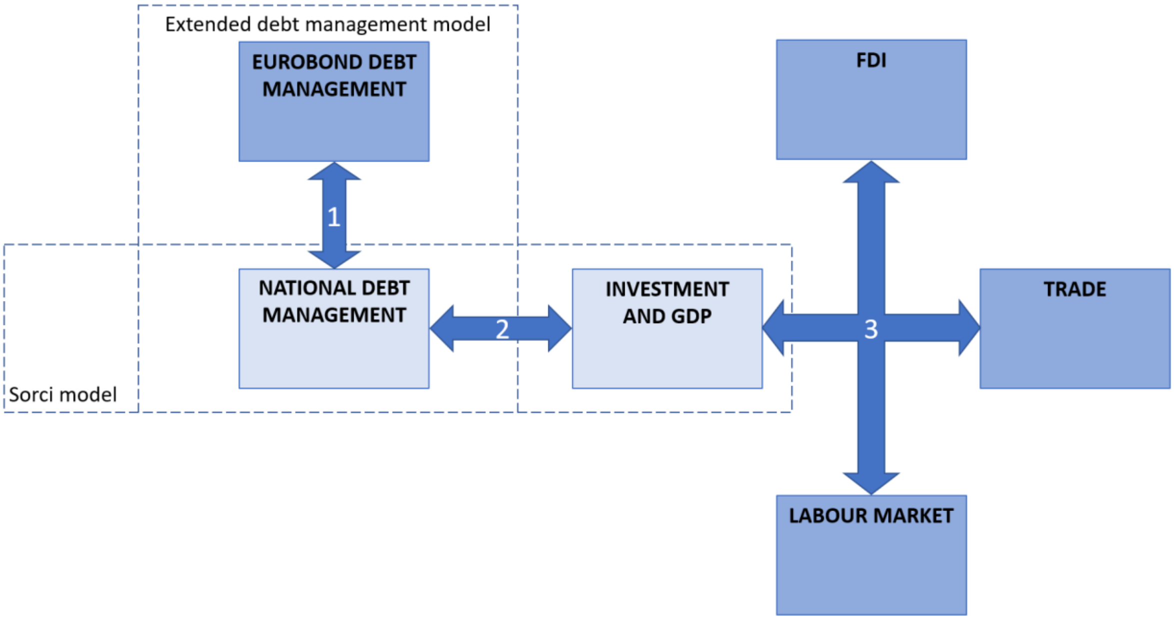

Figure 3.1 Visual representation of model structure.

Arrow 1 indicates that the debt management model has been extended to include a *Eurobond debt management* structure, next to the sovereign debt management. This is necessary for determining the size of outstanding Eurobond debt and the interest rate paid over this debt. Sub-section 3.5.1 provides more details on this.

The investment part of the initial model has been extensively modified. Sub-section 3.5.2 covers this in more detail. Arrow 2 shows that a clear subdivision has been made between the two parts of the original model. These two components both have a separate structure and are considered to be separate, but interacting sub-models.

Lastly, arrow 3 shows us that sub-models *FDI*, *Trade* and *Labour market* are all influencing each other, as well as the *Investment and GDP* sub-model. Trade and FDI have been identified as important components of cross-country economic spill-over effects, and modelling the labour market dynamics is a crucial link to facilitate the interactions between the other sub-models. Details on these sub-models and their interactions are discussed in sub-sections 3.5.3 to 3.5.5. For the stock-flow diagrams of all sub-models, see appendix B.2.

3.5.1 Debt management sub-model

In order to study the effect of a switch from the current situation to one with jointly issued eurozone-wide Eurobonds, the debt structure of the basis model has been extended.

Instead of consisting of one stock that represents sovereign debt, two stocks are required: the new one being the total outstanding mutualised (Eurobond) debt issued (by a particular country). The choice has been made to include two types of Eurobonds in the model. When the Eurobond policy is active (indicated by the *switch Eurobond* variable), Eurobond debt is issued, either up to a maximum of *max debt ratio* (i.e., 60% of GDP in most proposals), or without any limit.

The yield premium on the interest rates for both bonds is endogenously determined based on several factors, that can be either switched on or off in the model. The different ways of determining bond yields can be considered a structural uncertainty. The four methods included in the Eurobond model can be seen in table 1.

Table 1 The four yield determination methods. For a further discussion on this, see section 5.2.2.

Yield determination method	Yield drivers
0	Debt-to-GDP + Liquidity + Fiscal balance
1	Debt-to-GDP + Liquidity + Fiscal balance + Credit rating
2	Debt-to-GDP + Liquidity + Fiscal balance + Risk-free debt ratio
3	Debt-to-GDP + Liquidity + Fiscal balance + Credit rating + Risk-free debt ratio

The first determinant that most studies agree upon is the debt-to-GDP of a country (Alcidi and Gros 2019; Ardagna et al. 2007; European Commission 2018; D'Agostino and Ehrmann 2014; Grauwe and Ji 2013). In their quarterly report on the euro area, the European Commission itself has arrived at a yield elasticity value of 0.047, i.e. a 10 percentage point increase in the debt-to-GDP ratio increases sovereign yields by 47 basis points (0.47%) (European Commission 2018), whereas a working paper for the ECB finds this effect to vary between 30 and up to 100 basis points, depending on the year studied (D'Agostino and Ehrmann 2014). Both Alcidi and Gros (2019), and Ardagna et al. (2007) indicate that this negative relationship only occurs at debt-to-GDP levels above 60% and 65.4% respectively. This risk-free debt ratio is not included in all four ways to determine the yield premium, because not all studies agree upon its existence.

Market liquidity is included as a predicting variable in all but one (Alcidi and Gros 2019) of the studies mentioned. Often, the bid-ask spreads of sovereign bond markets are used as an approximation of market liquidity, with the European Commission (2018) finding that an increase in the bid-ask spread of 1 basis point increases yields by 5 basis points. However, it has been noted that the bid-ask spread is not an objective proxy for market liquidity (D'Agostino and Ehrmann 2014), and accurate country-level data for it are lacking. In the Eurobond model, liquidity is based on the total amount of outstanding debt, with Germany as a benchmark country; i.e. countries with a lower amount of outstanding debt that Germany will incur a yield premium, as suggested by a study into the determinants of EMU sovereign yield spreads (Gómez-Puig 2006). The value of *yield sensitivity to liquidity* in the Eurobond model has been empirically estimated. The liquidity premium achieved by introducing Eurobonds has been estimated in economic literature to be between 0 and – 300 basis points (Delpa and von Weizsäcker, 2010).

Another factor that is associated with increases in government bond yields is the fiscal balance (Kumar and Baldacci 2010; Gruber and Kamin 2012; Ardagna et al. 2007). This variable is expressed as the difference between government revenue and its total expenses, as a percentage of GDP. The studies find that an increase in government balance of 1% is associated with a 15 to 34 basis points decline in bond yields.

One more factor to consider when looking at the determinants of government bond yields are credit rating agencies. A working paper for DNB (Vries and Haan 2016) examines the relationship between credit ratings and bond yields. They present a regression model that illustrates credit ratings' influence on bond yield, as well as a model that predicts credit ratings themselves. When converting credit ratings to a continuous 0-to-100 range, a 1% decrease in credit rating has been found to increase yields by 3 basis points. However, the other bond yield drivers identified in this sub-section are also determinants of the credit rating itself, making its effect on bond yields exaggerated. Because the direction of the causality is ambiguous in the case of credit ratings, its effect is not included in all four ways to determine the yield premium.

A final determinant often indicated in literature is the expected year-on-year GDP growth. The European Commission has found that a 1 percentage point increase in the annual growth rate lowers yields by 17 basis points, whereas another study arrived at a value of 14 basis points (Grauwe and Ji 2013). However, it is noted that its effect is not significant in all studied years (D'Agostino and Ehrmann 2014). Expected GDP growth could be based on current GDP growth, but because GDP growth starts at 0 at time 0 in the Eurobond model (no slope determinable) and considering the relation between the interest rate and GDP growth (simultaneous equations), this effect is not included in the model.

3.5.2 Investment and consumption sub-model

GDP had only been included in the basis model on a superficial level. In reality, GDP is a flow variable consisting of multiple factors. For the purpose of this research, GDP is an important performance metric. To extend the model to such a degree that it allows variables to influence GDP in a realistic way, the simplistic structure has been abandoned. In the Eurobond model, GDP is determined using the expenditure method, meaning:

Y = C + I + G + (X – M) **(eq. 1)**

where Y is GDP, C is consumption, I is investment, G is government expenditures and (X – M) is net exports. This is represented in the Eurobond model as follows:

GDP[country] = Net domestic consumption[country] + Export[country] **(eq. 2)**

+ Incoming FDI[country] + Domestic investment[country],

with

Net domestic consumption[country] = (Total private consumption[country]+Total public consumption[country])(1-Average propensity to import[country])*, **(eq. 3)**

where [country] indicates that a variable has been subscripted on a country-level, i.e. it has a unique value for every included country.

Private consumption (C) depends on the *total disposable household* income and the *average propensity to save* (APS) (i.e., 1- average propensity to consume). The degree to which the APS is influenced by the interest rate, or whether this happens at all, is ambiguous due to the correlation between the interest rate and inflation (which has an opposite influence on the APS). However, many estimates of such a relationship do exist in scientific literature, as a literature review on the topic shows (Gylfason 1993). For this reason, the APS' sensitivity to interest rate changes has been included as a parametric uncertainty in this sub-model, and can also take the value 0.

Total disposable household income is the result of a subtraction of net taxes (i.e., minus social transfers) from *total pre tax household income,* which *is* calculated in the labour market sub-model and consists of *total pre tax household wage income* and *total gross operating surplus and mixed income* (i.e., the extra household profit income, in the form of dividend or self-employment). The latter is assumed to be equal to about 80% of wage income (Eurostat 2022). It is not included as a parametric uncertainty, because the initial bandwidth of performance metrics like GDP would get too large to properly analyse. See chapter 5 for a discussion on this.

The net taxes that are subtracted from *total pre tax household income* make up the *government revenue*. This is used for *government expenditure* and leads to public consumption (G). *What* remains after subtracting *government* expenditure is the *primary surplus*.

The government's primary surplus (i.e., public savings) is used either for redeeming debt or making public investments, depending on the current *average interest rate*. For the private sector, it is the *total disposable household income* that is used to either consume or to save. These savings lead to an increase in the stock *Planned public and private investment*.

It is important to note that the magnitude of the investment flows (I) is determined in accordance with assumption that total savings equal total investments. Despite the wide range of criticism of the Loanable Funds Theory (Lindner 2013; Storm 2017) that seems to be at the root of this assumption, it is considered a valid structural assumption within the scope of this model. See the discussion chapter 5 for a more detailed elaboration on this topic.

Looking at the equation for GDP in the Eurobond model, it is clear that the model includes two country-specific types of investment flows, that all add up in the *National capital stock*: *Incoming FDI*, and *Domestic investment*. The latter is an outflow of the stock *Planned public and private investment*, whereas the former is derived from the *Outgoing FDI* flows (also an outflow of *Planned public and private investment*) of other countries. The exact determination of *Incoming FDI* is further elaborated upon in sub-section 3.5.5.

3.5.3 Labour market sub-model

The labour market sub-model contains four main interacting elements that are all required to establish the *total disposable household income* per country, as well as each country's unit labour costs (as used in the trade sub-model). This sub-section will provide details on each of them, i.e. *labour productivity*, *average wage costs* and *labour force participation rate* and *active workforce*. For a causal-loop diagram of the most crucial feedback loops included in this sub-model, see appendix B.3.

Firstly, the stock variable *labour productivity* is necessary to determine *annual labour hours demanded* [labour hour/year], since this is equal to a country's *GDP* [euro/year] divided by its *labour productivity* [euro/labour hour]. Since *Labour productivity* is output (GDP) per hour worked (OECD 2002), the initial value of *labour productivity* depends on the variable *GDP*, divided by both the *active labour force* and the *average annual labour hours per worker*. *Labour productivity* itself is increased through *capital deepening*, which represents a bigger share of capital per labourer. This has been proven to explain up to of the increases in labour productivity (Our World in Data 2016; OECD 2019). The extent to which this effect takes place is determined by the value of *labour productivity sensitivity to capital deepening*. This is one of the parametric uncertainties included in this sub-model (all coloured orange in the stock-flow diagrams in appendix B.2). Note that the labour market sub-model prevents *capital deepening* from taking place as a consequence of a decrease in the workforce, by correcting for this. Otherwise, increased unemployment would always increase productivity.

The second variable of interest is *average wage costs*. It is initially equal to real-world values and is increased or decreased by changes in *labour scarcity* (in accordance with standard wage theory), and *labour productivity growth* (Millea 2002). For the latter, a discussion paper for the European Commission has found that 50 to 60 percent of labour compensation can be explained by productivity growth (Pasimeni 2018). For both relationships, an elasticity variable has been included.

The variable *labour participation rate* is also initially set to equal real-world values. It is further affected by the relative increase of *average wage costs* (Johansson 2002), determined by the elasticity variable *labour market flexibility*.

Finally, *active labour force* is initially equal to one minus real-world unemployment times the *available workforce*. It is increased by the flow *hiring* and decreased by the flows *firing* and *retiring.* This structure is inspired by existing work (Auping et al. 2016). *Retiring* depends on the change rate of the working-age population. Hiring and *firing* depend on *labour scarcity*, which itself is influenced by *active labour force*. *Active labour force* is used to establish *total pre tax household income*, which determines *total disposable household income* (used in the investment and consumption sub-model).

3.5.4 Trade sub-model

The purpose of the trade sub-model is to establish the values of imports and exports between each of the modelled countries. Since the Eurobond model includes the entire world, total imports equal total exports. Exports for country i are calculated by multiplying the imports of other countries from country i with its respective import share of country i's imports. To illustrate this:

*Export [country i] = Import shares [country i, country j] * Import [country j] + […] + Import shares [country i, country n] * Import [country n]* **(eq. 3)**

The *Import shares* of all country pairs can be found in appendix A.1. The import shares are increased or decreased depending on the *Relative unit labour costs decrease* of the exporting countries. Unit labour costs are often used as a general measure of (international) price competitiveness (OECD 2021), but its exclusive role in determining exports successes is questionable (Storm and Naastepad 2015). For more on this, see the discussion in chapter 5.

Import itself is determined by multiplying total consumption of a country with its *Average propensity to import*. This propensity is initiated by finding the ratio of initial imports to initial total consumption. The *Average propensity to import* is further affected by the *Capacity utilisation* of a country, which represents an imbalance in domestic demand and supply that is to be compensated with additional imports.

3.5.5 FDI sub-model

The FDI sub-model is the smallest sub-model that is included in the Eurobond model. It is used to establish the *Incoming FDI determinant* and the *Outgoing FDI ratio*. Just like with imports and exports, the total amount of *Incoming FDI* is equal to the total amount of *Outgoing FDI* in the Eurobond model.

The *Outgoing FDI ratio* is set to equal the actual initial outward FDI flow (see appendix A.1 and A.2) divided by the initial amount of planned investment. This ratio does not change during the runtime of the model and is used in the investment and consumption sub-model.

The *Incoming FDI determinant* is initialised to be equal to the real-world average yearly FDI inflow in dollars. The dollar denomination is irrelevant, since only the relative FDI positions are used to determine *Incoming FDI* (in the Investment and consumption sub-model). To illustrate this:

*Incoming FDI [country] = Incoming FDI Determinant [country] / (SUM (Incoming FDI Determinant [country!])) * (SUM (Outgoing FDI [country!]) - Outgoing FDI [country])* **(eq. 4)**

The *Incoming FDI determinant* is further influenced by a country's *GDP growth* rate and *Trade openness*, in accordance with the literature discussed in sub-section 2.3.2. *FDI elasticity* is included as a parametric uncertainty.

3.6 MODEL VALIDATION

For testing the validity of SD models, many tests exist and have been described in literature. The available tests can be categorised as structural validity tests and behavioural validity tests (Barlas 1989; Forrester and Senge 1980)**.** However, many of these tests are already included in the analysis (Auping 2018), due to the nature of the EMA approach.

3.6.1 Structural validity

First of all, a dimension-consistency test has been conducted for the Eurobond model. This test can be considered as rather mundane, but failing it is often a sign of a faulty model structure (Forrester and Senge 1980). Furthermore, the model does not produce any integration errors because a right time-step has been set during the time-step validation test. Additionally, the structure of each sub-model is in accordance with relevant scientific literature on the respective economic domains, as discussed in the previous sections of this chapter.

Assessing the boundary adequacy of the model is important for determining whether the model is fit for purpose. Since the purpose of the model is to explore the economic effects of introducing Eurobonds on the eurozone, only the essential sub-systems of the eurozone economy have been included. Also, the scope of the model is limited to the euro area economies. This has been done by using subscripts, which allow a variable to represent multiple things (in this case, country-specific values). Rather than including all other countries of the world as separate subscripted elements, the rest of the world is represented in the model as one aggregated subscript element. The in and outflowing trade and FDI between the eurozone and the rest of the world are also aggregated, based on net in and outflows. The aggregation of the rest of the world into a single element may not accurately capture the diversity and complexity of the global economy but due to the scope of this research, it is considered a sufficient level of detail. Note that the newest member of the eurozone, Croatia, is not included in the Eurobond model. Adding it to the model would not significantly affect the results of the model experiments, especially because of the size of Croatia's economy.

Parameter verification has been conducted to determine the uncertainty ranges of the parameters included in the model. These ranges are derived from available scientific literature as much as possible and the entire uncertain parameter set can be found in table 2. For some parameters (e.g., wage elasticity to labour scarcity), no exact values can be retrieved from literature. In cases like these, the uncertainty range has been empirically estimated, based on iterative experimentation with the model. Due to this deep uncertainty, the model is not suitable to make accurate macro economic predictions about the future of the eurozone economy. It is important to remember that that is also not the purpose of the Eurobond model. Rather, it is developed and used for exploring the relative effects and the robustness of policy implementations (i.e., a Eurobond programme) under a broad range of scenarios, compared to scenarios without any policy in place.

Lastly, extreme conditions testing is important for building trust in the system. In the case of this study, it is an inherent part the analysis, because of the inclusion of a wide range of input uncertainties and the large amount of experiments that cover many combinations of these uncertainties. An important part of the analysis (see section 4.3) is especially designed to test the resilience of the system by exposing it to extreme conditions (in this case, severe recessions).

3.6.2 Behavioural validity

With the EMA approach, which produces a variety of behaviours under a wide range of circumstances, behaviour anomality tests, surprise behaviour tests and sensitivity analyses are already taken into account. This section further covers some behaviour reproduction tests. First a GDP forecast validation, then a comparison of the interest rate behaviour to real-world interest rates, followed by a validation of the assumed relationship between interest rates and GDP growth and an assessment of the GDP spill-over effects in the euro area.

GDP is one of the most important performance metrics of the Eurobond model (see sub-section 3.7.2). It is important to assess whether the range of possible scenarios produced by the model (based on the uncertainty ranges discussed in sub-section 3.7.1) are realistic. For this, figure 3.2 compares the GDP results of 1000 different scenarios to the OECD's forecast (OECD 2022b) of euro area GDP. It is visible that the OECD forecast falls just outside the scenario range resulting from the model runs, but the growth rates are similar. However, its data is in 2010 USD, while the Eurobond model produces results in 2022 euros, as much as made possible. The forecast would fit within the lower range of the scenarios when correcting for this.

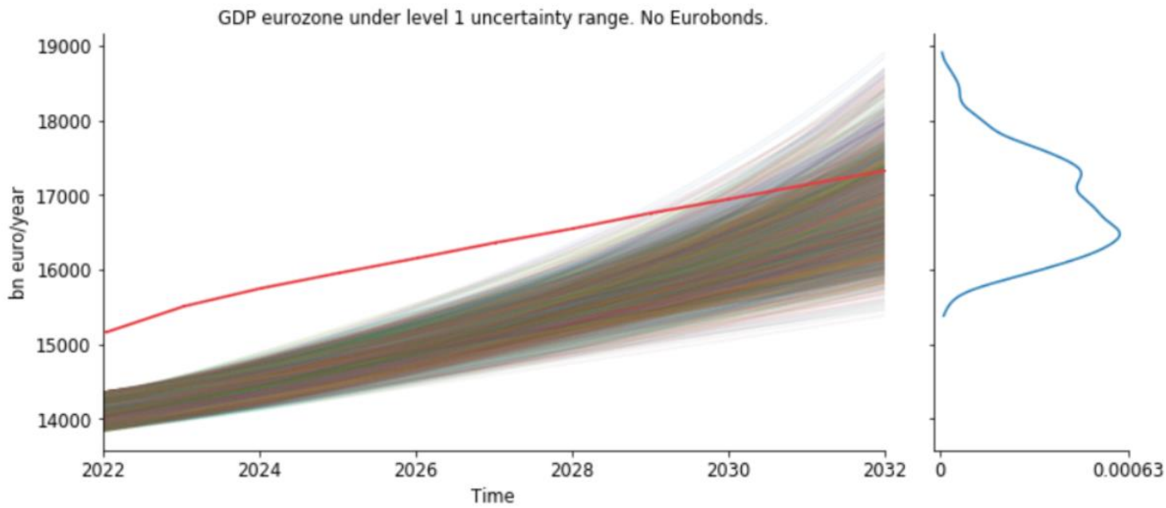

Figure 3.2 Eurozone GDP scenarios produced by the Eurobond model under level 1 uncertainty, fitted with an OECD forecast (in 2010 USD) (2022). 1000 runs.

Furthermore, the establishment of bond interest rates is a crucial part of the Eurobond model and it is therefor especially important to validate the behaviour of these interest rates. The interest rates produced by all four combinations of bond yield drivers in a scenario without Eurobonds have been compared to the actual interest rate statistics of Germany, France, Italy and the Netherland for the first half of 2022. This set of countries has been selected based on the divergency in their relevant economic properties. Methods 2 and 3 seem to most reliably resemble reality (see appendix C.1 for this comparison). In the subsequent analyses of this study, all four methods will be taken into account and their respective results compared.

Another important aspect of the economic arguments in favour of Eurobonds is that a lower interest rate can increase GDP growth. To test this, 1000 scenarios have been run with the Eurobond model, including all level 1 uncertainties (see sub-section 3.7.1). An additional exogenous shock variable is included that is set at either a 0% or 5%. This increases every country's sovereign bond interest rate. The results for the GDP of the entire eurozone are in line with the expected behaviour and can be seen in figure 3.3. Additional examples that include the other yield determination methods and some country-specific results can be found in appendix C.2.

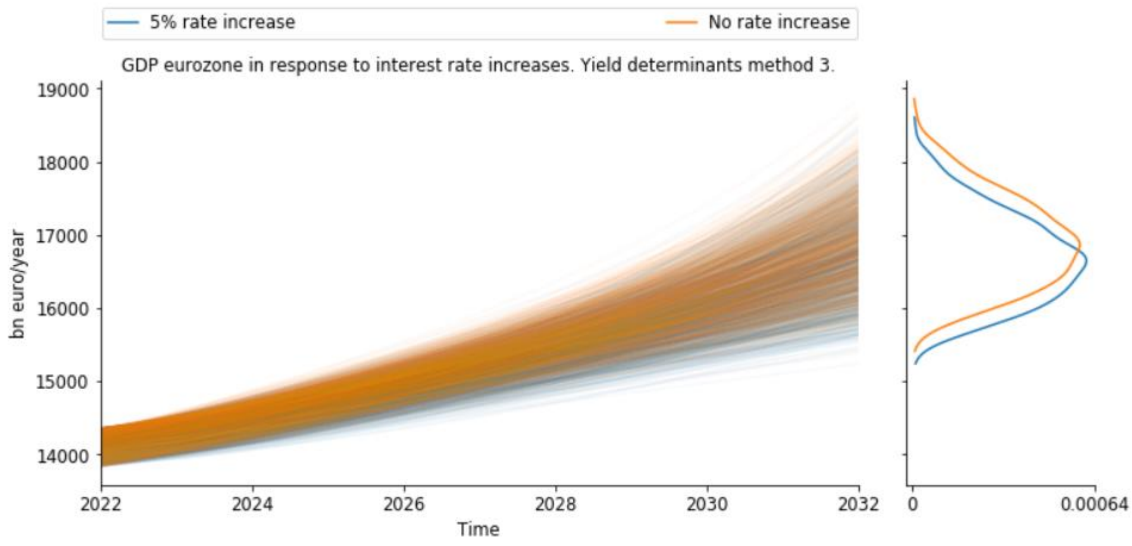

Figure 3.3 Eurozone GDP in response to a 5% interest rate increase. 1000 runs with the Eurobond model, including all level 1 uncertainties. Yield determination method 3.

The effects of the introduction of the exogenous shock on each country's imports and outgoing FDI supports the assumption that high interest rates can have a negative GDP spill-over effect on other countries. This negative effect on imports is less significant than its impact on outgoing FDI (see appendix C.3). The Eurobond model probably underestimates the trade-induced spill-over effects caused by changes in interest rates, because consumption is not directly influenced by the interest rate in the model (just indirectly, through dampened household income growth and an increasing propensity to save instead of consume), whereas investment is delayed based on the interest rate level.

3.7 EXPERIMENTAL SET-UP

The Eurobond model to be used in the analysis of this study has been developed using Vensim DSS version 9.3.4 (Ventana Systems 2022). The experiments with the model will be performed with version 2.4 of the EMA workbench, run in Python version 3.7.6. At the basis of the EMA approach used in this study is the XLRM framework (Lempert et al. 2003). For an overview of the XLRM elements, see figure 3.4.

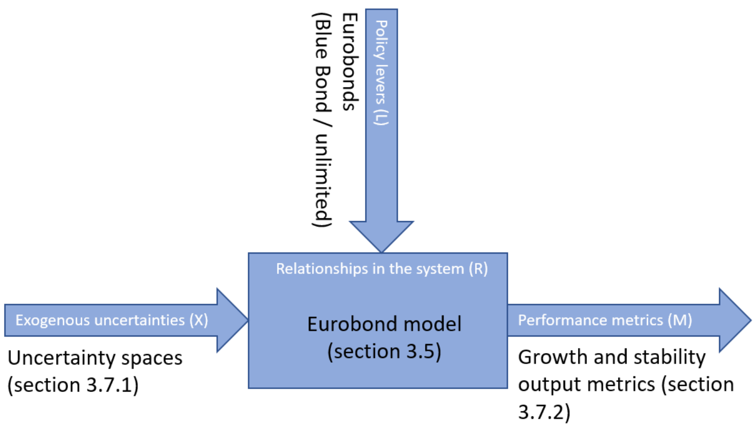

Figure 3.4 XLRM framework diagram.

The relationships (R) that define the system itself have been discussed in the previous parts of this report and are simply represented by the Eurobond model itself. The policies to be tested (i.e., Blue Bond or unlimited Eurobonds), are the policy levers (L) that have to be explored. Per policy, 1000 experiments will be run with the Eurobond model. These experiments encompass a wide range of possible future scenarios that are represented by 1000 unique configurations of the uncertainties (X) (i.e., scenarios, or points in the uncertainty space), repeated over all policy levers. The EMA workbench uses Latin hypercube sampling for sampling over all these uncertainties when performing experiments.

The uncertainties are categorised into three spaces (level 1, 2 and 3) and are elaborated upon in sub-section 3.7.1. The effectiveness of policies and the behaviour of the system are analysed by assessing the performance of certain outcome variables, the performance metrics (M). These metrics are elaborated upon in sub-section 3.7.2. The performance of the output metrics will be assessed by analysing their behaviour for large sets of scenarios. This is done by plotting the output metrics and comparing the distribution of the plotted outcomes over time relative to each other. Furthermore, built-in statistical functions of the EMA workbench (PRIM, EFTS) will be applied to explore the sensitivity of the output metrics to variations in the underlying uncertainty spaces, and to find regions of interest in these uncertainty spaces.

3.7.1 Uncertainties

The uncertainties related to the system of study can be sub-divided into three levels (see table 2). The level 1 uncertainty space (X = 25) only pertains to the system itself, without including anything related to the introduction of Eurobonds and without any variations in external circumstances. This level is used to assess the system's sensitivity to parametric uncertainties (e.g., wage elasticity parameters), and to the set of structural uncertainties (i.e., the different bond yield drivers, included as a categorical parameter switch). For the experiments run with the Eurobond model, the EMA workbench uses Latin hypercube sampling for generating scenarios.

The level 2 uncertainty space contains everything labelled both as level 1 and 2 (X = 27). This set of uncertainties is used to test the robustness of the policy intervention of Eurobonds (either no Eurobonds, Blue Bond Eurobonds or unlimited Eurobonds) to any of the underlying assumptions.

Finally, the level 3 uncertainty space encompasses all uncertainties listed in table 2 (i.e., 32 parameters, including categorical parameter switches). It is used for analysing the resilience of the system (with and without Eurobonds) under a set of predefined external circumstances (i.e., three configurations of the level 3 categorical parameter switches).

Table 2 Overview of the entire uncertainty space, including level 1, 2 and 3. 'dmnl' is dimensionless.

Name	Unit	Default	Minimum	Maximum	Source	Sub model	Type	Level
Average credit rating Eurobond	dmnl	100	95	100	Assumption	Debt management	RealParameter	2
Eurobond redemption priority	dmnl	0.8	0.75	0.95	Assumption	Debt management	RealParameter	2
Average debt duration	Year	8	7.6	10	OECD 2022	Debt management	RealParameter	1
Yield sensitivity to debt ratio	1/year	0.04	0.03	0.05	European Commission 2018, D'Agostino and Ehrmann 2014	Debt management	RealParameter	1
Yield sensitivity to liquidity	1/(euro*year)	1.00E-15	5.00E-16	2.00E-15	Emperical estimation	Debt management	RealParameter	1
Yield sensitivity to credit rating	1/year	-3.00E-05	-4E-05	-2E-05	Vries and Haan, 2014	Debt management	RealParameter	1
Yield sensitivity to fiscal balance	1/year	-0.002	-0.003	-0.001	Kumar and Baldacci 2010, Gruber and Kamin 2012	Debt management	RealParameter	1
Risk free debt ratio	dmnl	0.6	0.55	0.65	Alcidi and Gros 2019, Ardagna et al. 2007	Debt management	RealParameter	1
FDI elasticity	dmnl	0.1	0	0.5	Assumption	FDI	RealParameter	1
Maximum stimulus size relative to GDP	dmnl	0.1	0	0.35	Statista, 2021	Investment and consumption	RealParameter	1
Depreciation rate	1/year	0.046	0.03	0.06	ECB 2006	Investment and consumption	RealParameter	1
Time to consume income	Year	1	0.5	1.5	Assumption	Investment and consumption	RealParameter	1
Initial APS	dmnl	0.1	0.07	0.15	Národná banka Slovenska 2005	Investment and consumption	RealParameter	1
APS sensitivity	dmnl	0.01	0	0.015	Gylfason 1993	Investment and consumption	RealParameter	1
Interest rate investment sensitivit	dmnl	0.5	0.25	0.75	Assumption	Investment and consumption	RealParameter	1
Average net tax rate including social transfers	dmnl	0.1	0.05	0.2	OECD 2022	Investment and consumption	RealParameter	1
Government expenditure ratio	dmnl	0.97	0.95	1.05	OECD 2021	Investment and consumption	RealParameter	1
Capital productivity	1/year	0.25	0.2	0.3	Emperical estimation	Investment and consumption	RealParameter	1
Labour productivity sensitivity to capital deepening	dmnl	0.2	0.1	0.33	OECD 2019, Our World in Data 2016	Labour market	RealParameter	1
Wage elasticity to labour scarcity	1/year	0.05	0.03	0.07	Assumption	Labour market	RealParameter	1
Wage elasticity to labour productivity growth	dmnl	0.55	0.5	0.6	Pasimeni 2018	Labour market	RealParameter	1
Average hiring time	Year	1	0.5	1.5	Assumption	Labour market	RealParameter	1
Average firing time	Year	2	1	3	Assumption	Labour market	RealParameter	1
Labour market flexibility	dmnl	0.1	0	0.3	Assumption	Labour market	RealParameter	1
Import share sensitivity to price changes	1/year	1	0.8	1.2	Yilmazkuday 2019	Trade	RealParameter	1
Import propensity sensitivity to capacity utilisation	1/year	0	0	0.05	Assumption	Trade	RealParameter	1
Switch bond yield drivers	dmnl	0	0	3	N/A	Debt management	Categorical Parameter	1
Switch Eurobond	dmnl	0	0	2	N/A	Debt management	Categorical Parameter	2
Switch demographic scenario	dmnl	0	0	2	N/A	Labour market	Categorical Parameter	3
Switch investment profitability	1/year	0	0	2	N/A	Investment and consumption	Categorical Parameter	3
Switch ECB rate scenario	dmnl	0	0	2	N/A	Debt management	Categorical	3
Switch non-eurozone import demand	dmnl	0	0	1	N/A	Investment and consumption	Categorical Parameter	3

3.7.2 Output metrics

The analysis discussed in chapter 4 will consist of a system analysis (under uncertainty level 1), a policy analysis (uncertainty level 2) and a resilience analysis (with uncertainty level 3). In order to assess the robustness and resilience of the system, and the effectiveness of the policy interventions, certain output metrics have to be defined. These metrics will be analysed in all three phases of the analysis.

Table 3 provides an overview of these metrics, along with an explanation of their relevance. The top two output metrics are relevant for assessing the economic growth that is facilitated by both Eurobond policies, whereas the remaining metrics are used to judge the level of economic stability.

Economic growth is assessed by comparing GDP after 10 years of the model's runtime. Deviations from the base case (no policy) of more than 0.5% are considered significant. Economic stability is judged based on a country's debt-to-GDP ratio, and especially on the development of this ratio. Debt-to-GDP ratios are considered sustainable when their development on the mid to long term (up to 10 years in the model) is either stationary or declining.

Table 3 Overview of important output metrics, including a brief description.

Output metric	Relevance
GDP per country	GDP is a general measure that indicates the magnitude of yearly economic activity in a country. It is both useful for exploring the system's behaviour without policy intervention, as for assessing the possible effects of Eurobonds on economic growth and the distribution of GDP changes across the eurozone. For testing the resilience of the system, GDP development is also monitored in scenarios of adverse economic circumstances.
GDP eurozone	This metric helps determine the overall economic growth facilitated by Eurobonds on a eurozone-wide level.
Debt-to-GDP per country	This ratio is an important indicator for the sustainability of a country's public debt burden. Especially above 60%, the Debt-to-GDP ratio can become self-reinforcing.
Debt-to-GDP eurozone	The same ratio is important for the eurozone as a whole and can be used to compare the system-wide effects of Eurobonds to a situation without Eurobonds.
German-Italian sovereign bond interest rate spread	The German-Italian bond spread is a widely-used economic indicator for market trust, that measures the difference of the Italian and German government bond yields. German bonds are regarded as the safest of the eurozone, while Italian bonds are amongst the most risky.
German-Italian average bond interest rate spread	When (also) issuing mutual Eurobonds, with one interest rate, the average interest rate paid by Germany and Italy becomes more important for the respective fiscal positions of both countries.
Interest rate Eurobond	The interest rate of Eurobonds is endogenously determined by the Eurobond model and it is crucial for the degree to which Eurobonds can provide economic growth and stability.
Sovereign bond interest rate per country	Both in a situation with and without Eurobonds, the interest rates over each country's sovereign bond remains an important indicator for a country's fiscal sustainability and flexibility.
Average bond interest rate per country	Finally, in a situation with Eurobonds, the average interest rate paid by each country becomes important for assessing their fiscal position.

SQ2. Which system elements and uncertainties need to be considered when modelling the economic effects of Eurobonds?

The need for developing a simulation model to explore the economic effects of introducing Eurobonds has become evident in this chapter. The system of study is complex in nature and contains deep structural and parametric uncertainties. Due to the feedback loops and the stock-flow structure of the system, a system dynamics model has been developed.

The model contains many uncertainties that are either related to the system itself (level 1), to the introduction of Eurobonds (level 2), or to external circumstances (level 3). Each uncertainty has a range of plausible values, mostly retrieved from relevant literature. To account for this large number of uncertain parameters (listed in table 1), an exploratory modelling and analysis approach is used for this study's analysis. This approach tests the model's performance in a large set of scenarios (i.e., different configurations of the uncertain parameters, or so-called points in the uncertainty space), both with and without policy intervention.

The model itself consists of five distinguishable, interacting sub models. All sub models fulfil their own role to calculate essential variables:

- Investment and consumption (GDP, consumption, investment, capital stock)
- Debt management (national debt, Eurobond debt, interest rates)
- Labour market (labour productivity, wage costs, labour force)
- Trade (imports, exports, unit labour costs, propensity to import)
- FDI (outgoing FDI ratio, incoming FDI determinant)

To test the effectiveness of the proposed Eurobond policy (either *Blue bond Eurobonds* or *Unlimited Eurobonds*, compared to no Eurobonds), several output metrics have been defined. The policies are assessed based on the performance of the system on the following (either country-specific or eurozone-wide) metrics:

- GDP
- Debt-to-GDP
- German-Italian bond spread
- Sovereign interest rates
- Eurobond interest rate

4. RESULTS

This chapter will present the results of the experiments conducted with the Eurobond model. Section 4.1 presents the results of the system analysis, which explores the impact of various uncertainties on the performance of the Eurobond model, without any policy implementation. The second section of this chapter presents the results of the system's performance with Eurobond policies in place. Finally, the third section tests the resilience of the Eurobond policies in the face of recessions, by considering the impact of external uncertainties on the system's performance.

Overall, this chapter aims to provide a comprehensive understanding of the performance and robustness of the Eurobond model and the suggested policies, under different scenarios, attempting to provide an answer to sub-question 3. Each section will examine the model's behaviour with respect to the output metrics discussed in sub-section 3.7.2. Each experiment is conducted four times to account for the structural uncertainties: once for each of the four yield determination methods.

4.1 SYSTEM ANALYSIS

The system analysis conducted with the Eurobond model takes the entire level 1 uncertainty space (see table 2) into account. This section will examine the GDP development of the eurozone as a whole, and of a selection of countries, and will subsequently attempt to identify the most influential variables. Next to that, the debt levels and sovereign interest rates will be compared in order to assess debt sustainability, all when taking into account and comparing all four methods for determining bond yields (see table 1).

4.1.1 Economic growth

Figure 4.1 shows the eurozone GDP results for 1000 runs with the Eurobond model, for each of the four yield determination methods. Methods 0 and 1 generate similar results that are slightly lower than the results generated by methods 2 and 3, which are also similar to each other. Looking at the drivers behind the yield determination methods, it becomes clear that the difference is whether or not the risk-free debt level is included. This can be explained by the lowered sovereign interest rates that are a consequence of this risk-free debt level. Country-specific results have shown that the magnitude of this effect on GDP differs across countries, and is equivalent to the relative differences in interest rates as a consequence of the used yield determination method. Countries with higher initial debt ratios are more heavily affected by the choice of the yield determination method that is used.

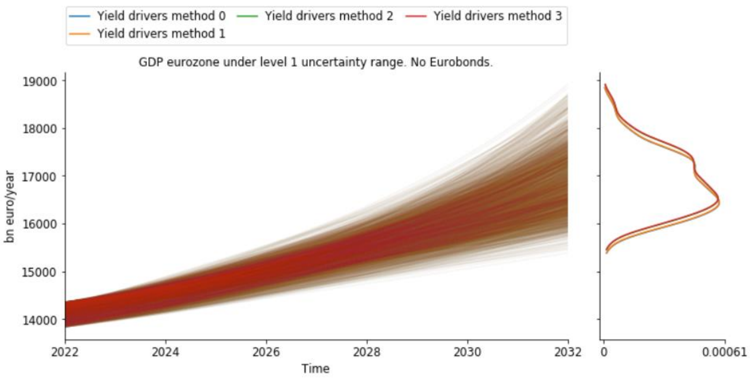

Figure 4.1 GDP eurozone under level 1 uncertainty. 1000 runs, for each yield determination method.

To get an idea of what drives the GDP development of four important eurozone economies, figure 4.2 shows a feature scoring analysis of Italian, German, French and Dutch GDP (left four columns). This analysis shows that there are several important variables that these four countries have in common. W*age elasticity to labour scarcity* has the largest influence by far. This variable plays an important role in the development of wage cost growth in the model. This directly affects consumption, as well as a country's export attractiveness, which are both significant components of a country's GDP (because GDP in the Eurobond model is calculated using the expenditure method). The same is true for the variable *Average net taxes including social transfers*, which determines which part of disposable household income can actually be consumed or saved, and which part will be taxed by the government and subsequently used for investment or debt redemption.

Another variable of interest is *Import propensity sensitivity to capacity utilisation*. This factor stands out because of its disproportionately large influence on German GDP. This can be explained by the fact that Germany has a large trade surplus (i.e., the difference between exports and imports). So when every country imports more, Germany's exports grow disproportionately (with respect to GDP), whereas the other countries have more balanced imports/exports ratios, so the additional imports are balanced out by additional exports, leading to a more modest influence of the variable of interest.

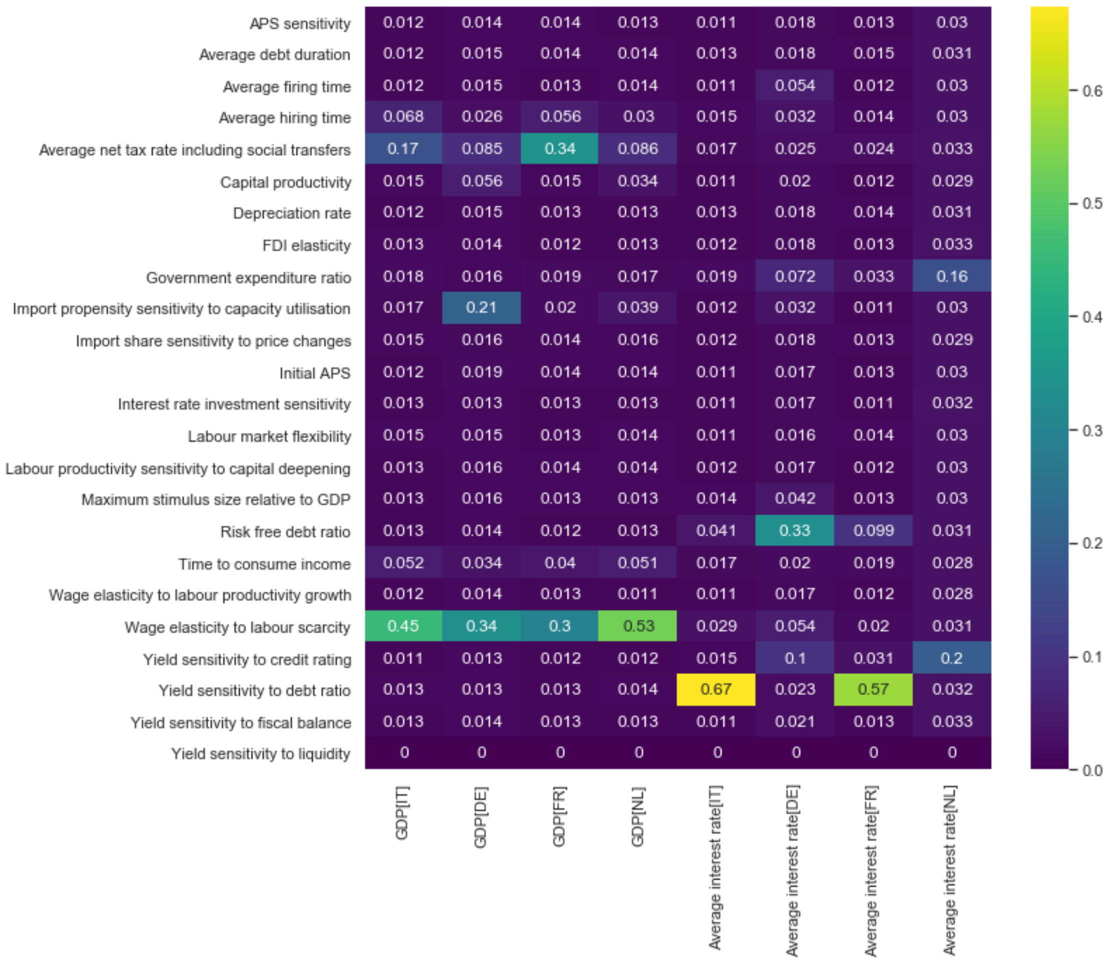

Figure 4.2 Feature scoring overview for the GDP (left four columns) and the interest rate (right four columns) of Italy, Germany, France and the Netherlands under level 1 uncertainty. Yield determination method 3. 1000 runs per policy.

4.1.2 Debt sustainability

Another thing to consider is the four right columns of the same feature scoring tree (figure 4.2). It shows the variables that most significantly influence the interest rates paid over the sovereign bonds of the same set of countries, using yield determination method 3. Since yield determination method 3 contains all yield drivers, these results are most insightful. A first thing to notice is that Germany scores very high on *Risk free debt ratio*, because the German debt-to-GDP ratio is very close to 60%, so any variations in this ratio make a significant difference. Secondly, the *Yield sensitivity to credit rating* is more important for the Netherlands and Germany, because these countries have the maximum average credit rating in the model (and subsequently the largest yield decrease). A final variable of interest is the *yield sensitivity to debt ratio*. The fact that Italy and France have a high score on this variable is to be expected, because their initial debt-to-GDP ratios are significantly higher than those of Germany and the Netherlands.

Figure 4.3 shows the debt-to-GDP ratios for Italy, Germany, France and the Netherlands over time. The four yield determination methods are again an important factor to consider, as the long-term sustainability of the debt levels depends on them. The inclusion of the risk-free debt level (in methods 2 and 3) is clearly even more relevant for Italy and France, as it prevents the debt-to-GDP ratios from displaying exponential growth and reaching levels of more than 150% of GDP. The results also indicate that a declining debt-to-GDP ratio is only possible when the initial ratio is not so high that it becomes self-reinforcing (the ‘doom loop’), as is the case for France and Italy. This is a typical example of a feedback loop. In these scenarios, the interest rate is high because the debt stock becomes so large, that GDP growth cannot keep up with the growth of debt (i.e., GDP growth is structurally lower than the interest rate paid over debt), and GDP growth is further slowed down by the tighter fiscal position and the interest rate’s influence on investment. This can become exponential, as is the case in some scenarios for France and Italy. For Germany and the Netherlands, there are still scenarios where the debt-to-GDP ratio even declines over time.

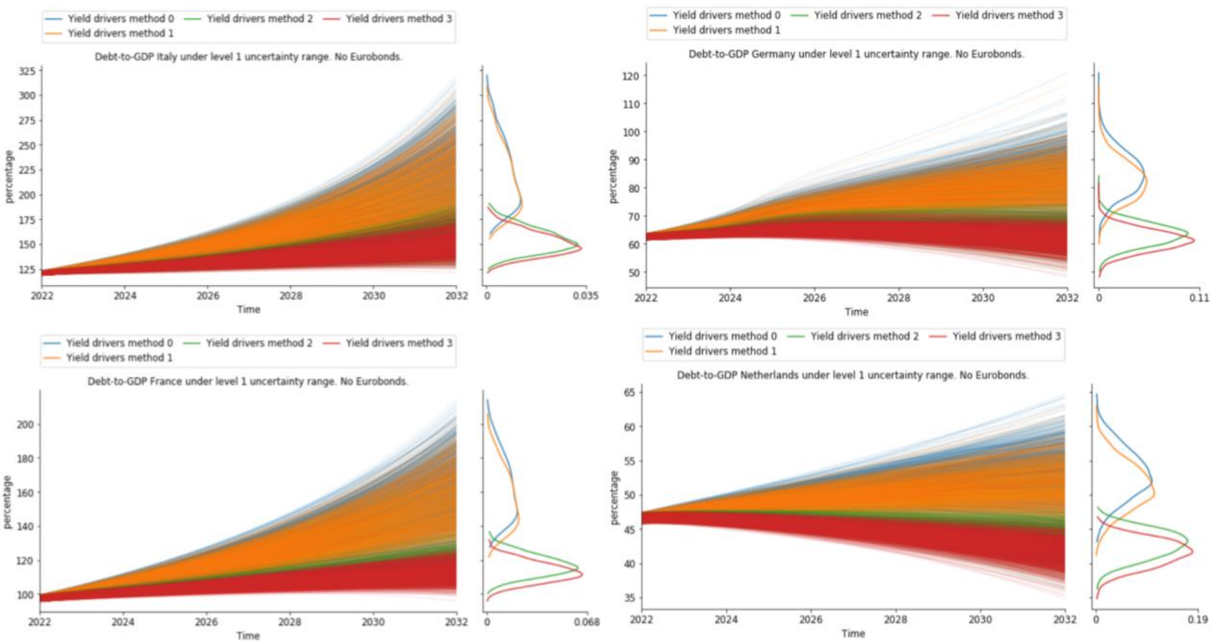

Figure 4.3 Debt-to-GDP for Italy, Germany, France and the Netherlands. France and Italy are more likely to reach unsustainable debt levels than Germany and the Netherlands. 1000 runs, for each yield determination method.

The sovereign interest rate results for the same group of countries in figure 4.4 further supports these observations. It is clear that higher initial interest rates can lead to scenarios of an ever-increasing interest rate. These results show that Italy and France are in a more tight fiscal position than Germany and the Netherlands. This situation only further reinforces the north-south economic divergence that is already present in the eurozone.

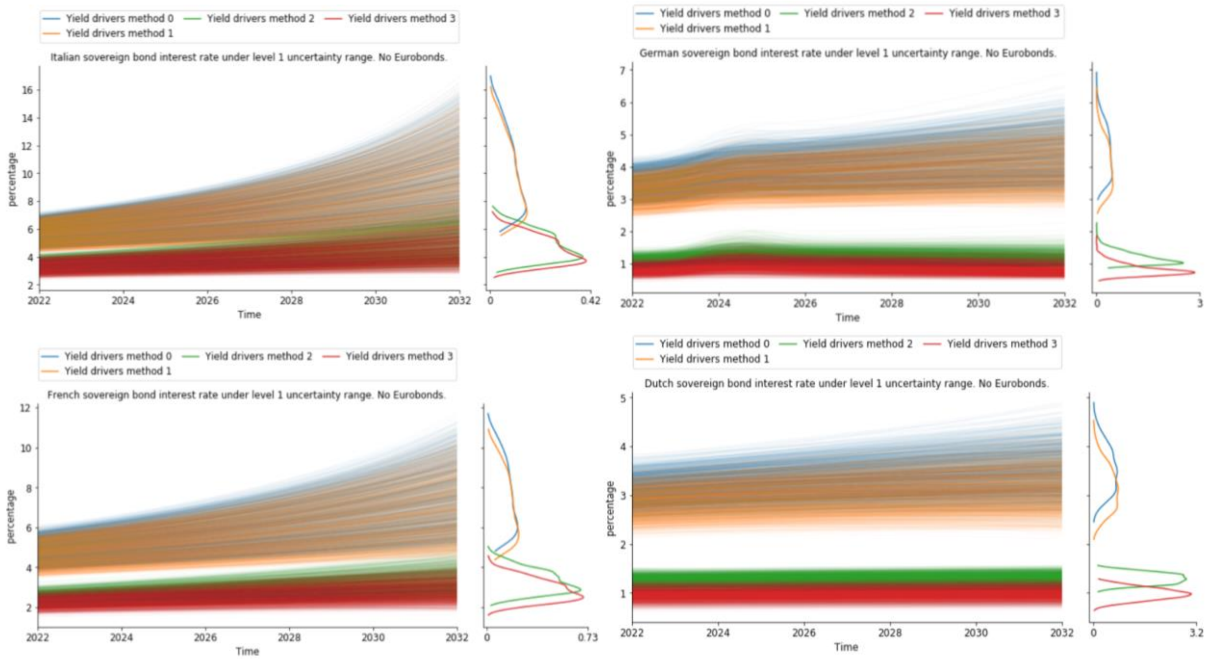

Figure 4.4 Sovereign bond interest rates for Italy, Germany, France and the Netherlands. France and Italy are more likely to reach unsustainable debt levels than Germany and the Netherlands. Note that the hike of the interest rate around 2024 for Germany is due to a temporary deterioration of the fiscal balance that is caused by anti-cyclical public investment (as a response to a GDP decline due to an initial labour surplus, which decreases wages, and subsequently consumption). 1000 runs, for each yield determination method.

As a widely-used indicator for the economic divergence in the eurozone - that could already be deducted from the graphs in figure 4.4 - the German-Italian bond spread is also analysed for all of the bond yield determination methods. The spread is found to always have a positive value and to never decrease, in each of the modelled scenarios. This means that there is always some degree of German-Italian divergence, or at least no convergence. The initial bandwidth of the spread is between 2 and 3 percentage points, with some scenarios (using yield determination methods 0 and 1) even leading to spreads of up to 10% after 10 years. With the inclusion of the risk-free debt ratio (i.e., methods 2 and 3), the worst-case scenarios only lead to spreads of up to 6% after 10 years. This level can be considered unsustainable. Historically, the German-Italian 10-year bond spread has only exceeded 5% during the European sovereign debt crisis. This situation could only be alleviated at the time by unconventional and drastic measures by the ECB, something that is not accounted for in the Eurobond model.

To find the conditions that allow the spread not to reach extreme values, the patient rule induction method (in short PRIM) can be used. This is a package of the EMA workbench that allows for scenario discovery, under user-set conditions. This method is applied to the German-Italian bond spread outcomes to find regions of interest in the uncertainty space that lead to the condition to be fulfilled that the spread stays under either 3% (for yield determination methods 2 and 3), or 4% (for yield determination methods 0 and 1). The results of this analysis are presented in figure 4.5 that shows the box that explains most behaviour. It can be concluded that for all bond yield methods, the yield sensitivity to the debt-to-GDP ratio is the most important variable restriction for explaining the German-Italian yield spread. The lower this sensitivity, the smaller this spread stays. Other, more specific result boxes that were identified did not provide any meaningful information.

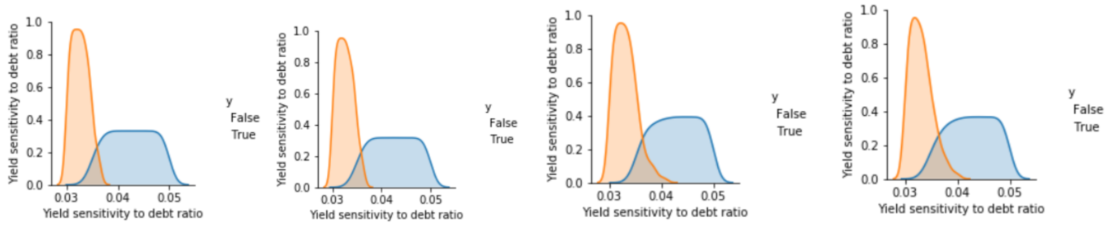

Figure 4.5 PRIM results for the German-Italian bond spread to stay under 3% (two graphs on the right) or 4% (two graphs on the left). Red is true, blue is false. From left to right: bond yield determination methods 0 to 3. 1000 runs.

4.2 POLICY ANALYSIS

The policy analysis conducted with the Eurobond model takes the entire level 2 uncertainty space (see table 2) into account. In the first part, this section will examine the GDP development for the eurozone as a whole, and of a individual countries, and will subsequently attempt to identify the most influential variables. Next to that, the debt levels and both sovereign and mutual (i.e., Eurobond) interest rates will be compared in order to assess debt sustainability, all when taking into account and comparing all four methods for determining bond yields (see sub-section 3.5.1).

4.2.1 Economic growth

Total eurozone GDP is not significantly affected by both Eurobond policies. For illustration, see table 4 for the average GDP increases (of 1000 scenarios) observed after 10 years for the total eurozone, Germany, and Italy, for all four yield determination methods. Note that these are the averages of 1000 scenarios that are conducted per policy.

Table 4 Overview of average GDP increases of the eurozone as a whole, Germany, and Italy. Results for both Eurobond policies are presented, as well as all four yield determination methods. 1000 runs per policy.

Blue Bond/Unlimited Eurobonds	GDP increase Method 0	GDP increase Method 1	GDP increase Method 2	GDP increase Method 3
Eurozone	0.20%/0.21%	0.20%/0.21%	0.14%/0.16%	0.14%/0.15%
Germany	0.09%/0.07%	0.09%/0.06%	0.05%/0.04%	0.04%/0.04%
Italy	0.30%/0.39%	0.30%/0.39%	0.23%/0.28%	0.23%/0.28%

The results indicate that total eurozone GDP is not significantly affected by these policies, with both Eurobond policies only marginally increasing eurozone GDP (with unlimited Eurobonds providing negligibly higher results than Blue Bond Eurobonds). Additionally, it has been found that the bond yield determination methods have a small effect on the policies' effectiveness with regard to GDP growth, with methods 0 and 1 providing small advantages over methods 2 and 3. When looking at the results for Germany and Italy, it becomes clear that unlimited Eurobonds are slightly less favourable for the former, whereas they are slightly more favourable for the latter, compared to the effects of Blue Bond Eurobonds. This indicates that a choice for unlimited Eurobonds, rather than Blue Bond Eurobonds, can be perceived as a relative transfer of wealth from Germany to Italy, albeit small. When analysing all individual model runs, it is found that there are no scenarios where either Eurobond policy decreases German, Italian or eurozone GDP. Feature scoring analysis has shown that the variables *Interest rate investment sensitivity* and *Yield sensitivity to debt* ratio together explain about 50% of the GDP gains facilitated by both Eurobonds policies.

To get a more comprehensive understanding of the distribution of benefits across the entire eurozone, figure 4.6 (left side) shows a map of Europe with country-level relative GDP gains caused by both Eurobond policies, compared to a situation without any Eurobond policy in place. Southern countries like Greece, Portugal and Italy jump out as the top three beneficiaries of this policy (with Greece achieving an average 0.57% GDP increase with Blue Bond Eurobonds, and a 0.73% increase with unlimited Eurobonds). These countries have their initial high debt-to-GDP ratio in common. The higher this initial ratio, the more there is to gain from introducing Eurobonds (see the right side of figure 4.6 for the distribution of average interest rate declines). The results for the other yield determination methods can be found in appendix D.1 and they show a similar pattern. One clear difference is, that the exclusion of the risk-free debt ratio in methods 0 and 1 offers more relative benefits to the initially less indebted nations, compared to the results shown in figure 4.6.

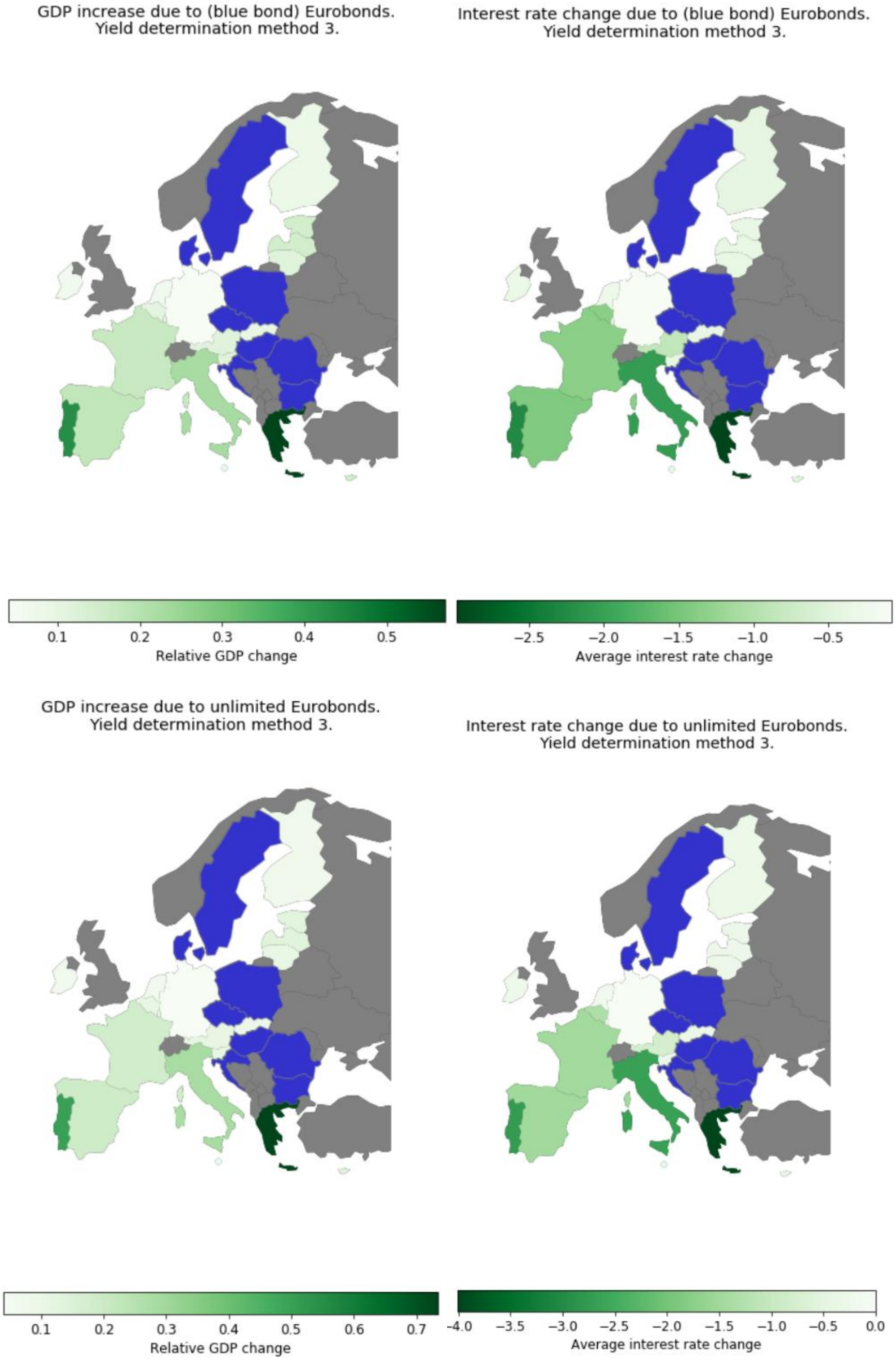

Figure 4.6 Map of the EU, with the average relative GDP gains (left) and the average interest rate decline (right) due to Blue Bond Eurobonds (top) and unlimited Eurobonds (bottom). Blue countries are non-eurozone EU member states and grey countries are not part of the EU. For the results of methods 0, 1 and 2, see appendix D.1. 1000 runs per policy.

As already suggested by figure 4.6, there is a negative correlation between the changes in average interest rate and the relative changes in GDP, as shown in figure 4.7. This is true for all yield determination methods (see appendix D.2). Note that some of the countries positioned at the top left of the scatterplot show a deviating pattern compared to the rest (i.e., higher GDP growth), because they represent relatively small economies (e.g., Estonia and Luxembourg), making the offset caused by increased incoming FDI and exports more significant. Furthermore, note that Germany's results show the least gains in GDP and interest rate gains, whereas the most beneficial results (the right bottom corner) can be attributed to Greece. These countries represent two extremes in the eurozone.

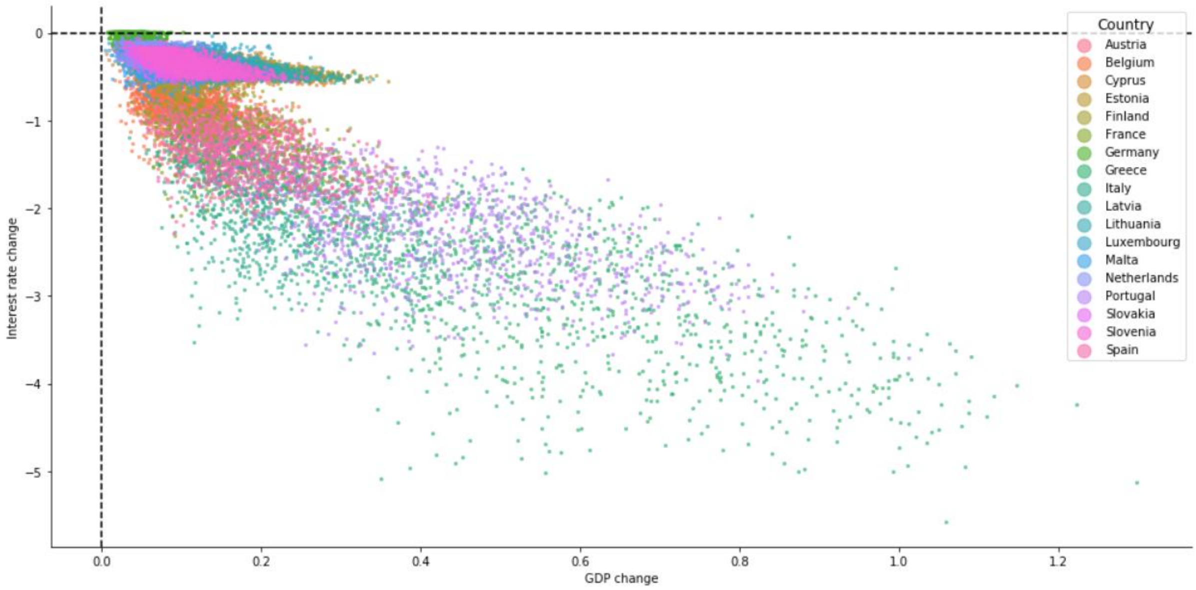

Figure 4.7 Scatter plot of the average interest rate decline against the average relative GDP increase for all eurozone countries. The figure shows a negative correlation between the two. For the results of methods 0, 1 and 2, see appendix D.2. 1000 runs per policy.

Lastly, assessing the degree to which the Eurobond policies facilitate economic growth for a country through increased trade and incoming FDI – apart from the economic growth attributed to the decrease in the average interest rate for that country – requires a different situation to be set up. Germany is taken as an example and its exports and incoming FDI are analysed in a situation with a stable sovereign interest rate of 2%, ceteris paribus. This set-up isolates the positive spill-over induced economic effects of Eurobonds (i.e., implemented for all eurozone countries except Germany) on the German economy. The outcomes show a positive, but insignificant spill-over effect, with only 1% of scenarios leading to a 0.10% increase in GDP after 10 years for Blue Bond Eurobonds. For both policies, an average increase in German exports of respectively 0.056% and 0.060% (roughly 1 billion euros) after 10 years, are observed. For German incoming FDI these numbers are 0.13% and 0.15% (roughly 50 million euros) respectively.

4.2.2 Debt sustainability

Now that the economic growth potential of introducing Eurobonds has been discussed by looking at the distribution of GDP gains and the corresponding interest rate declines and economic spill-over effects, it is time to assess the effects on debt sustainability caused by Eurobonds. Figure 4.8 shows the development of the debt-to-GDP ratio of the eurozone as a whole, for yield determination method 3 (for the results of the other methods, see appendix D.3).

It is clearly visible that both Eurobond policies can significantly increase the sustainability of the eurozone's total public debt, by preventing it from reaching extreme hights. It has to be noted as well, that the additional benefits of unlimited Eurobonds are extremely marginal. This is true for all yield determination methods.

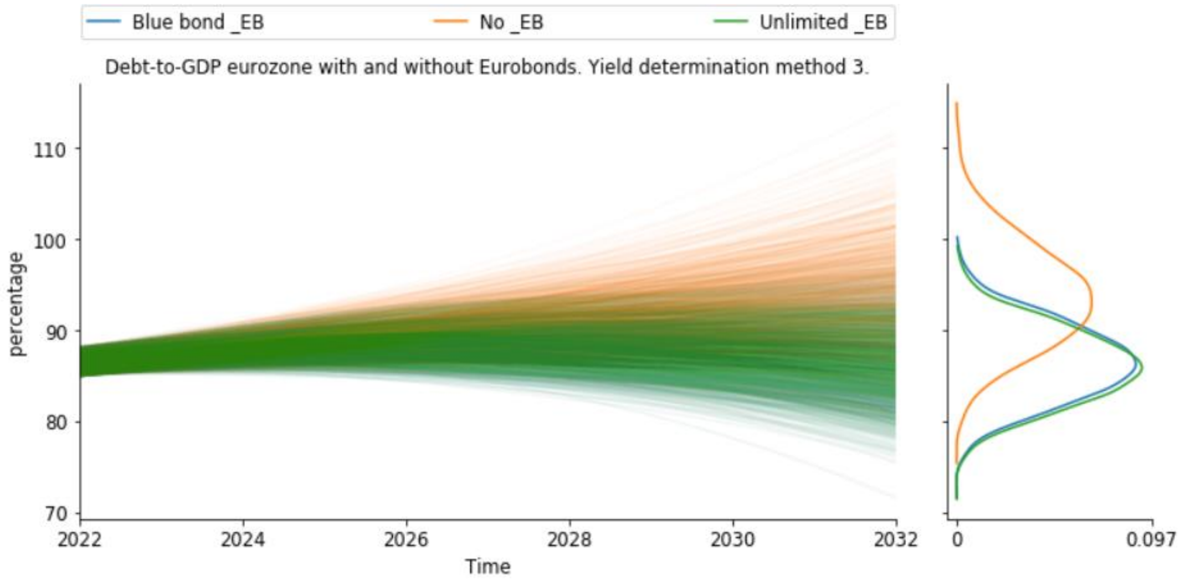

Figure 4.8 Debt-to-GDP eurozone under level 2 uncertainty. For the results of methods 0, 1 and 2, see appendix D.3. 1000 runs per policy.

As for specific countries (see Italy and Germany in figure 4.9), the potential gains from Eurobonds are again unevenly distributed, with highly indebted countries benefiting most strongly. Another interesting finding is that for countries like Germany and the Netherlands (with low initial debt levels), Blue Bond Eurobonds do actually provide slightly lower debt-to-GDP ratios than unlimited Eurobonds.

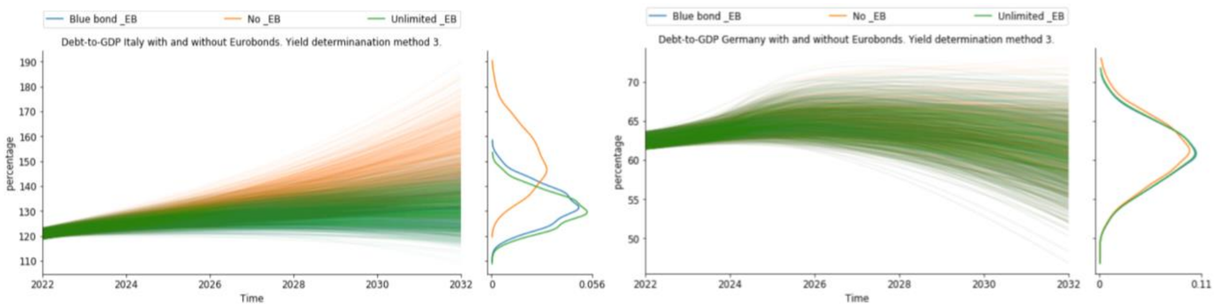

Figure 4.9 Debt-to-GDP for Italy (left) and Germany (right) under level 2 uncertainty. For the results of methods 0, 1 and 2, see appendix D.3. 1000 runs per policy.

This can be explained by looking at the development of the interest rate paid over the two types of Eurobonds, as seen in figure 4.10. Note the difference between yield determination methods 0 and 1, which produce an ever-increasing Eurobond interest rate, and the results of yield determination methods 2 and 3, which produce a steady interest rate. This difference is due to the risk-free debt ratio that is included in methods 2 and 3. Also note, that in the first years of the simulation runs, the interest rates of both Eurobond policies show identical behaviour, but they start to diverge after 5 to 6 years, for each method. This is due to the fact that the issuance of Blue Bond Eurobonds is limited to 60% of GDP for each country, so the total stock of Eurobonds stops increasing when this amount is reached (note that this moment can differ per country). This prevents Blue Bond Eurobond interest rates from reaching above a certain level, since the debt-to-GDP level is included as an important yield determinant for Eurobonds in all four methods. In the case of Germany, the interest paid over unlimited Eurobonds will exceed the interest rate paid over sovereign bonds towards the end of the model's runtime. At this point, the market's risk perception of German sovereign bonds is more positive than its risk perception of the unlimited Eurobonds.

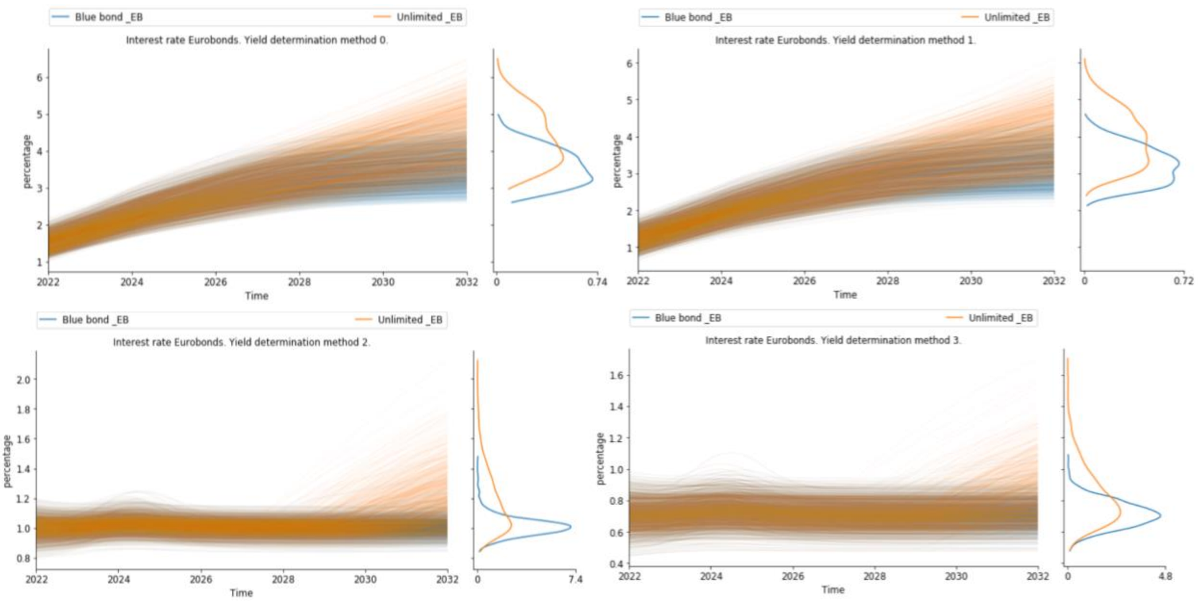

Figure 4.10 Interest rate Eurobond. Blue Bond Eurobonds and unlimited Eurobonds compared. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

Finally, it is interesting to see what happens to the sovereign bond interest rates of specific countries in response to introducing Eurobonds. Germany is an especially interesting example, as its bonds are considered the safest debt assets of the eurozone. Because of this, they also have the most to fear from a possible devaluation of their bonds as a consequence of Eurobonds (that would have a senior repayment status). The results of the experiments show that the effects of both Eurobond policies on Germany's interest rate for all four yield determination methods are small and, if anything, even slightly positive. This is true for all four yield determination methods (see appendix D.4). Despite the extra built up Eurobond debt that is also accounted for when calculating the sovereign bond's risk premium, the sovereign interest rate does not increase. This is because the German government also issues less national debt when the Eurobond programme is introduced, which keeps the total debt stock for Germany the same as it would be (be it sovereign or mutualised debt). At the same time, the fiscal position of the German government becomes even more positive for yield determination methods 0 and 1, due to the lower Eurobond interest rate (see figure 4.10). For the results of the sovereign interest rate of Italy, also see appendix D.4. Note that for Italy, introducing Eurobonds always improves their fiscal position and hence always also improves their sovereign interest rate.

To see how the Eurobond policies affect the German-Italian sovereign bond spread, see the graph on the left in figure 4.11. The graph on the right shows the German-Italian average bond spread (i.e., a weighted average, including Eurobond interest rates), which tells more about the actual interest payments made by both countries in case of the introduction of Eurobonds. As expected, both bond spreads are significantly reduced by the introduction of both types of Eurobonds. For the average bond spread, notice that unlimited Eurobonds cause the spread to approach 0 (i.e., a high degree of fiscal convergence), as both countries exclusively issue Eurobond debt, which then starts to make up the majority of their respective debt stocks.

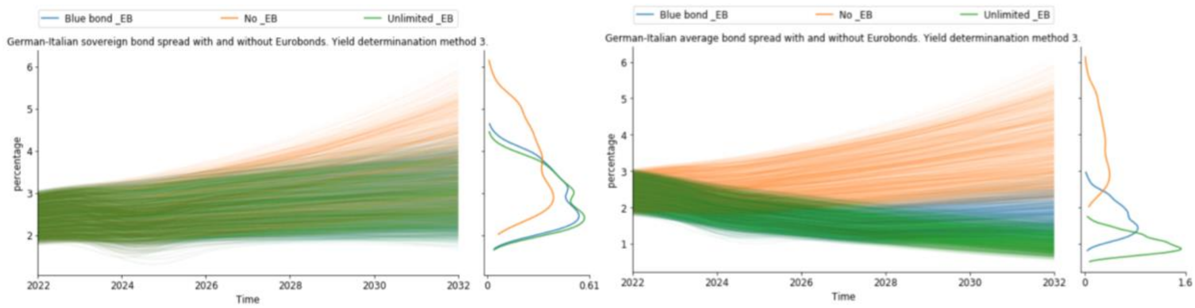

Figure 4.11 German-Italian sovereign bond spread (left) and German-Italian average bond spread (right) under level 2 uncertainty. Yield determination method 3. For the results of yield determination methods 0, 1 and 2, see appendix D.5. 1000 runs per policy.

4.3 RESILLIENCE

In this final section of the results chapter, the Eurobond policies will be tested in worst-case scenarios. These scenarios encompass the entire level 3 uncertainty space. The demographic scenario switch has been included as a categorical uncertainty, whereas the switches related to investment productivity, the ECB interest rate and the imports from non-eurozone countries are used in three different configurations in order to simulate three types of recessions. These are as follows:

- A world-wide recession, without a change in the ECB's rate policy.
- A world-wide recession, with the ECB lowering rates to stimulate the eurozone economies (an approximation of quantitative easing).
- A world-wide recession, with the ECB fighting inflation by raising rates (an approximation of quantitative tightening as a response to stagflation).

In all three scenarios, the returns on investment are linearly reduced from 5% to 1%, over the course of 2 years. Furthermore, total non-eurozone import demand is halved over a period of 10 years. The ECB interest rate is either increased or decreased by 50 basis points, every 6 months, for the first 2.5 years. These extreme circumstances have been picked in such a way that they negatively affect all eurozone economies. It is exactly situations like these that put the resilience of any Eurobond policy to the test. Just like the previous two sections, the policies' effectiveness will be tested with respect to the economic growth facilitation and the debt sustainability.

4.3.1 Economic growth

In all crisis scenarios run with the Eurobond model, total eurozone GDP decreases in most cases. The only exceptions are scenarios with additional demographic growth, which mitigates the reduced investment by increased private consumption. On a country-level, it is interesting to note that German and Dutch GDP decrease in almost all scenarios, because of their high extra-eurozone export dependency, whereas Italy and France are less hard hit by decreases in import demand from outside the eurozone.

To illustrate the magnitude of the anticipated mitigating effects both Eurobond policies could have in these situations, table 5 presents the GDP increases for the eurozone as a whole, Germany, and Italy, using yield determination method 3. Note that for both Eurobond policies, in all three crises, the average additional economic growth (or dampened economic decline, in most scenarios) is not significant. Only the results with yield determination methods 0 and 1 find a significant average GDP increase (i.e., > 0.50%) with unlimited Eurobonds for Italy.

Table 5 Overview of average GDP increases of the eurozone as a whole, Germany, and Italy. Results for both Eurobond policies are presented. Yield determination method 3. 1000 runs per policy.

Blue Bond/Unlimited Eurobonds	GDP increase (%) Stable ECB rate	GDP increase (%) ECB rate decrease	GDP increase (%) ECB rate increase
Eurozone	0.21%/0.21%	0.11%/0.11%	0.24%/0.25%
Germany	0.19%/0.18%	0.09%/0.09%	0.21%/0.21%
Italy	0.24%/0.29%	0.20%/0.22%	0.28%/0.36%

4.3.2 Debt sustainability

Figure 4.12 shows the development of the interest rates of the two types of Eurobonds, in all three types of recessions. In all three situations, the unlimited Eurobonds' interest rates eventually reach higher values than the Blue Bond Eurobonds. This is again due to the Eurobond debt stock increasing to levels that are restricted for Blue Bond Eurobonds.

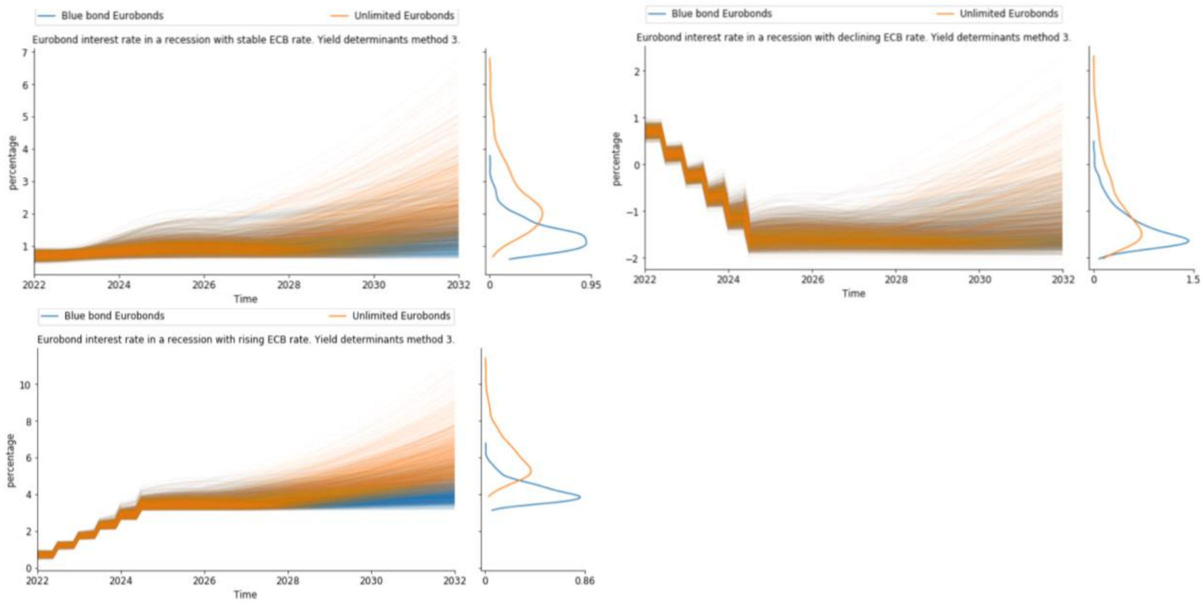

Figure 4.12 Interest rate Eurobonds under level 3 uncertainty. From top left to bottom: recession with stable ECB rate, recession with declining ECB rate and recession with increasing ECB rate. Yield determination method 3. For the results of methods 0, 1 and 2, see appendix D.6. 1000 runs per policy.

Lastly, in all three recessions, the debt-to-GDP ratio for the entire eurozone is significantly reduced by both Eurobond policies, similar to the results of the policy analysis in section 4.2 (see appendix D.7). This effect has been found to be robust for all four yield determination methods. These reductions in debt-to-GDP ratios are attributed to lower total debt levels, again especially for the heavily indebted economies, and not to increased GDP (which is mostly insignificant, as seen in table 5).

SQ3. Do Eurobonds facilitate economic growth and stability for the eurozone, and which countries have most to gain or lose with Eurobonds?

The results of the experiments with the Eurobond model have provided insights into the dynamic behaviour of the system, as well as the effects of the Eurobond policies on that system.

It has been shown, that Eurobonds only provide marginal economic growth benefits to the eurozone as a whole. On a country-level, this growth is unevenly distributed and mostly attributed to lowered borrowing costs. The anticipated positive economic spill-over through increased trade and FDI is mostly insignificant as a fraction of GDP. For small economies, it can be significant. Smaller and initially heavily indebted countries have disproportionately much to gain from introducing Eurobonds.

The extra economic growth facilitated by unlimited Eurobonds compared to Blue Bond Eurobonds is negligible. For financially sound countries like Germany and the Netherlands, Blue Bond Eurobonds are even more beneficial than unlimited Eurobonds, since the latter deteriorates their fiscal position on the long-term.

When it comes to debt sustainability, both Eurobond policies provide significant benefits to the eurozone as a whole, and especially to heavily indebted member states. In many cases, Eurobonds even improve the fiscal position of the best performing eurozone economies. Again, the additional benefits that unlimited Eurobonds provide compared to Blue Bond Eurobonds, are small.

Even in cases of severe recessions, with varying ECB rate policies, both Eurobond policies keep providing the benefits discussed above.

5. DISCUSSION

The purpose of this chapter is to reflect on both the results of the model experiments, as on the model itself. Several model limitations will be addressed and discussed. This chapter will end with a reflection on the scientific relevance of this study.

5.1 INTERPRETATION OF RESULTS

The results produced by the experiments with the Eurobond model in chapter 4 have provided valuable insights into the effects of Eurobonds on the eurozone economy. In line with prior expectations, both Eurobond policies have significant positive effects on European debt sustainability, whereas the observed effects on economic growth are insignificant for most countries in most scenarios.

Both Eurobond policies only facilitate a small increase in the GDP outlook of the eurozone, with the growth benefits not equally distributed amongst its member states. The increased economic growth that does occur is mostly attributed to the decreased interest rate pressure. A lower interest rate encourages additional domestic investment and provides more fiscal space for governments to make public investments. The larger the difference in old and new interest rates, the bigger the growth potential facilitated by Eurobonds. One crucial assumption is of course that the extra fiscal space is put to productive, rather than consumptive use.

The anticipated positive trade-induced GDP spill-over from the big beneficiaries to countries like Germany has not been found to be of significant magnitude. This might not be far from reality, since exports and imports are relatively rigid and depend on established specialisations and non-price competitiveness factors. This does not seem to be very convincing for these countries to participate in a Eurobond programme, especially because it does not justify the need for a transfer of fiscal sovereignty away from the national level. However, the lack of significant results can partially be explained by the structure of the model and the output metrics that have been analysed. First of all, imports are directly linked to consumption in the Eurobond model (as a fraction: the average propensity to import), whereas the introduction of Eurobonds does not directly affect consumption itself, but only indirectly through increased wages, induced by increased productivity as a consequence of increased investment. This has been a modelling choice. In reality, however, investment also induces consumption and imports. If implemented in the model, this could have made increases in trade volumes more significant. One other thing that is overlooked in the analysis of this study, is the welfare gains achieved across the eurozone that are attributed to productivity gains (e.g., when Italian productivity rises, German consumers eventually spend less on imports), something that is linked to increased investment, and thus to the introduction of Eurobonds.

Next to that, Eurobonds do provide significant improvements to the debt sustainability of participating countries, and to the eurozone as a whole. The benefits especially hold for the heavily indebted, southern economies. Countries like Greece, Italy and Portugal have a lot to gain from a structurally lowered interest rate. This fact might seem to support the criticism of sceptical northern Europeans that fear that Eurobonds could remove any incentive for fiscal responsibility in the south, leading to a high mutual debt burden in the end. In the case of unlimited Eurobonds, these fears are justified by the lack of country-level market incentives. Furthermore, the model experiments with unlimited Eurobonds show that once the stock of issued Eurobond debt reaches a certain size, the interest rate paid over these Eurobonds will exceed the German sovereign interest rate. On the longer term, this would subsequently deteriorate Germany's debt sustainability. An unlimited Eurobond programme would still offer the benefit of reducing the risk of a southern default by significantly reducing their debt burdens, but whether this is worth the costs for countries like Germany and the Netherlands remains a political question. In the past, these countries have shown to prefer a focus on austerity measures when dealing with high indebtedness. Considering that these countries are the most important contributors to the credibility of a Eurobond programme, and considering the sceptical public opinion in these countries, this is not an attractive prospect for the advocates of unlimited Eurobonds.

However, the experimental results for Blue Bond Eurobonds do not seem to substantiate the northern fears of a transfer union. Blue Bond Eurobonds have the potential to improve the debt sustainability of all participating countries, including Germany and the Netherlands (be it to a lesser degree). This is because the model's results indicate that introducing Blue Bond Eurobonds can achieve a decrease in the interest rate for all countries. To judge the robustness of these results, the experiments have taken multiple ways of determining bond yields into account as a structural uncertainty. As to the fears related to the lack of market discipline, Blue Bond Eurobonds also appear more attractive for the doubting northern Europeans. Due to the design of the proposal, participating countries are still subject to market forces, because 'red' debt (i.e., sovereign debt in the Blue Bond proposal) remains of importance, especially so when a country has already issued its maximum share of 'blue' debt. These market incentives are even expected to be stronger, due to the junior status of the red debt, encouraging compliance with the maximum debt-to-GDP ratio of 60%, as included in the Stability and Growth Pact. Furthermore, blue debt issuance can be embedded in a framework that prevents fiscally irresponsible behaviour by setting conditions for issuing mutual debt, further mitigating the risk of moral hazard. Based on recent political history, it is expected that critical countries will only agree to participate under strict fiscal conditions. The details of such conditions are up to the member states to decide on collectively.

5.2 MODEL ASSUMPTIONS AND LIMITATIONS

Developing a simulation model always requires assumptions to be made, since models are approximations and simplifications of reality. Especially in the field of economics, disagreement about theoretical assumptions always seems right around the corner. That is why this section will critically discuss some of the fundamental assumptions and modelling choices that were important to the Eurobond model and this study.

5.2.1 Loanable funds theory

One of the key economic assumptions of the Eurobond model is that total savings equal total investments. This assumption is widely adopted amongst classical economists and it is at the base of the loanable funds theory, which states that savings provide the supply of loanable funds, whereas investment is simply the demand for loanable funds. The interest rate can then be interpreted as the price resulting from the loanable funds' demand-supply curve. This theory seems like an all-encompassing way to describe the relationship between the interest rate, the propensity to save and, as a consequence, the propensity to consume, making it very suitable to use for the investment and consumption sub-model of the Eurobond model.

However, the loanable fund theory fails to explain the dynamics behind phenomena like secular stagnation and it fails to appreciate the fact that the interest rate is not just a market-clearing price, but a monetary instrument that is actively used by central banks. Because this study attempts to explore the influence of a monetary innovation on the eurozone economies, a partial implementation of the loanable funds theory was deemed necessary and is thus used in the Eurobond model, despite its shortcomings. Because of the scope of this thesis project, it was not possible to include structural uncertainties that represent alternative economic theories, but it is important to be aware of this choice.

5.2.2 Yield determination methods

A structural uncertainty that has been included in the model, and is widely reported upon in the results chapter, is the four different ways of determining bond yields. Because the market's risk perception of debt assets remains a human matter, many different interpretations of this mechanism exist in literature. Many studies have even found the observable yield determinants to change over time.

The choice of these methods has been proven to be important for the development of debt levels in the model, but less so for economic growth. However, as already stated in sub-section 3.5.1, the model does not allow every yield determination method to be considered. Think of GDP growth that is not included as a yield driver, even though it does often appear in literature as a significant yield determinant. Secondly, all yield determination methods included in the model represent a linear relationship; no quadratic relationships are taken into account, even though some of the studies into the yield determinants do indicate their existence. Thirdly, approximating the debt markets' liquidity has been done by comparing the size of a country's outstanding debt to that of Germany, and the sensitivity to this approximated liquidity subsequently had to be empirically estimated. The EMA approach is helpful to account for this type of deep structural and parametric uncertainty as much as possible, but it fails to account for all conceivable yield drivers. Because of these shortcomings, it is important for anyone interested in the results of this study to be aware of its limitations in representing all possible structures.

5.2.3 Total gross operating surplus and mixed income

Total gross operating surplus and mixed income is included in the labour market sub-model of the Eurobond model, and it represents the part of household income that is not derived from wages. Calculating household income is important for determining *total private consumption*, which is necessary for calculating GDP according to the expenditure method (see eq. 1). This non-wage fraction of income is based on European economic data and kept stable throughout the model run time. In reality, the fraction of household income not attributed to wage income is not static, but would be dynamic in response to changes in other macro economic indicators.

However, implementing this would require a more extensive labour market sub-model, for which the scope of this research is too narrow. Furthermore, because the Eurobond model is not meant to make accurate predictions about the future, the exact dynamics behind this variable are not as relevant. Leaving the variable out all together would not be an option because without it, total private consumption would be structurally too low and lead to unrealistically low GDP values and, as a consequence, would result in unrealistically hight debt-to-GDP ratios. The way the variable is currently included in the model does not produce any GDP values that are outside the range of what is realistic (see figure 3.2). The variable is not a part of the parametric uncertainties, since this would only increase the initial GDP bandwidth, making any subsequent analysis less meaningful.

5.2.4 Export competitiveness

In the way it is currently modelled, the Eurobond model assumes that import shares respond to relative changes in the unit labour costs of the exporting countries. The decrease in unit labour costs is calculated in every timestep and, through the *Import share sensitivity to price changes*, the import shares (for specific country pairs) are either increased or decreased incrementally. The import shares are initialised to equal real-world inter-country trade shares.

Even though this dynamic produces realistic behaviour, the role of relative unit labour costs in determining export competitiveness is controversial. It would rather be better to rely on changes in the real exchange rate. The model structure does not allow for this unfortunately. Unit labour costs are a good approximation of this and it takes the development of wage costs and labour productivity into account, two variables that are affected by the Eurobond policies that are explored with the model.

Lastly, many non-price competitiveness factors also play a role in the real world (e.g., a country's reputation and the physical distance between trade partners). However, changes in non-price competitiveness factors cannot be accounted for in the Eurobond model, and it is also not the purpose of the model to predict anything like that. What is important is the change of the trade shares, based on wage and productivity changes, starting from their initial value.

5.2.5 Data issues

Some of the data required for the Eurobond model is very specific or hard to gather. The country-specific data shown in appendix D does not originate from one single source, simply because that was not possible. Some data is expressed in US dollars, whereas other data is expressed in euros. Furthermore, 2022 was always preferred, but sometimes not available. This means that some data is from the years 2017 to 2021. Despite the relatively small year-to-year differences, this is not ideal data consistency, but it has to be accepted as a fact. Even if all data were to be retrieved from one institution, this institution would still rely on national statistical bureaus for country-specific data. Despite the European efforts to harmonise data standards, this is not always the reality.

For some data, like the *initial average propensity to save*, no reliable country-specific value ranges exist in economic literature. For cases like this, a value range has been included as a parametric uncertainty, but not on a country-specific level. If additional data would become available on a country-level, the model could easily be adapted to incorporate this.

Apart from these inconsistencies, some data is simply inherently imprecise, like each country's capital stock. The data used for the national capital stocks is derived from an IMF estimation. However, this data turned out to lead to unrealistic *output capacity* values, when combined with realistic *capital productivity* value ranges. To correct for this, the capital productivity has been set unrealistically high, at a value iteratively determined using the model, with the purpose of resulting in realistic output capacity data that is not too far off from the GDP produced by the model. This is conceptually wrong, but the results of the experiments have indicated that the influence of this variable is limited for the output metrics relevant to this study.

Lastly, some data types do not display continuous behaviour in the real world. FDI is a good example of this. This data is discontinuous in nature, because it heavily depends on individual investment decisions taken by large firms. To overcome this, the data used to initialise FDI in the model is the average of the past five years. However, the model's results of course produce continuous data, which is not realistic and should be interpreted as an average expectation, with the real world results possibly deviating significantly.

5.2.6 Model scope

Finally, it is important to critically discuss the adequacy of the scope of the Eurobond model. Since the development of the model has been done in an iterative way, starting 'from scratch', the model's boundaries have evolved in a similar fashion. Now that the analysis phase of this study is over, it should be noted that not all sub-models have been used and analysed to their maximum extent. For example, the labour market sub-model contains many elements that have been left out of the analysis, due to the limited scope of this thesis. Knowing this, the Eurobond model could have been communicatively stronger if the focus had been more clear, free of possibly redundant components.

Lastly, due to the chosen time horizon of 10 years, the Eurobond model does not provide useful insights into the long-term effects of introducing Eurobonds. However, if the model's time horizon would have been set further in the future, the results would have been far-fetched extrapolations. For example, some debt-to-GDP ratios would reach unrealistically high values, making the model invalid because it does not take into account all aspects of European debt management. It is crucial to realise that the Eurobond model is no all-encompassing simulation of the eurozone economy and that the behaviour produced by it is only valid under limited conditions, like how it is used in this study.

5.3 SCIENTIFIC RELEVANCE

This research has been the first known attempt at developing a system dynamics model for exploring the effects of introducing Eurobonds on the eurozone economy. It can serve as a reference for future system dynamics modellers operating in the field of macro economics. The Eurobond model can be especially useful to those interested in exploring European debt management dynamics, though it could also be set up for alternative monetary unions. Additionally, the other components of the Eurobond model could serve as an inspiration for any study into one of the areas covered by the sub-models.

This study is a novelty in its way of combining several theories on the determination of bond yields in an exploratory modelling and analysis approach, and to produce a wide range of possible future scenarios with country-level results. The inclusion of these structural uncertainties can serve as an encouragement for future researchers in this field to include even more yield determination methods in their models, potentially leading to more robust conclusions, and subsequently decision-making. The same is true for the large set of included parametric uncertainties, many of which could benefit from improved accuracy.

Lastly, the EMA approach used in this study is a powerful tool for exploring and understanding a system and the effects of policies on that system. It provides a wide range of insightful functionalities, many of them not even used in this study. By showing a fraction of the possibilities of the EMA approach, this study hopes to have contributed to its wider adaptation within the world of economics modelling.

6. CONCLUSIONS AND RECOMMENDATIONS

This research has attempted to model the eurozone economy and to explore the effects of introducing Eurobonds. For this purpose, a system dynamics simulation model has been developed and put to use in an exploratory way, taking all uncertainties related to the system of study into account. This chapter will summarise the conclusions of this report, followed by some actionable recommendations.

6.1 CONCLUSIONS

First of all, it has been established that Eurobonds' main purpose is to facilitate economic growth and stability for the eurozone. Several types of Eurobond proposals have been suggested in the past years. The characteristics of these proposals differ concerning the suggested distribution of liability, the institutional requirements, and the maximum issuance, with the former two being mostly political questions. For the purpose of this research, the effects of both Blue Bond Eurobonds and unlimited Eurobonds have been explored.

Because the economic system of the eurozone is complex in nature and contains many deeply uncertain relations, mental models are not sufficient to analyse the system. Because of the feedback structures, the delays and the accumulation of stocks, a system dynamics model has been developed to simulate the system. To take the inherent parametric and structural uncertainties into account, an exploratory modelling and analysis approach has been used to perform model experiments. The model's performance on growth- and stability-related output metrics has been tested for a wide range of scenarios. The results with and without Eurobond programmes have been compared in order to assess the policy's effectiveness.

The results of the experiments with the Eurobond model have shown that both Blue Bond Eurobonds and unlimited Eurobonds have the potential to offer significant eurozone-wide benefits with regard to public debt sustainability. This effect is strongest for the most heavily indebted eurozone economies, which could see their debt burden significantly decreased. It has to be noted, that unlimited Eurobonds can lead to very big stocks of issued Eurobond debt, which eventually deteriorates the market's risk perception of Eurobonds. This can lead to a situation where safe sovereign debt assets (e.g., German bonds) become more attractive than Eurobonds. Due to the policy's design, Blue Bond Eurobonds do not allow for this risk.

The degree to which Eurobonds can facilitate economic growth depends mostly on the interest rate decrease realised by their introduction. The difference in growth facilitated by the two Eurobond policies is negligible, with unlimited Eurobond even being less beneficiary for countries like Germany and the Netherlands. Furthermore, since the interest rate decrease is unevenly distributed amongst the eurozone members, the heavily indebted economies benefit most from the policy. The positive spill-over effects induced by increased cross-country trade and investment are insignificant in magnitude and proportionally largest for small economies.

Lastly, Eurobonds can mitigate the negative effects of different types of recessions on the eurozone. The experiments have shown that Eurobonds still provide growth and stability benefits to the eurozone economy in situations of decreasing global demand for European goods, diminishing returns on investment and varying ECB rate policies.

6.2 RECOMMENDATIONS

Based on all of the above, it can be concluded that it would be sensible for the European Commission and the national governments it represents, to openly speak out their support for introducing (a variant of) Blue Bond Eurobonds. Eurobonds are necessary to avert a future of unsustainable public debt levels, one of the biggest existential threats to the Euro, and subsequently the EU itself. Compared to Blue Bond Eurobonds, Unlimited Eurobonds do not provide significant additional benefits to growth and stability. Furthermore, Blue Bond Eurobonds by design (unlike unlimited Eurobonds) do not remove country-level market pressure for fiscal discipline, due to the 'red' (sovereign) debt.

This research has mostly provided insight into the potential economic benefits of Eurobonds, and it is up to European decision-makers to overcome the political obstacles standing in the way of a Eurobond programme. However, some more specific conclusions can also be drawn based on the assumptions at the root of the Eurobond model. When introducing Eurobonds, it is important to set concrete terms for the types of investment to be made with the newly supplied funds, so that it is actually put to a productive use, something that is assumed in this study. Also, it is in the interest of all participating member states to strive for compliance with the existing fiscal guidelines (as included in the Maastricht criteria and the Stability and Growth Pact), in order to uphold the market's trust in the eurozone's financial soundness, affecting the Eurobonds' credit rating. This should ideally be achieved through positive incentives. Lastly, an option to penalise non-compliance is advised as a last resort.

In no way does this study provide any institutional or legal framework for a Eurobond programme to be set up. Neither does it deny the uncertain political future circumstances the eurozone could find itself in on the mid to long term, or pretend to prescribe the different institutional characteristics that such circumstances would require of a Eurobond programme. Rather, this study provides an intuitive framework for understanding the economic dynamics relevant for the success of a Eurobond programme, and the sustainability of European public debt in general, hoping to be a meaningful contribution to the political debate.

6.3 SUGGESTIONS FOR FUTURE WORK

Any future researcher that wants to use system dynamics modelling to explore the effects of Eurobonds will probably be faced with different European economic circumstances and possibly alternative economic insights. Luckily, the Eurobond model allows for different parameterisations to be set up, to account for any future changes, and its modularity allows others to further develop (a part of) the model. Of course, no model is perfect, and certainly not this one. The discussion chapter has already indicated some of the shortcomings of the Eurobond model that could be improved upon in future versions. Apart from that, several additional suggestions for future research are made in this final section.

First of all, the Eurobond model could serve as a basis for further exploratory experimentation with different types of Eurobond programmes. Think of a further division that could be made between short term and long term debt, in order to explore the implications of the average time to maturity on the policy's performance or resilience. Next to that, the model also allows future researchers to explore whether there is an optimal maximum issuance of Eurobonds, now just set at either unlimited or at 60%. Additionally, it would be interesting to explore the effects of the different ways of implementing the Eurobond policies, in order to find out what the effects of an initial sovereign debt reduction would be on Eurobonds' success, or whether it is best to implement Eurobonds immediately or gradually.

Secondly, the aggregation level of the model could be lowered, if a modeller is interested in the effects of specific shocks on the system. This can be done by explicitly modelling more countries or groups of countries. This would allow the modeller to assess the effects of, e.g., Fed policy changes, countries joining the eurozone, or a decrease in trade with China. Next to that, improvements could include adding a price level for more accurately determining consumption and trade, or to estimate inflation, or to model the period after 2032, to explore the long-term consequences of introducing Eurobonds. Finally, several model elements could be included for additional insights, like a more elaborate, cohort-based population sub-model, endogenous labour migration, or a more dynamic labour costs sub-model.

Lastly, the robustness of any results derived from exploratory model experimentation would benefit from an accuracy increase of the parametric uncertainty ranges, and from the inclusion of alternative economic theories as structural uncertainties.

7. REFERENCES

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8. APPENDIX

This chapter contains all appendices deemed relevant to this study. The list spans from A to D and the they are referred to in the corresponding chapters of this report.

A. ECONOMIC DATA

Appendix A contains several tables of data that are used in the Eurobond model.

A.1. Import shares

The column of table 4 includes all importing countries. Each table entry represents the share of imports from the corresponding exporting country (shown in the top row), as a fraction of total imports of the importing country. By definition, the rows of this table all add up to 1. The colour scheme has been applied to illustrate the relative trade interdependence of country pairs.

*Table 6 Import shares of all included country pairs (Trading Economics 2022b). * Values have been determined by combining data with an exports dataset (WTO 2021).*

D\S	AT	BE	CY	EE	FI	FR	DE	EL	IE	IT	LV	LT	LU	MT	NL	PT	SK	SI	ES	WORLD
AT		0.023	0.00019	0.00057	0.0034	0.023	0.41	0.0016	0.0034	0.064	0.00041	0.0017	0.0025	0.00013	0.046	0.0019	0.026	0.017	0.012	0.3632
BE	0.0073		0.00009	0.0006	0.0033	0.1	0.16	0.0007	0.055	0.044	0.00051	0.0017	0.0049	0.00013	0.21	0.0033	0.0036	0.0009	0.034	0.36997
CY	0.0063	0.031		0.0005	0.0021	0.017	0.063	0.24	0.0095	0.1	0.0007	0.0013	0.0013	0.011	0.052	0.0035	0.0026	0.0021	0.033	0.4231
EE	0.0084	0.016	0.00064		0.092	0.025	0.1	0.001	0.0022	0.028	0.048	0.06	0.0005	0.00016	0.027	0.0016	0.0068	0.0019	0.015	0.5658
FI	0.011	0.021	0.0002	0.033		0.025	0.15	0.0015	0.0097	0.029	0.0044	0.0079	0.0013	0.00014	0.047	0.0068	0.0048	0.0022	0.022	0.62306
FR	0.001	0.11	0.00016	0.00064	0.0038		0.17	0.0028	0.014	0.084	0.0052	0.0011	0.0044	0.00045	0.09	0.0012	0.0089	0.003	0.079	0.42035
DE	0.039	0.042	0.00015	0.00069	0.0074	0.054		0.0024	0.018	0.057	0.00094	0.0023	0.0029	0.0004	0.079	0.0062	0.015	0.0058	0.03	0.63682
EL	0.01	0.033	0.0069	0.00049	0.0026	0.041	0.11		0.018	0.082	0.00045	0.00086	0.0015	0.0007	0.056	0.0021	0.0032	0.0034	0.035	0.5928
IE	0.035	0.023	0.000041	0.00014	0.019	0.12	0.083	0.0083		0.021	0.00057	0.0012	0.00048	0.00013	0.037	0.0043	0.00067	0.00042	0.02	0.625749
IT	0.023	0.045	0.0002	0.00035	0.0064	0.084	0.16	0.0069	0.011		0.00046	0.0015	0.0016	0.00058	0.059	0.0054	0.0075	0.0087	0.052	0.52641
LV	0.089	0.02	0.0012	0.089	0.037	0.016	0.11	0.0016	0.0035	0.031		0.17	0.00048	0.000072	0.041	0.0015	0.0076	0.0026	0.013	0.365448
LT	0.012	0.025	0.00034	0.034	0.029	0.032	0.13	0.0015	0.0039	0.046	0.078		0.0018	0.000063	0.053	0.0032	0.0064	0.0036	0.017	0.523197
LU	0.0075	0.25	0.00013	0.00019	0.0021	0.13	0.25	0.00056	0.0044	0.033	0.00048	0.0021		0.00005	0.045	0.0048	0.0053	0.0012	0.0014	0.26179
MT	0.0028	0.015	0.0019	0.0005	0.00068	0.071	0.067	0.02	0.018	0.2	0.00068	0.00049	0.046		0.036	0.0037	0.00063	0.0018	0.051	0.46282
NL	0.0069	0.11	0.00023	0.001	0.0092	0.038	0.19	0.0017	0.02	0.03	0.0016	0.0037	0.0024	0.00017		0.0049	0.0027	0.0015	0.022	0.554
PT	0.0055	0.031	0.0001	0.00046	0.0028	0.067	0.12	0.002	0.0097	0.052	0.00027	0.001	0.001	0.0006	0.054		0.0026	0.0015	0.33	0.31847
SK	0.029	0.011	0.0002	0.00067	0.0024	0.039	0.21	0.0016	0.0034	0.038	0.00061	0.0014	0.0011	0.00027	0.013	0.0039		0.0043	0.016	0.62415
SI	0.069	0.013	0.00021	0.0004	0.0028	0.028	0.13	0.0096	0.0048	0.11	0.00036	0.001	0.0011	0.00044	0.017	0.0028	0.014		0.015	0.58049
ES	0.0069	0.028	0.000091	0.0004	0.0034	0.1	0.11	0.0025	0.0084	0.067	0.00046	0.0013	0.0013	0.00015	0.05	0.04	0.0054	0.0014		0.573299
WORLD*	0.033476	0.073112	0.001052	0.003791	0.017323	0.10894	0.358468	0.009926	0.043109	0.124284	0.003812	0.008107	0.001468	0.000629	0.114501	0.009085	0.01938	0.009805	0.059735	

A.2. FDI inflows and outflows

Table 5 provides an overview of the country-level FDI outflows for all eurozone member states, as well as aggregated net data for the rest of the world. This data is used to initialise the Eurobond model. Table 6 presents the FDI inflows for the same set of countries, and for the rest of the world.

*Table 7 FDI outflows in mln USD (OECD 2022a). * (CEIC 2020) ** (National Statistics Office Malta 2021) *** Equal to eurozone FDI inflows (World Bank 2021a). The dollar denomination is irrelevant, since only relative FDI inflows are relevant in the Eurobond model.*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average
AT	22004	13060	15598	-665	6915	-1323	10679	5678	12655	-2222	10925	8482.182
BE	-	77031	24853	26737	61561	40164	29563	43554	-9306	11745	45756	35165.8
CY*	-	-	-	-	-	-	-	-	-	-	-	1852
EE	-1455	1054	516	42	182	486	888	45	1966	219	-578	305.9091
FI	5016	7546	-2307	1743	-16080	24252	-575	11448	4864	5850	3891	4149.818
FR	51462	35453	20365	49785	53206	64785	35908	101978	43812	8428	15512	43699.45
DE	78002	62188	39512	83968	99003	63599	86333	97172	137289	60486	151671	87202.09
EL	1774	678	-785	3015	1578	-1665	168	477	642	547	926	668.6364
IE	-1166	22557	29164	41182	168443	30055	-2043	4314	34442	-46482	62229	31154.09
IT	53677	7992	25130	26327	21640	16165	24478	31523	19786	-1852	11757	21511.18
LV	61	193	412	540	73	160	138	203	-104	269	3361	482.3636
LT	750	541	132	59	377	43	80	704	1746	2868	663	723.9091
LU	9052	-13402	46599	43365	31912	-1240	14987	-25462	-2576	102391	25395	21001.91
MT**	-	-	-	-	-	4852	6425	6370	6320	6344	-	6062.2
NL	34818	6174	69690	53951	233817	183488	18501	-46994	13678	-189359	23176	36449.09
PT	13627	-8474	769	-3260	4810	879	-928	1374	4011	2566	-1231	1285.727
SK	491	-73	-313	43	6	95	1323	291	43	235	389	230
SI	200	-258	-214	275	267	290	338	281	610	518	1303	328.1818
ES	45248	-2479	14294	36743	41917	43902	55926	37523	24826	34941	-1096	30158.64
WORLD***	818250	543520	603500	384850	776150	584940	465920	-14620	159410	48490	-	437041

*Table 8 FDI inflows in mln USD (OECD 2022a). * (Lloyds Bank 2022) ** (National Statistics Office Malta 2021) *** Determined combining data of known FDI outflows and FDI inflows. The dollar denomination is irrelevant, since only relative FDI inflows are relevant in the Eurobond model.*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average
AT	10820	4003	5813	4800	1295	-8401	14926	5512	2913	-14963	5855	2961.182
BE	-	88627	-5751	32082	-24013	68178	-3057	27119	-9209	13881	22955	21081.2
CY*	-	-	-	-	-	-	-	-	34362	4669	406	13145.67
EE	1006	1566	771	684	36	1058	947	1516	3184	3388	-29	1318
FI	2552	4156	-106	18548	2110	8576	2858	-2170	13455	-1422	9054	5237.364
FR	31671	16069	34264	2669	45355	23055	24780	41807	13100	2149	26973	23808.36
DE	67573	28190	12771	-3200	30534	15618	48538	72053	52664	64442	31263	38222.36
EL	1144	1741	2817	2683	1268	2762	3477	3971	5019	3205	5731	3074.364
IE	23566	48901	50585	48186	217820	39377	52722	-12512	158489	82122	15926	65925.64
IT	34355	93	24267	23224	19631	28441	23996	37659	18145	-23568	8486	17702.64
LV	1469	1113	903	896	741	253	708	963	902	1011	5326	1298.636
LT	1801	802	574	-133	1055	302	1019	976	3022	3484	2053	1359.545
LU	13302	2825	23288	20034	45422	17564	-27311	-26029	12801	102036	-9053	15898.09
MT**	-	-	-	-	-	3673	3153	3484	3398	3408	-	3360.75
NL	24391	20121	51096	45018	163574	52601	6791	88039	-16776	-104754	-96583	21228.91
PT	5997	8157	8216	4560	9180	5684	6912	7175	12251	7566	7980	7607.091
SK	2146	2826	-604	-512	106	805	4008	1643	2511	-1926	59	1005.636
SI	1088	339	-151	1050	1675	1245	896	1383	1463	219	1773	998.1818
ES	32412	24667	28342	22571	8557	31538	41877	57427	17416	12607	14458	26533.82
WORLD***	-	-	-	-	-	-	-	-	-	-	-	496186.7

A.3. Economic country-level data

Table 7 provides an overview of country-level economic data that is used to initialise the Eurobond model. It was not possible to extract all data from one single source, but everything is retrieved from reliable institutional sources.

The capital stock represents a measure of the total amount of physical capital in an economy, important for establishing the output capacity of an economy. The national debt is used as an initial value for the country-specific debt stocks and includes all outstanding public debt. Initial import shows the amount of yearly imports per country. Labour costs are the total hourly costs for labour, used to determine unit labour costs. The labour force participation rate represents the percentage of the working-age population that is part of the labour force. The working-age population at times 0 and 10 includes everyone between 15 and 64 years old. The yearly working-age population growth rate is derived from these numbers. The inward and outward FDI flows are derived from tables 5 and 6 and represent yearly numbers. Lastly, the average annual labour hours represents the average amount of hours worked by a person in the labour force during one year.

Table 9 Overview of country-level economic data (IMF 2017; IMF 2021; European Commission 2022; Statista 2022; OECD 2022).

Country	Abreviation	Capital stock bn [euro]	National debt mln [euro]	Initial import thousand [euro]	Labour costs [euro/hour]	Labour force participation rate [dmnl]
Austria	AT	1101.934064	348755	158084296	36.7	81.03
Belgium	BE	1230.429752	562532	385374914	41.1	78.21
Cyprus	CY	48.78228896	25158	8353864	17	83.25
Estonia	EE	58.71696904	5629	16969263.8	13.6	85.84
Finland	FI	654.7989773	184626	65350104.8	34.3	84.27
France	FR	6660.089359	2901846	554320875.6	37.5	80.77
Germany	DE	8542.345224	2482516	1090616983	36.6	83.57
Greece	EL	509.9838841	357665	54511021.8	16.9	75.9
Ireland	IE	582.7966263	234882	90513053.6	32.3	80.31
Italy	IT	4861.2402	2755390	419372869.4	29.8	71.67
Latvia	LV	65.669881	14632	16105372.2	10.5	83.23
Lithuania	LT	83.01467392	23308	31429093.6	10.1	85.76
Luxembourg	LU	103.5443944	16880	19670086	42.1	80.53
Malta	MT	21.06753973	8672	5642111.2	14.5	81.97
Netherlands	NL	1868.288446	446419	452186688.6	36.8	84.75
Portugal	PT	528.5147982	275995	76324068.6	15.7	84.28
Slovakia	SK	213.8242559	61874	79080238.2	13.4	83.14
Slovenia	SI	114.0074169	40225	33259099.2	19.9	82.44
Spain	ES	3199.830426	1453853	323562193.4	22.8	81.52
Outside eurozone	WORLD	196353.9953	194359988	2278600000	9	58

Abreviation	Working-age population t=0 [person]	Working-age population t=10 [person]	Working-age population growth rate [1/year]	Outward FDI mln [USD]	Inward FDI mln [USD]	Annual labour hours [hour/person]
AT	5924859	5716905	-0.003566556	8482.18182	2961.18182	1442.5
BE	7355742	7356640	1.22075E-05	35165.8	21081.2	1493.1
CY	606967	628751	0.003532313	1852	13145.6667	1745.3
EE	838062	812203	-0.003129271	305.909091	1318	1767.1
FI	3406292	3372679	-0.000991201	4149.81818	5237.36364	1518.3
FR	41360574	40815934	-0.001324678	43699.4545	23808.3636	1490.3
DE	53103231	49489369	-0.007023211	87202.0909	38222.3636	1349.3
EL	6688035	6215091	-0.007307146	668.636364	3074.36364	1872.2
IE	3354109	3631097	0.007966429	31154.0909	65925.6364	1775
IT	38263239	36134772	-0.005707053	21511.1818	17702.6364	1668.5
LV	1172347	1002972	-0.015482901	482.363636	1298.63636	1601.2
LT	1777189	1509122	-0.016217544	723.909091	1359.54545	1620
LU	445411	468734	0.005116846	21001.9091	15898.0909	1382
MT	358868	396555	0.010036038	6062.2	3360.75	1882.2
NL	11328788	11305131	-0.000209018	36449.0909	21228.9091	1416.5
PT	6541176	5993807	-0.008700945	1285.72727	7607.09091	1648.9
SK	3621885	3458557	-0.004603686	230	1005.63636	1583.2
SI	1345768	1294764	-0.003856187	328.1818	998.181818	1596.4
ES	31216144	30763523	-0.001459507	30158.6364	26533.8182	1640.9
WORLD	4959565092	5394894941	0.008449	340854.253	400000	1900

B. MODEL

This appendix contains information related to the structure of the Eurobond model.

B.1. Sorci's model

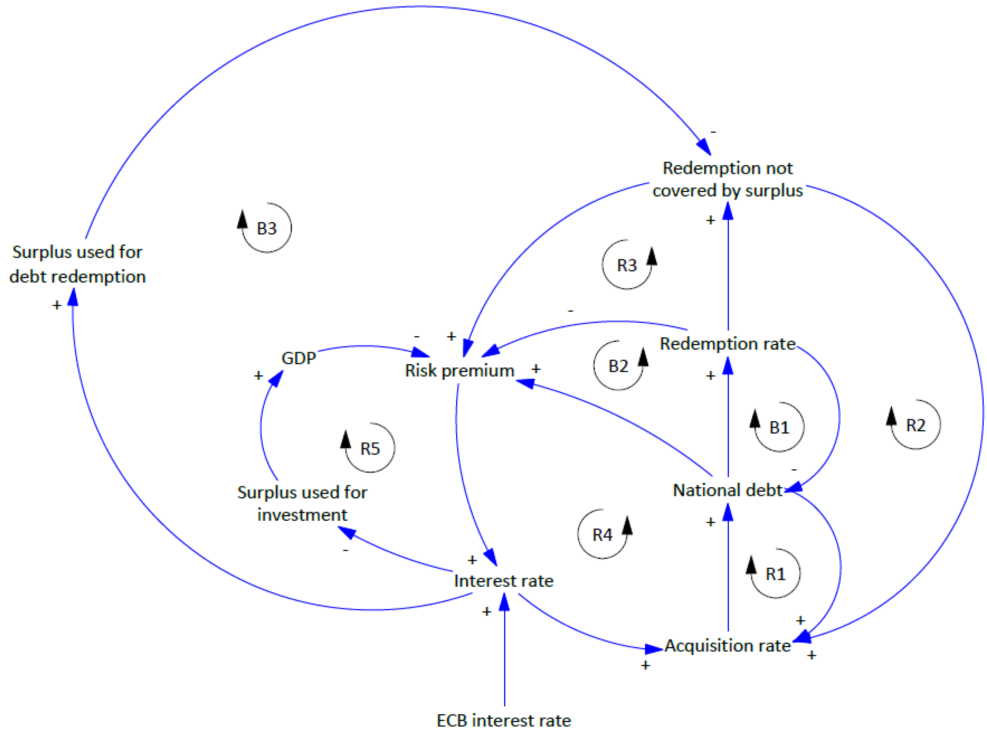


Figure 8.1 Causal loop diagram of Sorci model.

Feedback loops present in figure 8.1:

- B1. Higher debt means higher redemption. This in turn decreases the amount of debt, which decreases redemption.
- B2. The risk premium increases acquisition, which increases redemption. This decreases the risk premium again.
- B3. A higher interest rate increases the part of the surplus being used for debt redemption, lowering acquisition rate and so decreasing the interest rate.
- R1. A higher acquisition rate increases the debt stock, which increases the acquisition rate again because of the interest paid over the debt.
- R2. This loop shows that the acquisition rate increases if the debt redemption that is not covered by the country's surplus increases. An increased acquisition rate increases the debt stock, which increases redemption. This again increases the redemption that is not covered.
- R3. This loop is about the endogenously determined risk premium that is increased by a higher uncovered redemption. The risk premium itself increases acquisition and subsequently the redemption.
- R4. Similarly to R3, the risk premium gets increased by national debt in this case, which itself is increased via the risk premium through acquisition.
- R5. This is the so-called doom loop, which shows us that a higher interest rate is self-reinforcing because it decreases investment, negatively affecting GDP. This further increases the interest rate, leaving no fiscal room for public investment without new debt acquisition anymore.

B.2. Stock-flow diagrams sub-models

Figures 8.2 to 8.6 show the stock-flow diagrams of the sub-models *Debt management*, *Investment and Consumption*, *Labour market*, *Trade*, and *FDI* respectively. The orange variables in the following stock-flow diagrams represent variables with an uncertain value, whereas grey variables contain initial values. Rectangles are stock variables, arrows are flow variables, and circles are switch variables. The rest are constants or auxiliary variables.

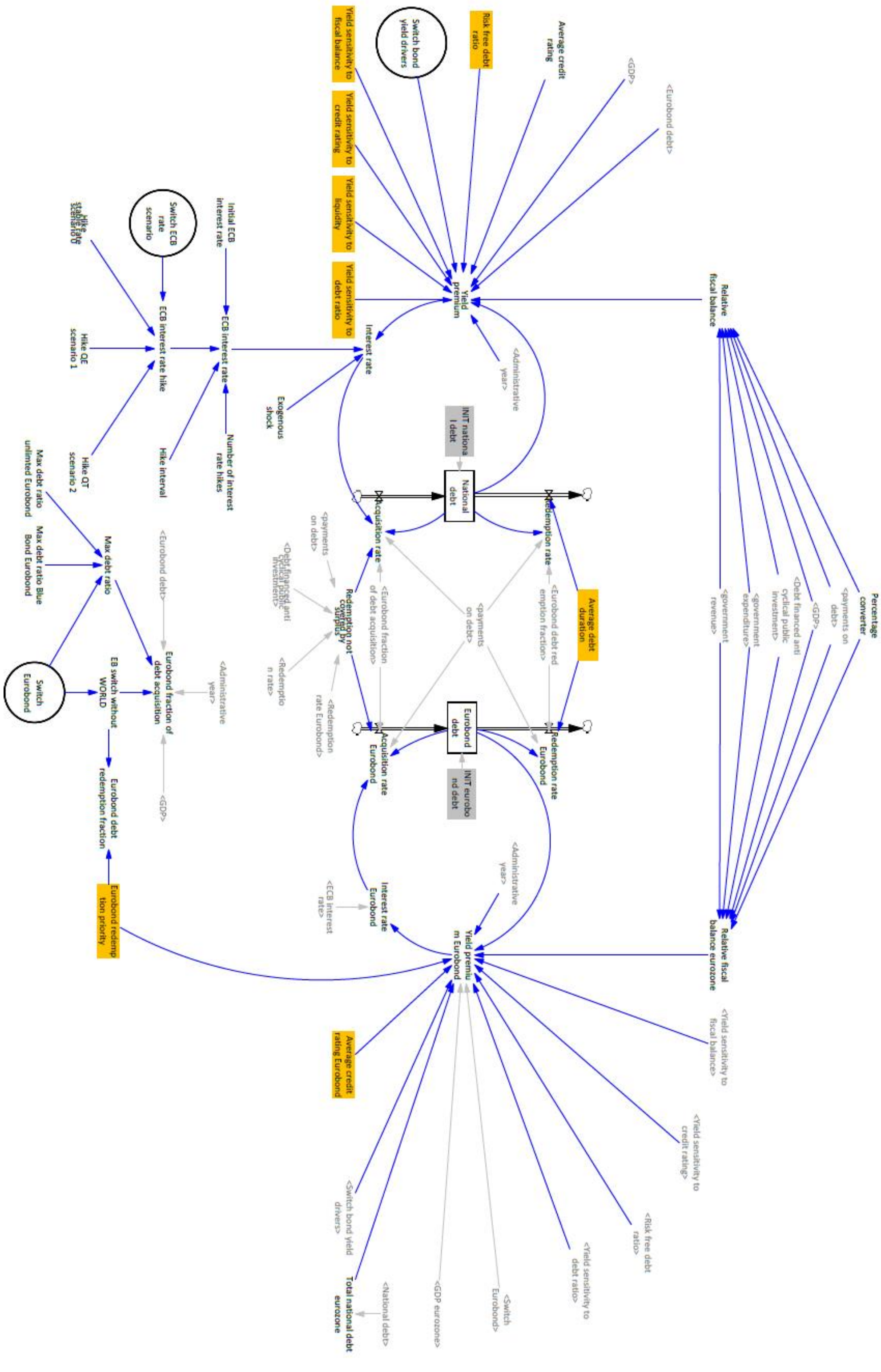


Figure 8.2 Stock-flow diagram of debt management sub-model.

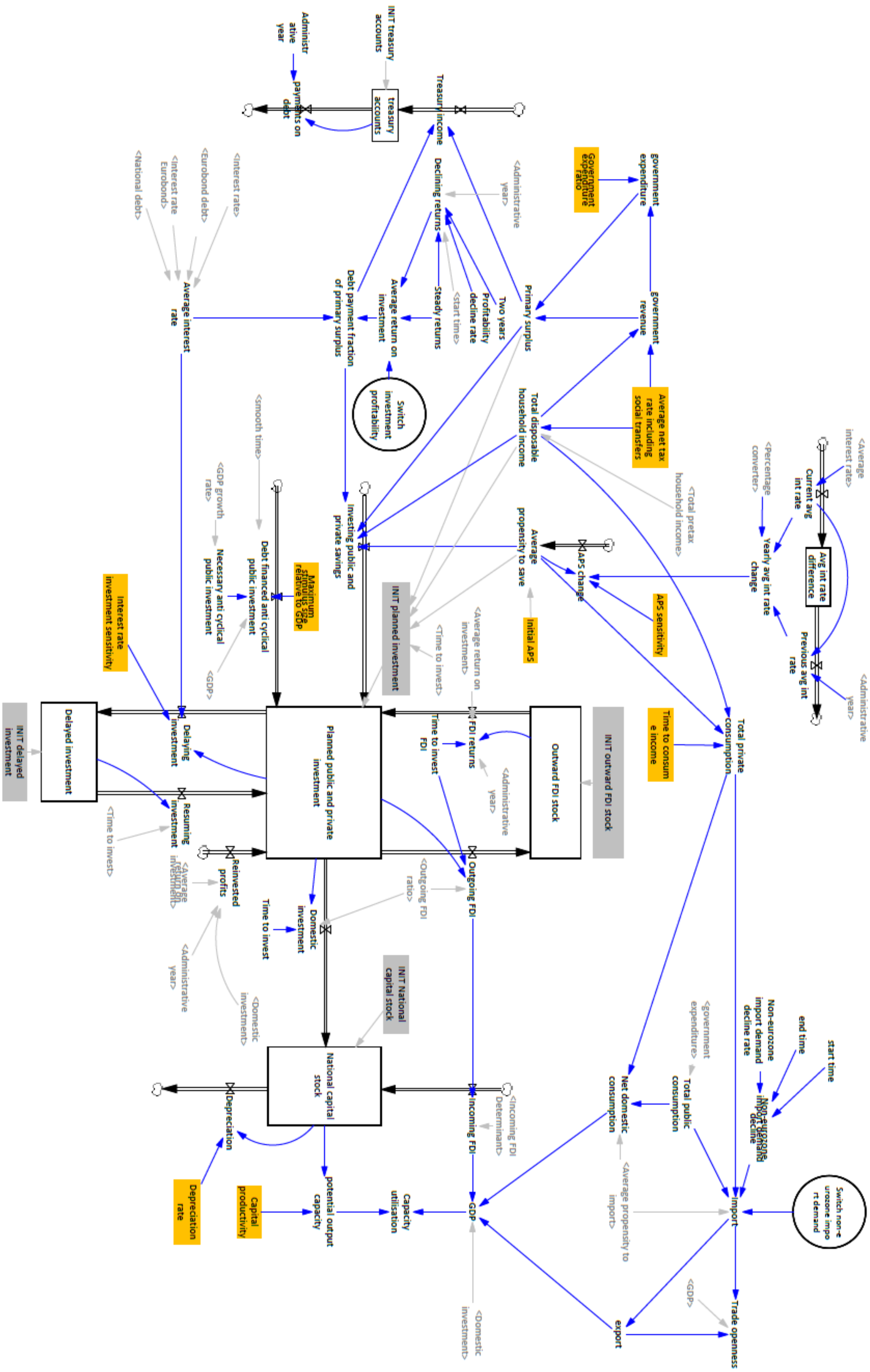


Figure 8.3 Stock-flow diagram of investment and consumption sub model.

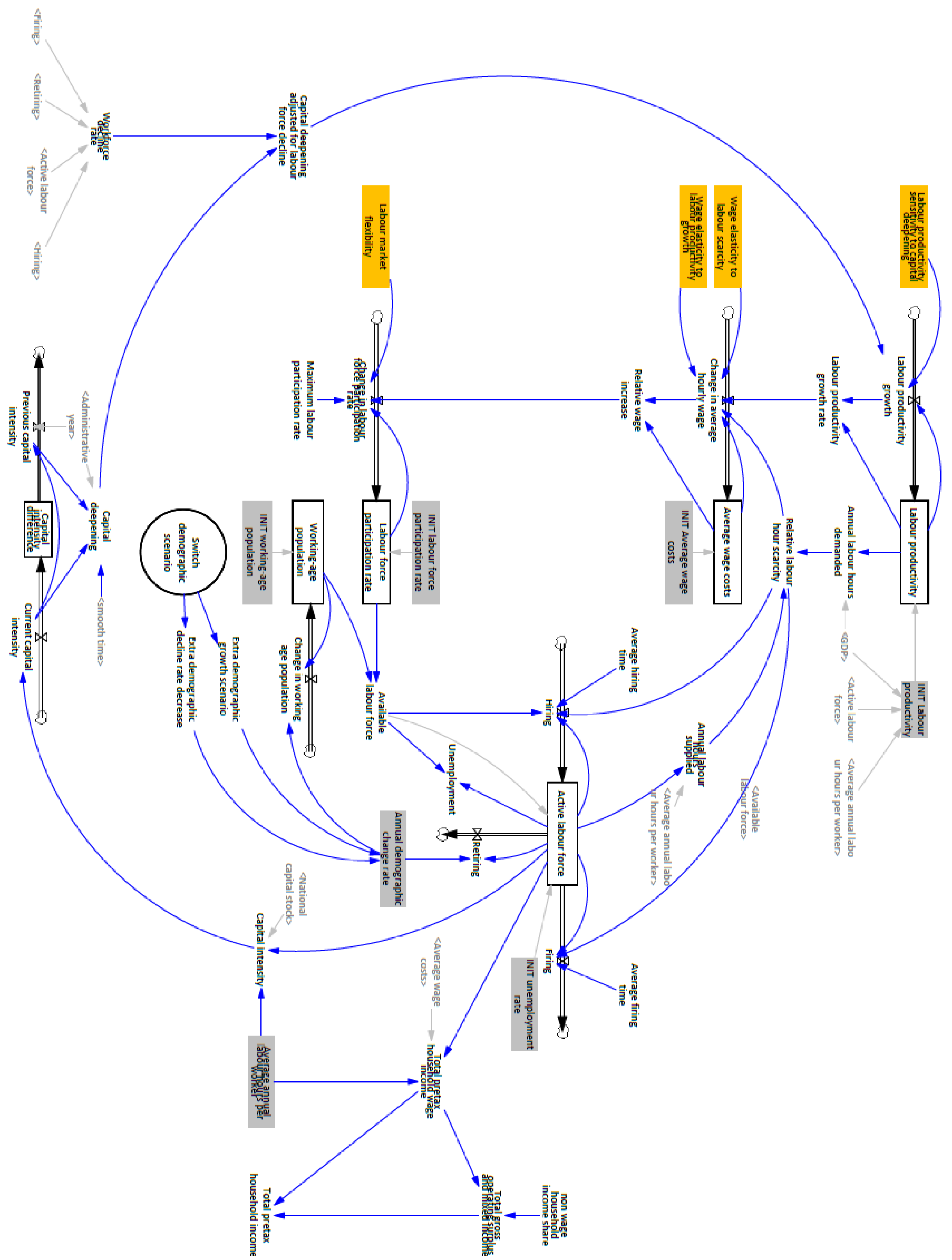


Figure 8.4 Stock-flow diagram of labour market sub-model.

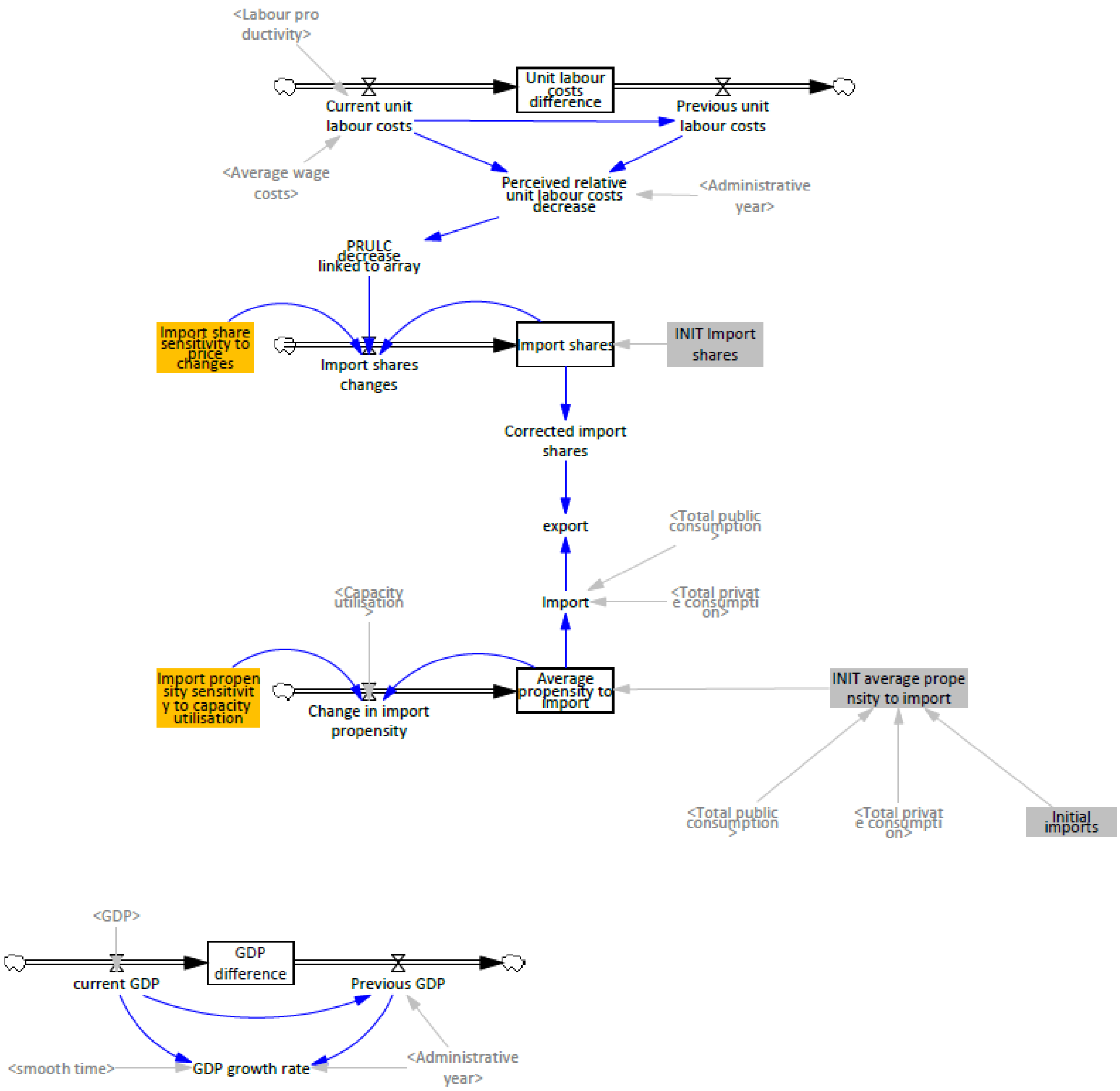


Figure 8.5 Stock-flow diagram of trade sub-model.

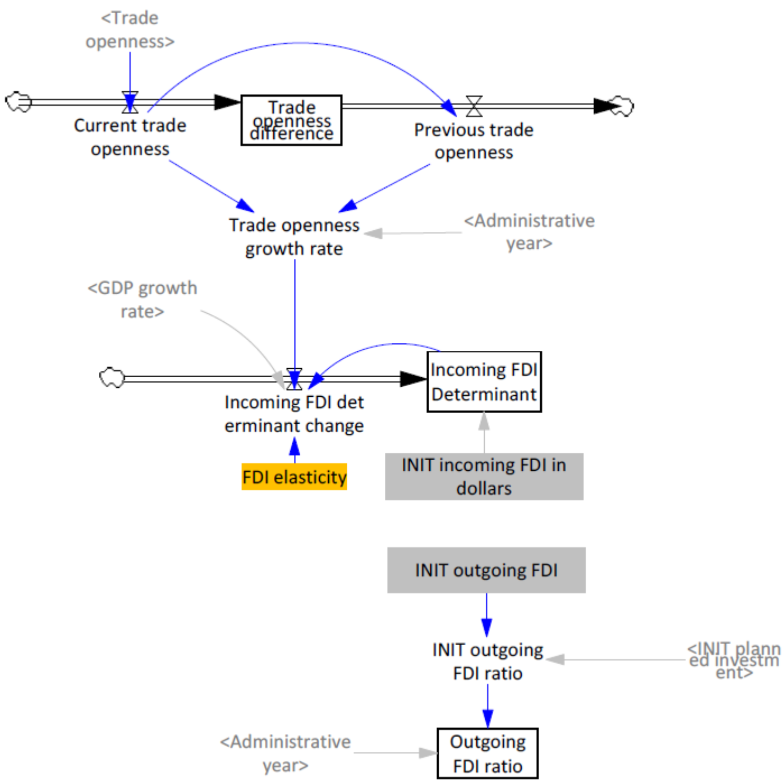


Figure 8.6 Stock-flow diagram of FDI sub-model.

B.3. Causal loop diagram labour market sub-model

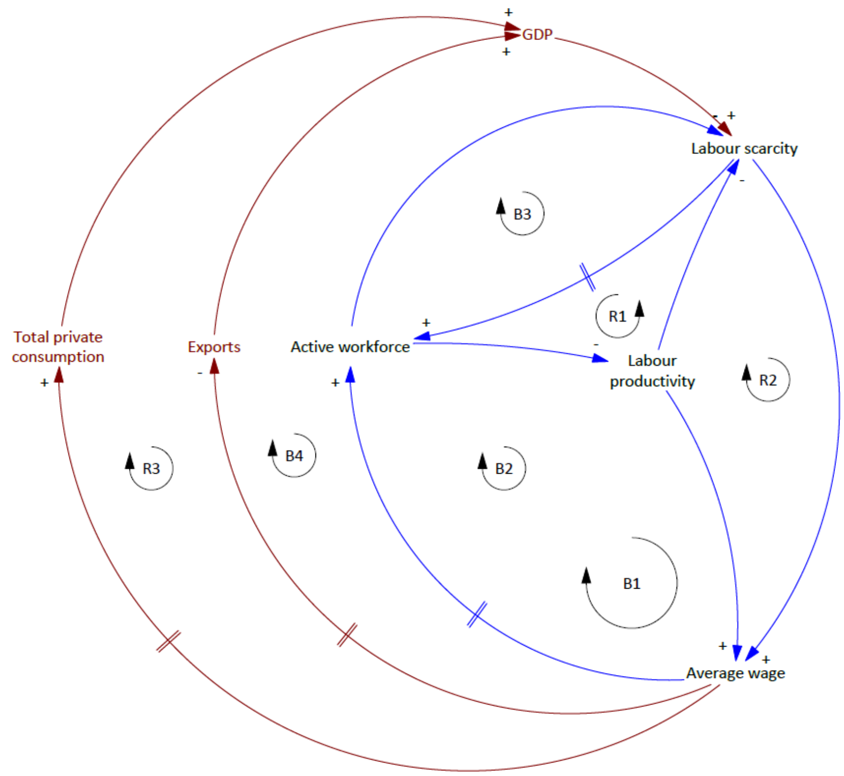


Figure 8.7 Causal-loop diagram of Labour market sub-model. Red part belongs to other sub-models.

Feedback loops present in figure 8.7:

- B1. The big loop. A large active workforce decreases labour scarcity, which dampens wage growth. Lower wages decrease the active workforce with a delay via the labour force participation rate.
- B2. A large active workforce decreases productivity through negative capital deepening. Lower productivity leads to lower wages. This decreases the active workforce again.
- B3. A large active workforce decreases labour scarcity. Lower labour scarcity influences hiring and firing, decreasing the size of the active workforce.
- B4. A higher GDP increases labour scarcity (labour hours demanded equals GDP/labour productivity), increasing wages. This then decreases exports, and GDP again.
- R1. A large active workforce decreases productivity. Lowered productivity increases labour scarcity. This increases the size of the active workforce again.
- R2. The bottom half of the blue circle. A large active workforce leads to a decreased labour productivity. This in turn increases labour scarcity, leading to higher average wages. This further increases the active workforce.
- R3. High average wages increase total private consumption, be it slightly delayed. This increase GDP, and subsequently labour scarcity. This again increases the average wage.

C. VALIDATION

This appendix contains additional material related to the validation of the Eurobond model.

C.1. Comparison of interest rates for yield determination methods

The four methods for determining bond yields are compared to national interest rate data for Germany, Italy, France and the Netherlands for the first half of 2022. The data is retrieved from the ECB. The model outputs are retrieved by using the default values of the input parameters (see table 2).

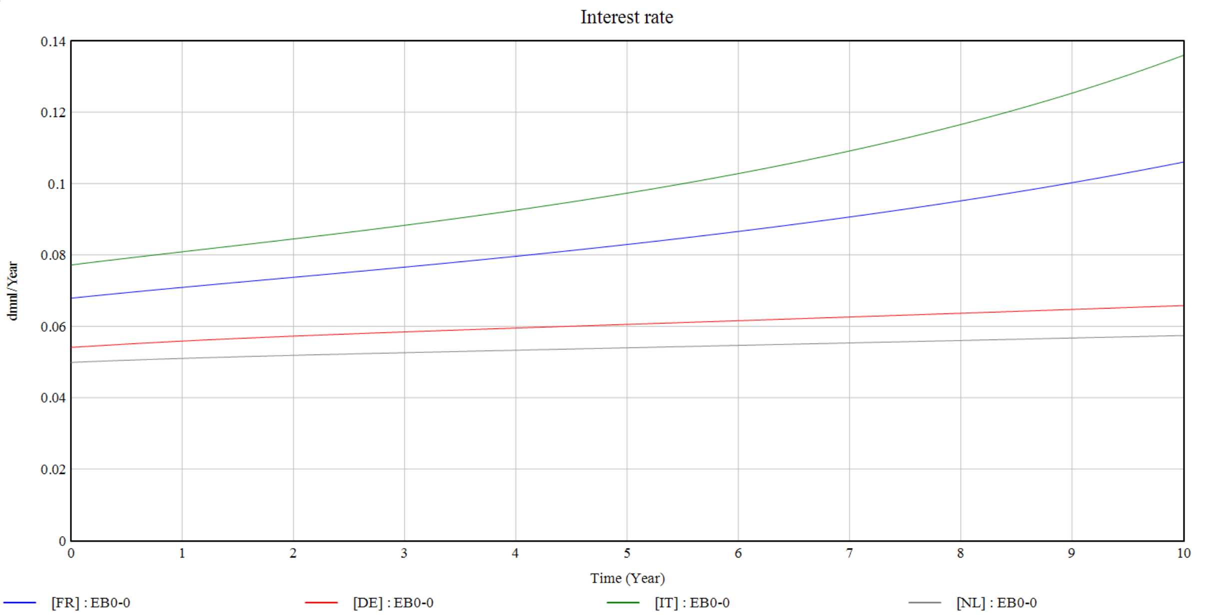


Figure 8.8 Results of method 0: Debt-to-GDP + Liquidity + Fiscal balance.

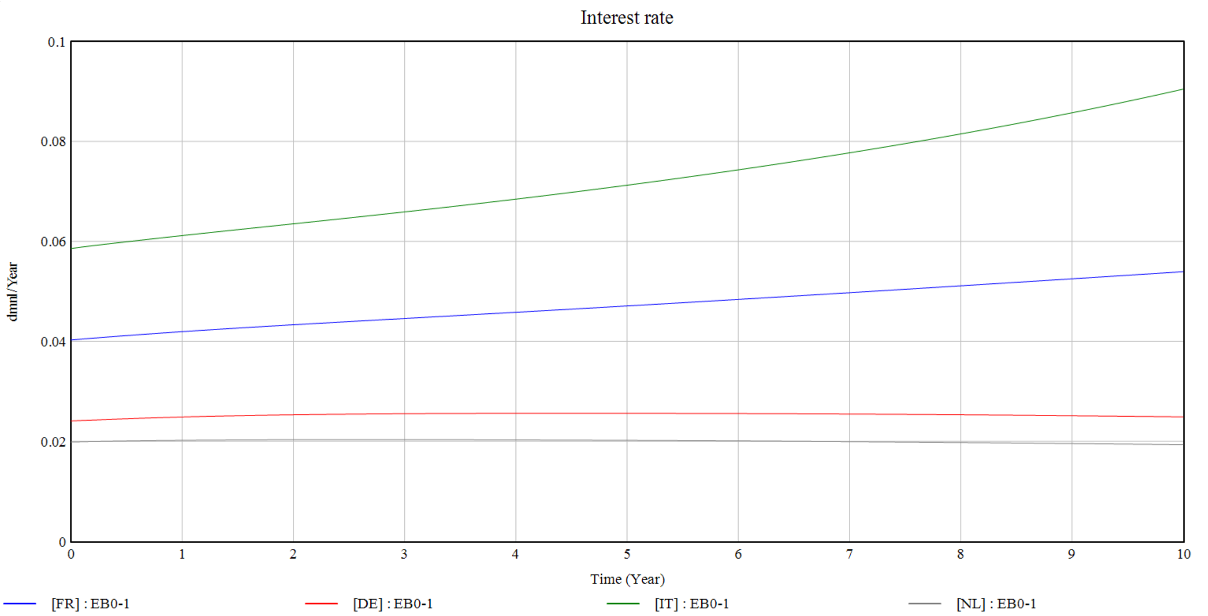


Figure 8.9 Results of method 1: Debt-to-GDP + Liquidity + Fiscal balance + Credit rating.

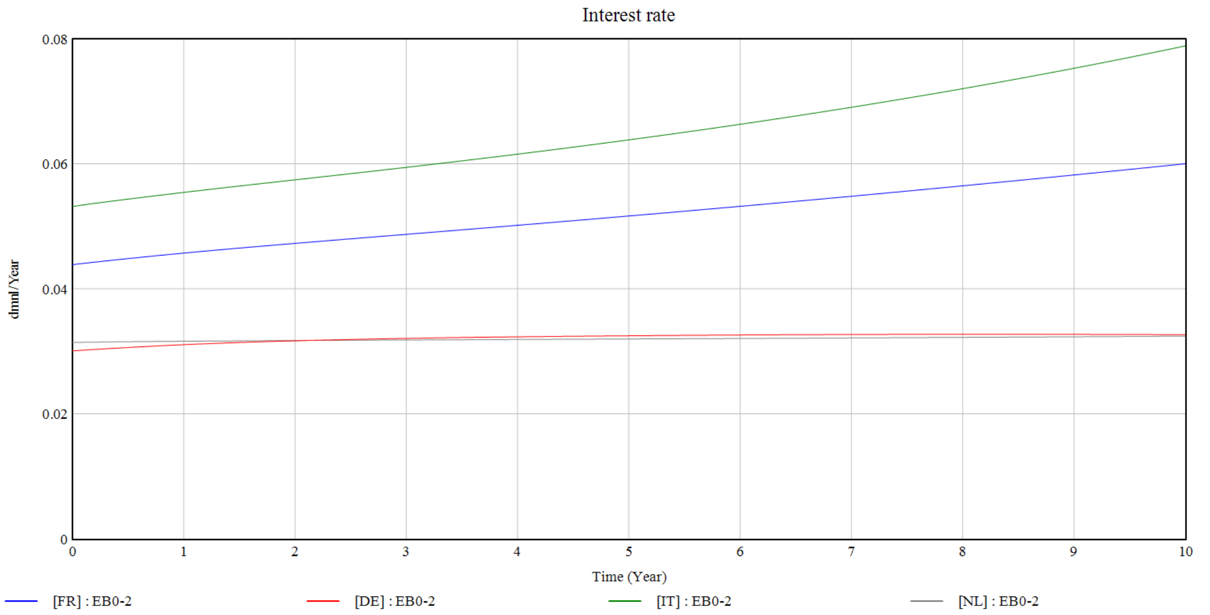


Figure 8.10 Results of method 2: Debt-to-GDP + Liquidity + Fiscal balance + Risk-free debt ratio.

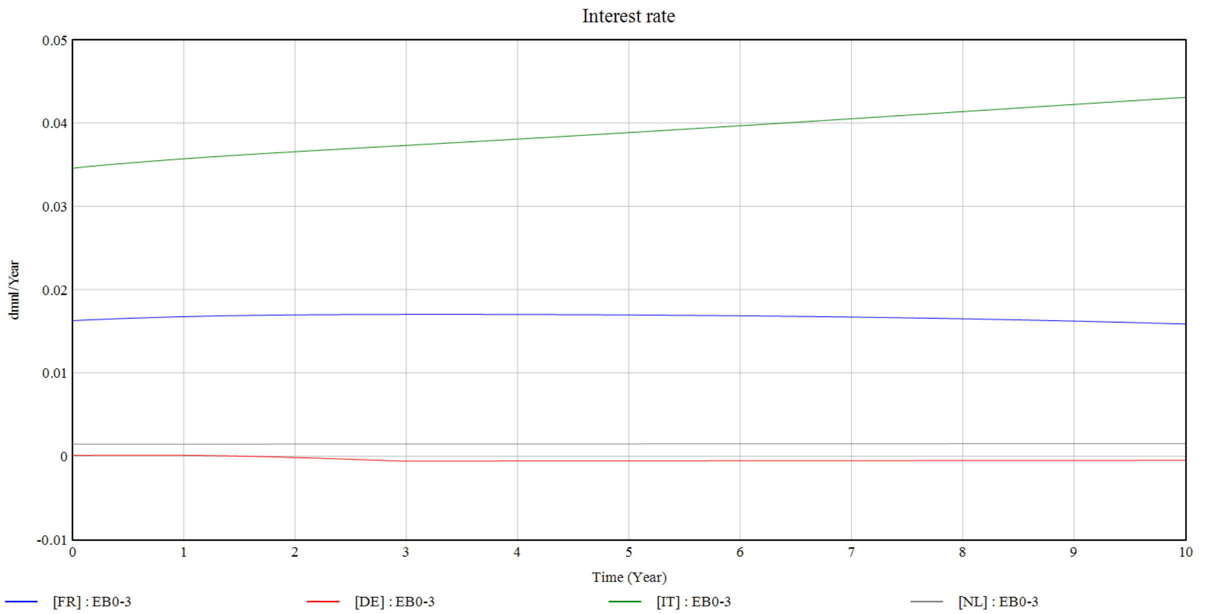


Figure 8.11 Results of method 3: Debt-to-GDP + Liquidity + Fiscal balance + Credit rating + Risk-free debt ratio.

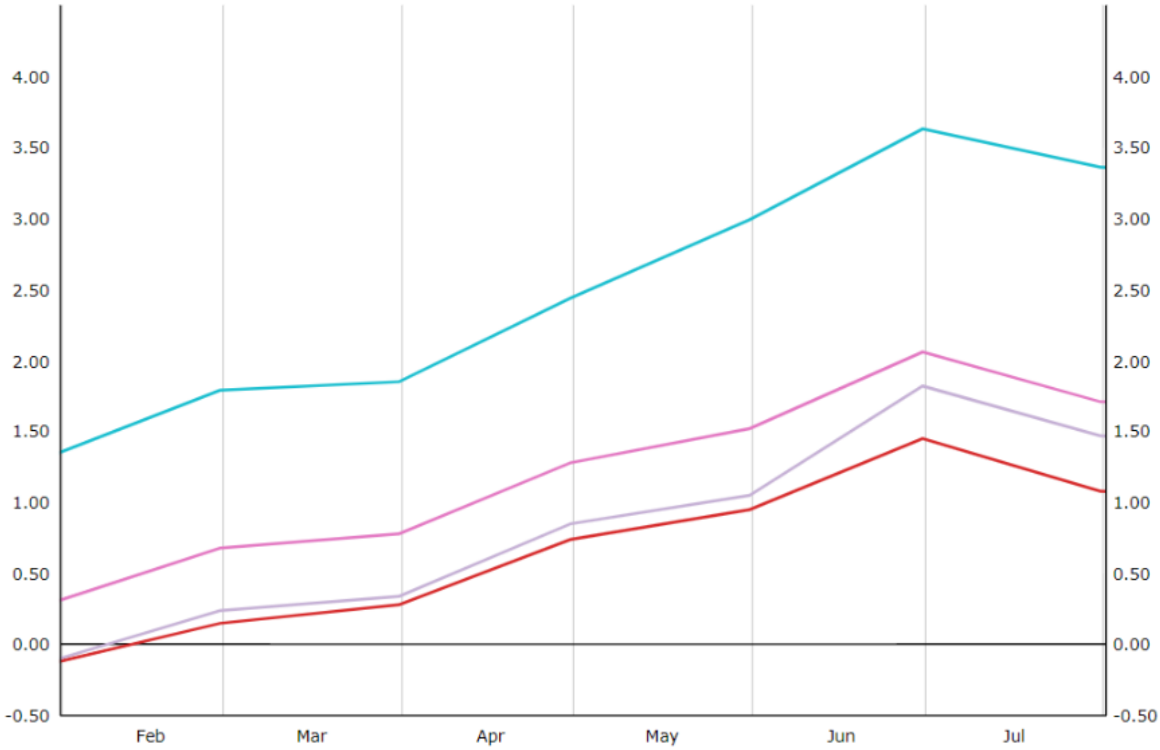


Figure 8.12 Real interest rates for Germany (red), France (purple), Italy (blue) and the Netherlands (grey), first half of 2022 (ECB 2022).

C.2. GDP in response to interest rate increase under level 1 uncertainty

This section contains the model results for eurozone GDP, under the level 1 uncertainty space. Results for all yield determination methods are included. Similar behaviour is displayed for all four methods. Subsequently, Germany and Italy are picked as examples, and their GDP results shown (for yield determination method 3). In all cases, GDP growth is dampened by an increase in interest rates. The observed behaviour more visible for Italy, due to its initial debt level.

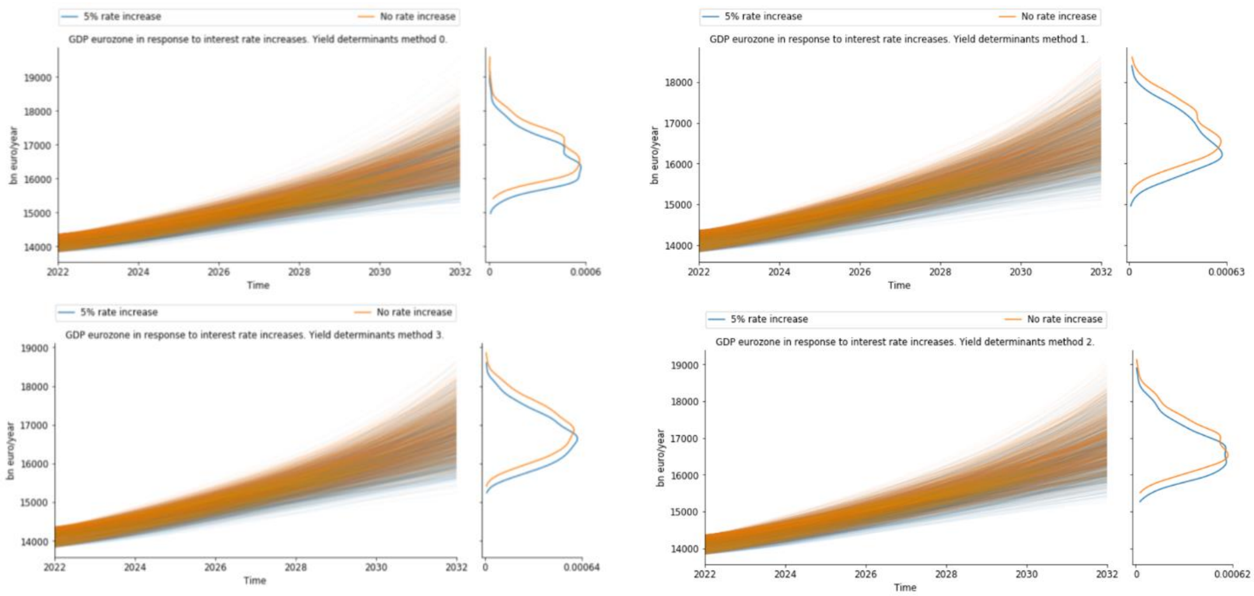


Figure 8.13 Eurozone GDP in response to a 5% interest rate increase. 1000 runs with the Eurobond model, including all level 1 uncertainties. Bond yield determination methods 0 to 3 compared.

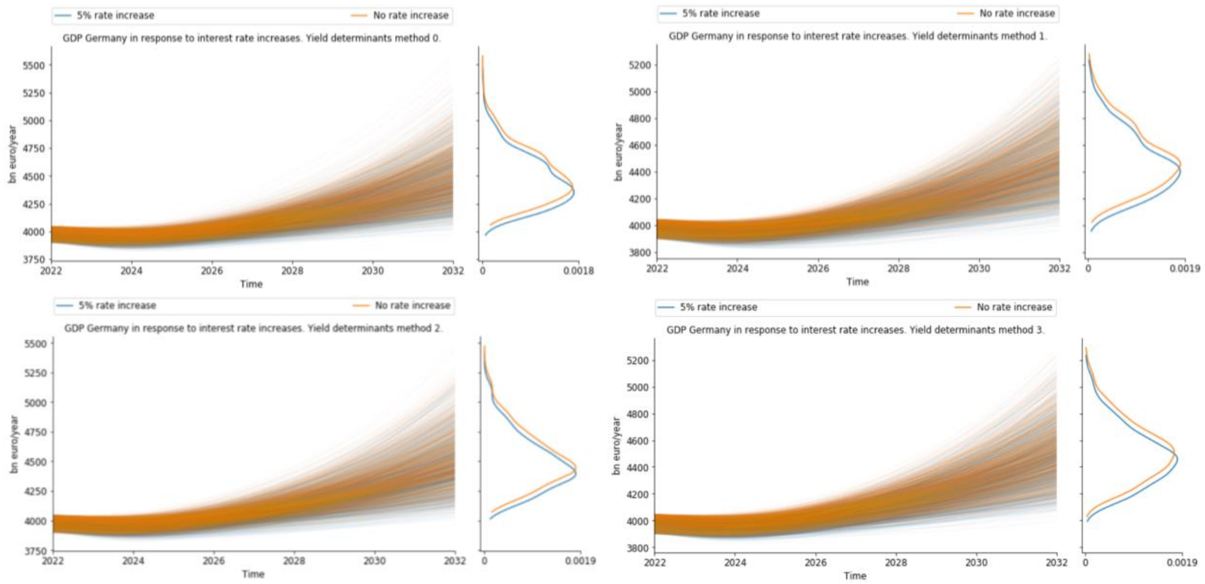


Figure 8.14 German GDP in response to a 5% interest rate increase. 1000 runs with the Eurobond model, including all level 1 uncertainties. Bond yield determination methods 0 to 3 compared.

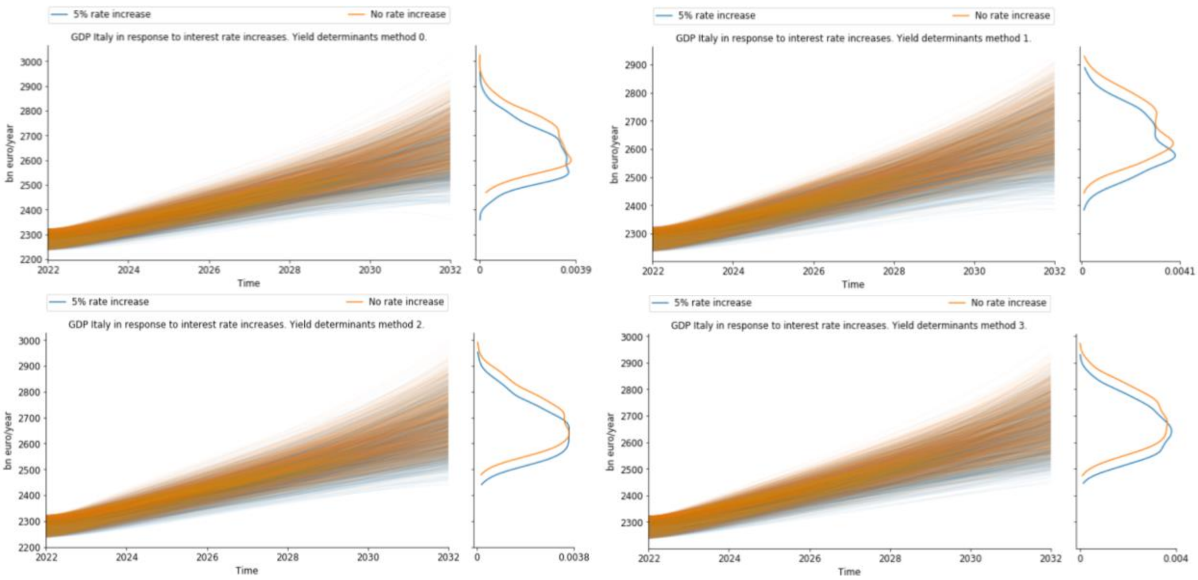


Figure 8.15 Italian GDP in response to a 5% interest rate increase. 1000 runs with the Eurobond model, including all level 1 uncertainties. Bond yield determination methods 0 to 3 compared.

C.3. Italian outgoing FDI and imports in response to interest rate increase

Italy is taken as an example here. The same behaviour is observed for all included countries. The outgoing FDI declines in response to the increased interest rate (see figure 8.16). This same effect is barely visible for imports (only declining by 0.32% on average for Italy, see figure 8.17).

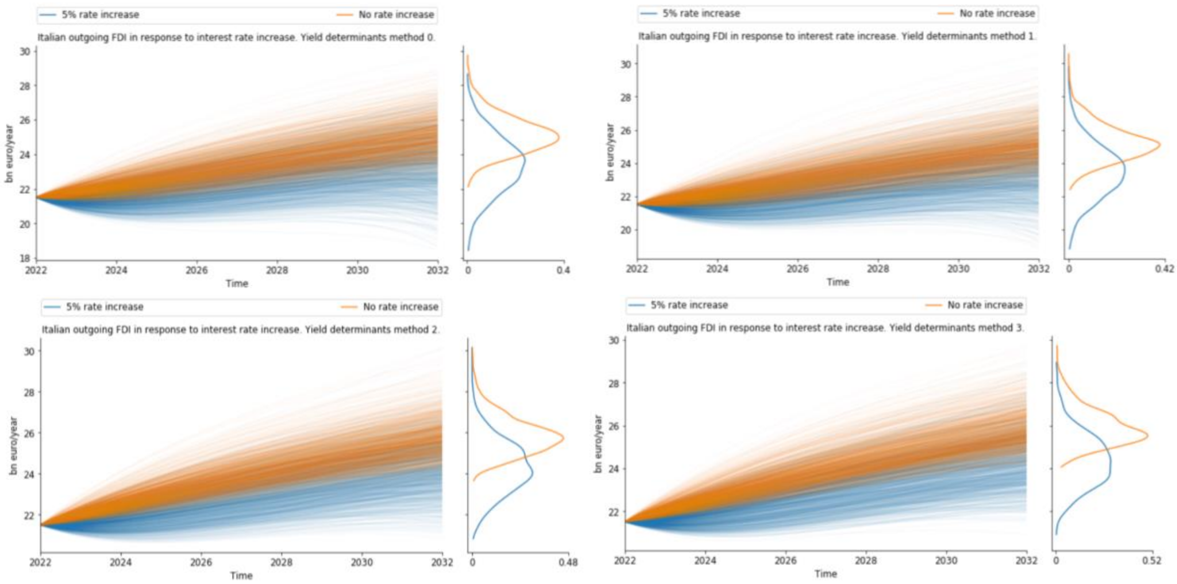


Figure 8.16 Italian outgoing FDI in response to a 5% interest rate increase. 1000 runs with the Eurobond model, including all level 1 uncertainties. Bond yield determination methods 0 to 3 compared.

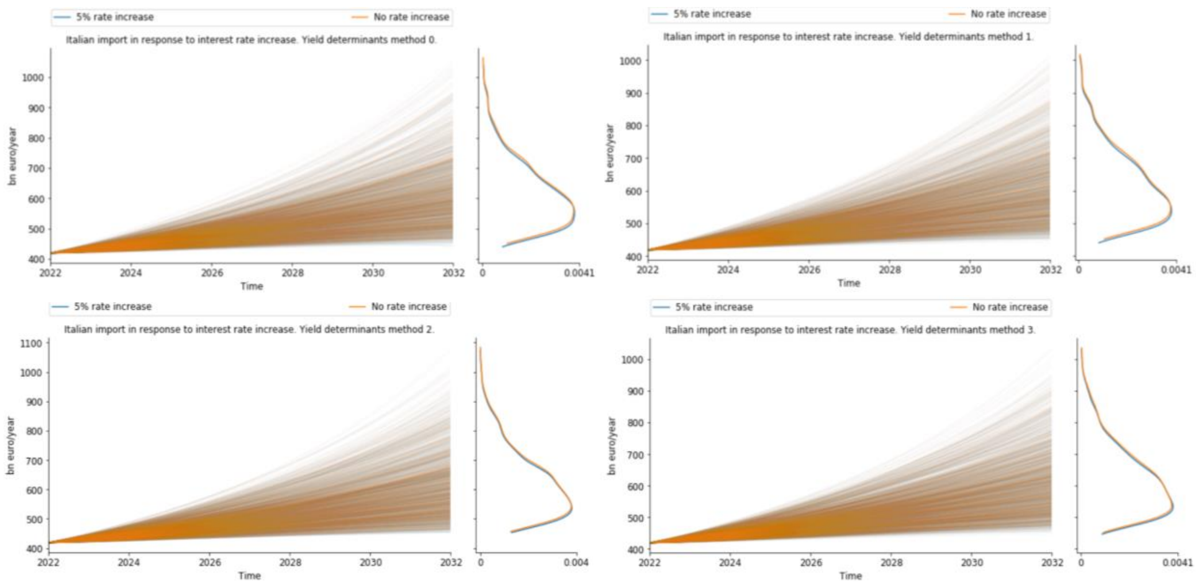


Figure 8.17 Figure 8.18 Italian imports in response to a 5% interest rate increase. 1000 runs with the Eurobond model, including all level 1 uncertainties. This figure shows a barely visible 0.32% average decline in imports. Bond yield determination methods 0 to 3 compared.

D. ANALYSIS

This appendix contains all additional material referred to in the policy and resilience analysis sections of chapter 4.

D.1. Distribution of policy effects amongst eurozone members

Figure 8.18 shows the distribution of the relative GDP gains facilitated by Blue Bond Eurobonds, amongst the eurozone member states. The results of yield determination methods 0 and 1 are similar, and indicate possible GDP gains that are more evenly distributed than the results of methods 2 and 3. These differences can be explained by the results presented in figure 8.21, which shows the distribution of the interest rate decreases.

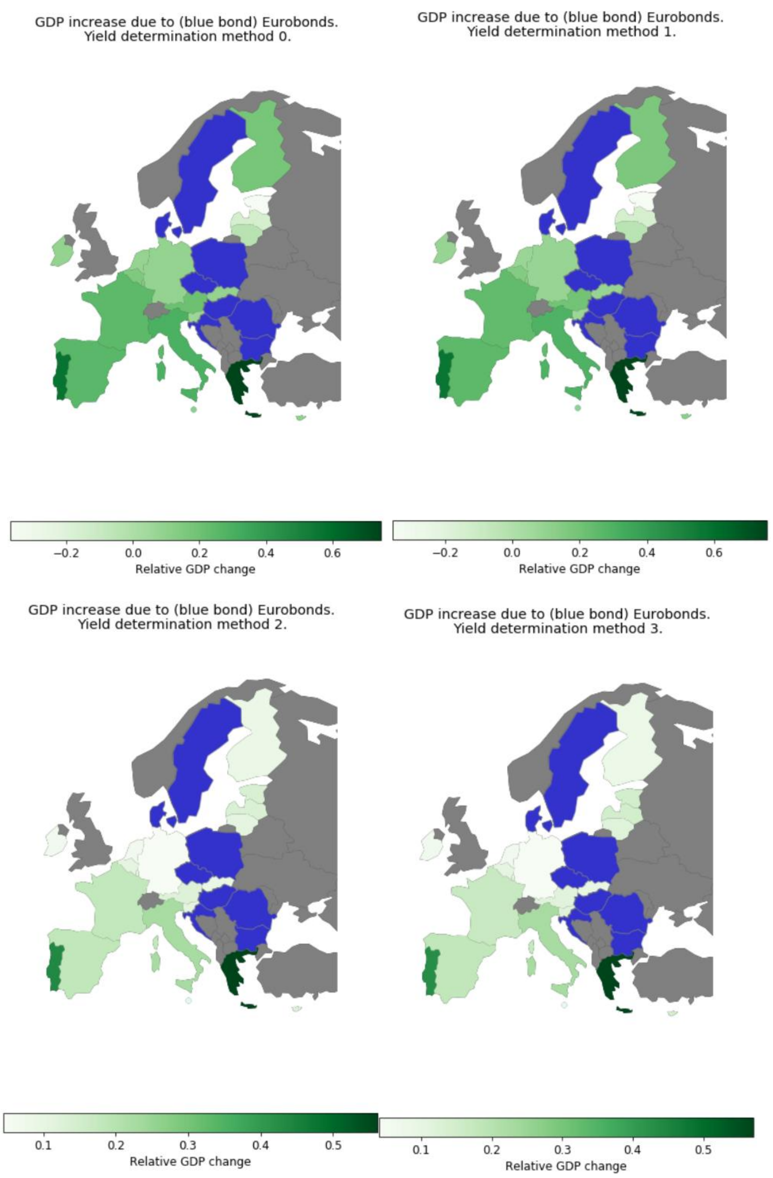


Figure 8.18 Map of the EU, with the average relative GDP gains due to Blue Bond Eurobonds. Blue countries are non-eurozone EU member states and grey countries are not part of the EU. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

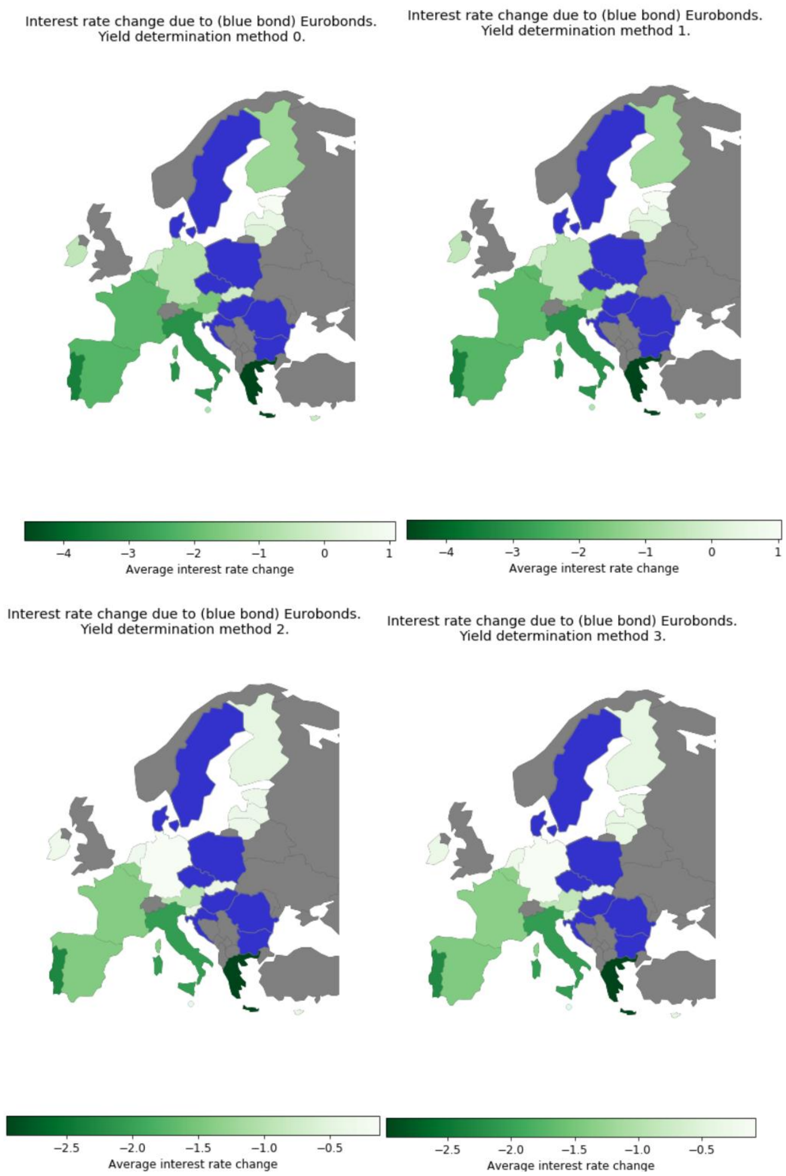


Figure 8.22 Map of the EU, with the average interest rate decline due to Blue Bond Eurobonds. Blue countries are non-eurozone EU member states and grey countries are not part of the EU. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

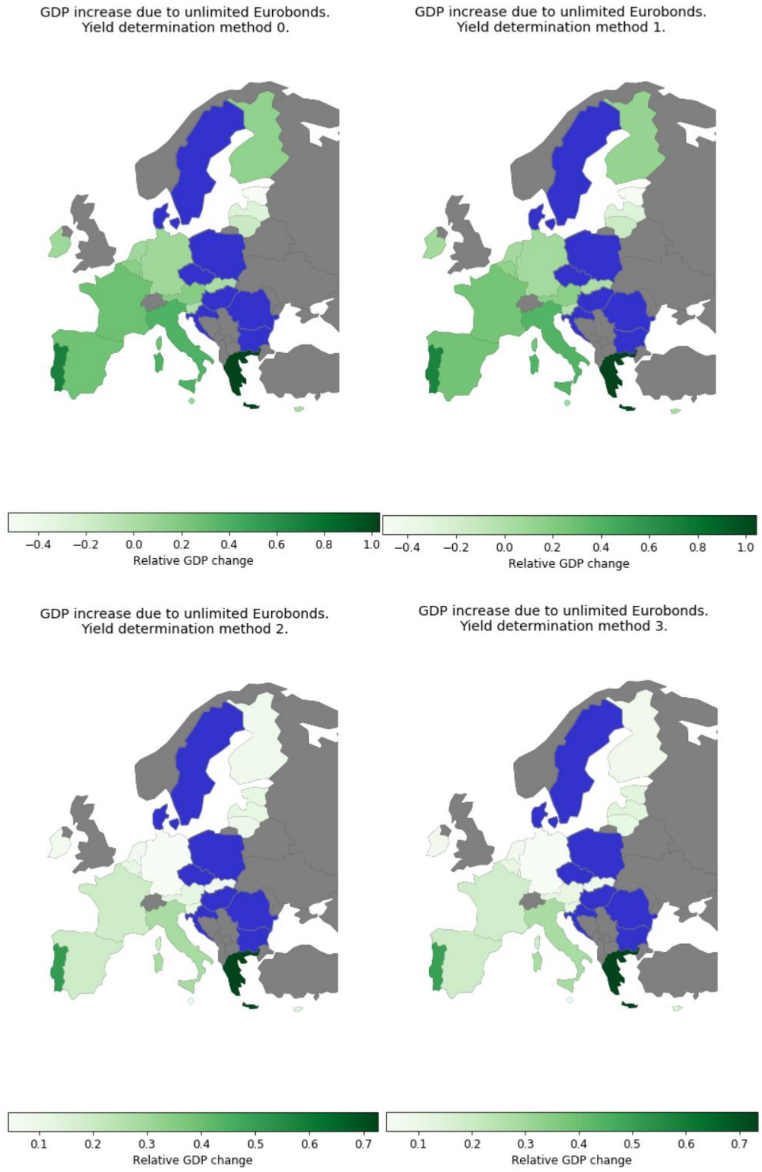


Figure 8.19 Map of the EU, with the average relative GDP gains due to unlimited Eurobonds. Blue countries are non-eurozone EU member states and grey countries are not part of the EU. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

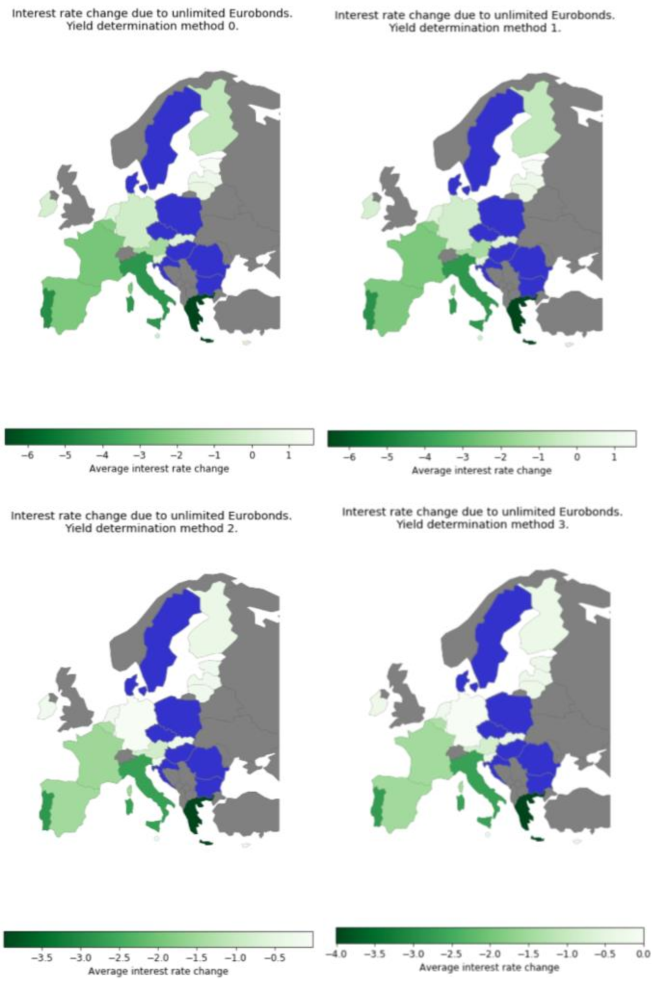
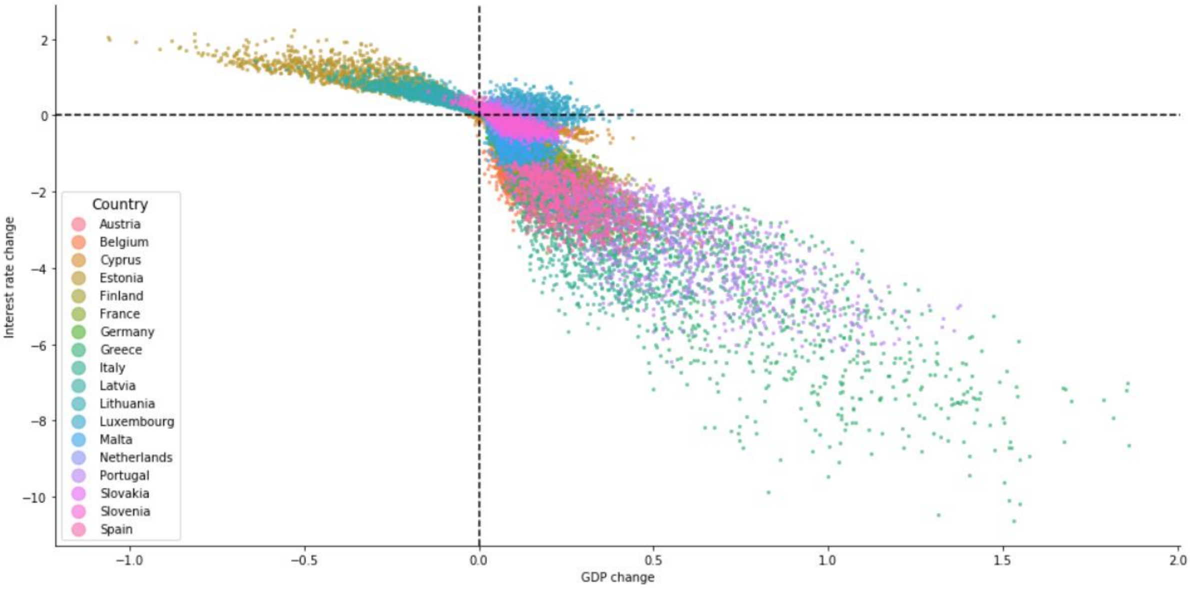
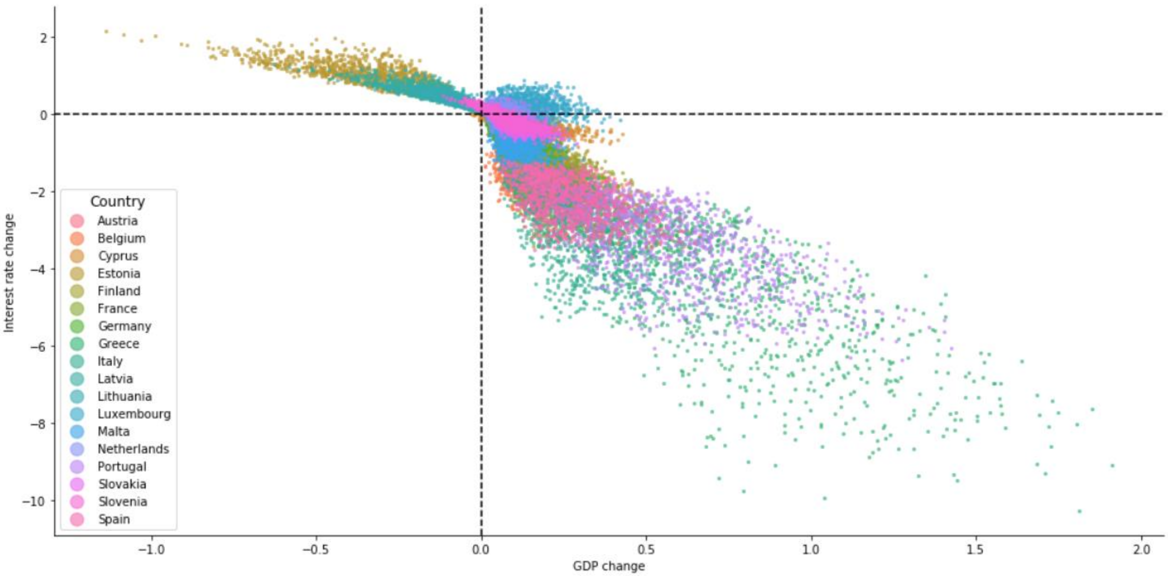


Figure 8.20 Map of the EU, with the average interest rate decline due to unlimited Eurobonds. Blue countries are non-eurozone EU member states and grey countries are not part of the EU. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

D.2. Relationship between interest rate decline and GDP increase

Figure 8.23 shows the change in average interest rates (horizontal axes), plotted against the relative GDP changes (vertical axes), for all four yield determination methods. For yield determination methods 2 and 3, no country sees its GDP decrease. Note that methods 0 and 1 find some countries with an increase in average interest rate, and a subsequent decrease in GDP, with the exception being Luxembourg and Slovenia (showing an increase in interest rate and an increase in GDP, due to a mitigation by increased exports and incoming FDI). The results in the first quartile can be explained by the exclusion of the risk-free debt ratios in methods 0 and 1, which means that Eurobond interest rates reach higher values than these countries' sovereign interest rates. A clear example is Estonia, which has a very low initial debt stock.





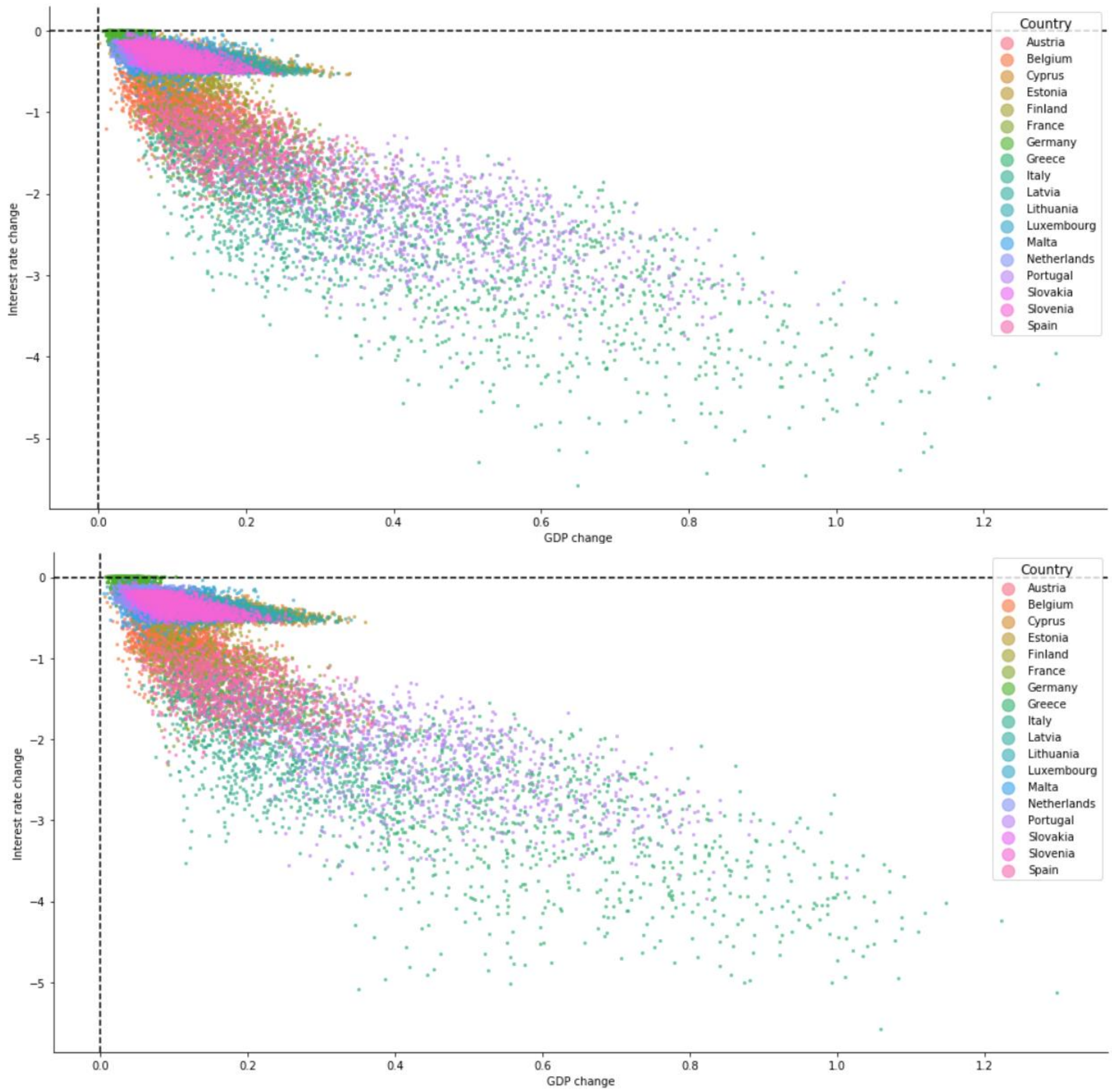


Figure 8.23 Scatter plots of the interest rate change (horizontal axis) versus the GDP increase (vertical axis). From top to bottom: yield determination methods 0 to 3. 1000 runs per policy.

D.3. Debt-to-GDP under level 2 uncertainty

Note that the effects of the Eurobonds policy show the same pattern for each of the yield determination methods, with methods 2 and 3 leading to overall higher debt levels. The additional benefits of unlimited Eurobonds (compared to Blue Bond Eurobonds) are marginal for each of the methods.

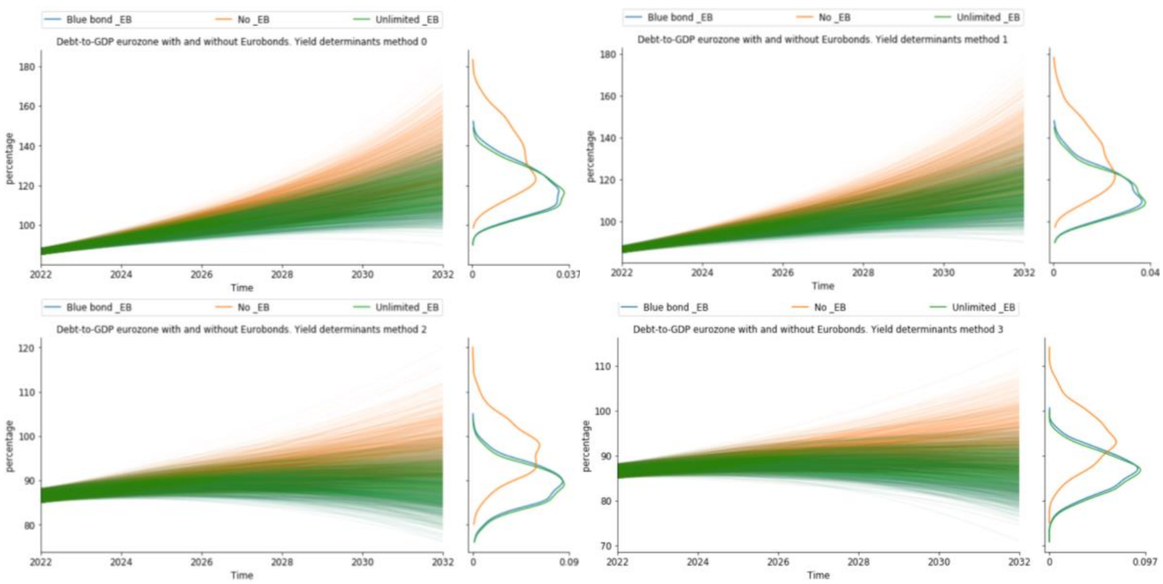


Figure 8.21 Debt-to-GDP eurozone under level 2 uncertainty. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

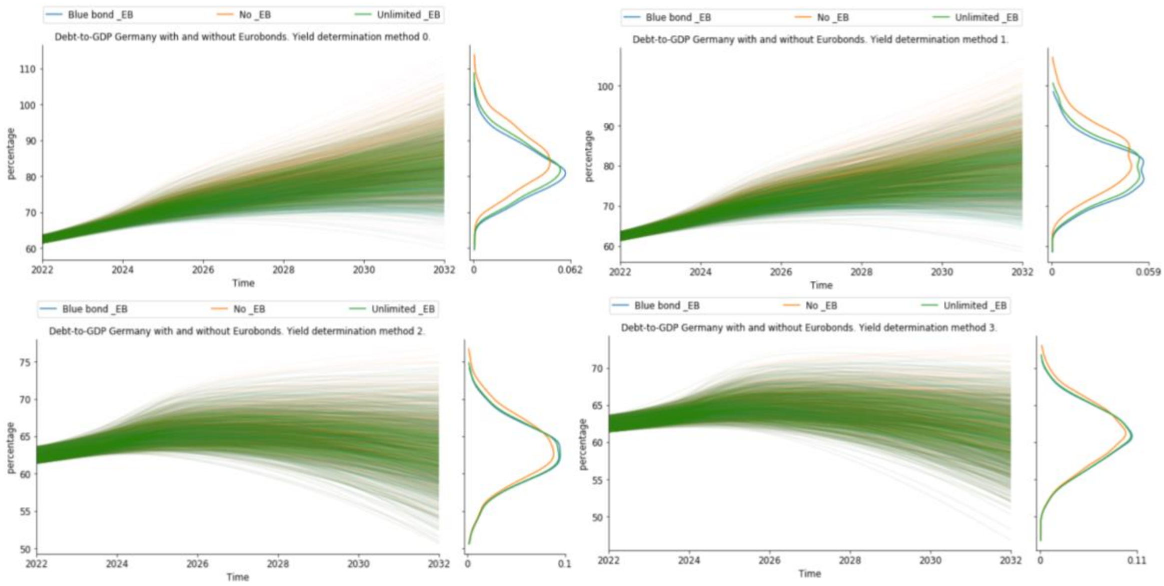


Figure 8.22 Debt-to-GDP Germany under level 2 uncertainty. From top to bottom: yield determination methods 0 to 3. 1000 runs per policy.

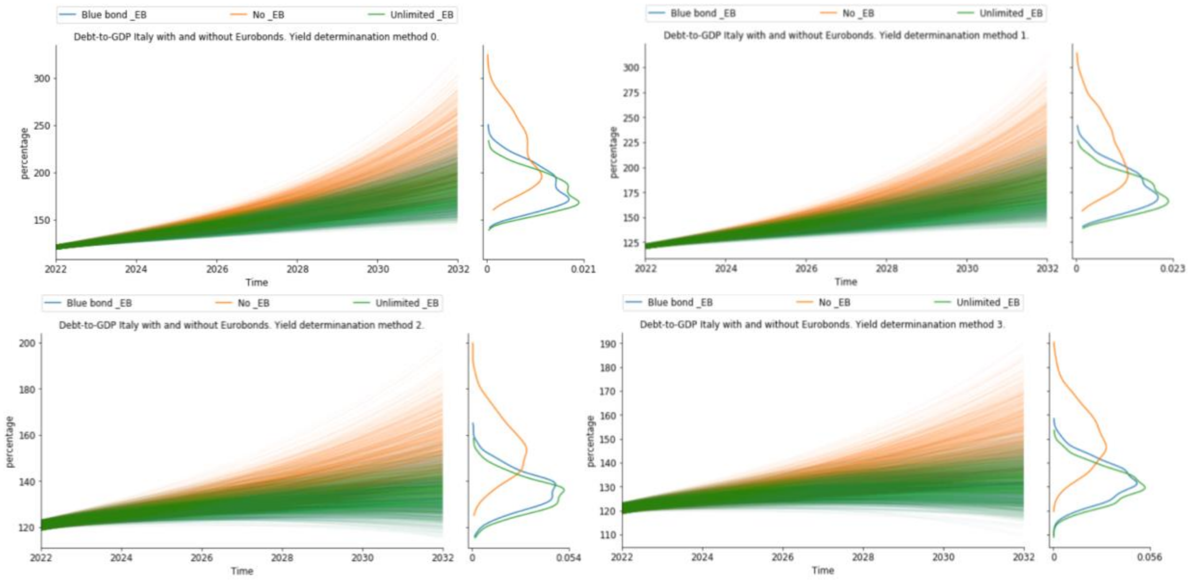


Figure 8.23 Debt-to-GDP Italy under level 2 uncertainty. From top to bottom: yield determination methods 0 to 3. 1000 runs per policy.

D.4. German and Italian sovereign interest rates under level 2 uncertainty

Figure x shows the sovereign interest rate for Germany, without policy, and with both Eurobond policies, for each yield determination method. Figure x shows the same for Italy. For Germany, the sovereign interest rate is not significantly affected by both policies. For Italy, each yield determination method results in sovereign interest rates being decreased due to the introduction of Eurobonds, because of the Italian government's improved fiscal position.

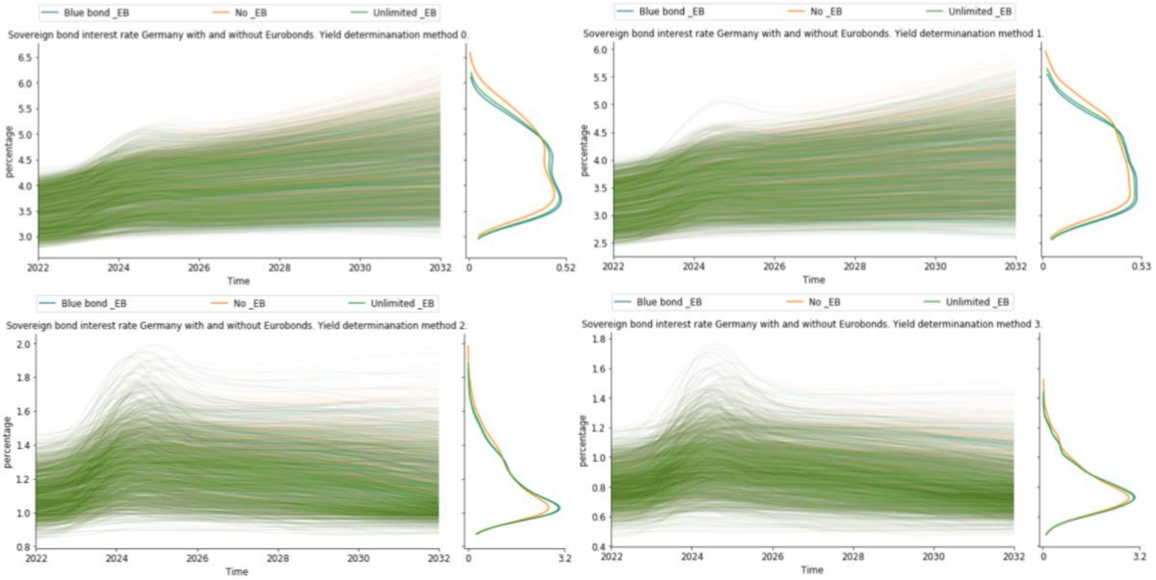


Figure 8.24 Sovereign interest rates Germany. From top left to bottom right: yield determination methods 0 to 3. Note that the hike of the interest rate around 2024 is due to a temporary deterioration of the fiscal balance that is caused by anti-cyclical public investment (as a response to a GDP decline due to an initial labour surplus, which decreases wages, and subsequently consumption). 1000 runs per policy.

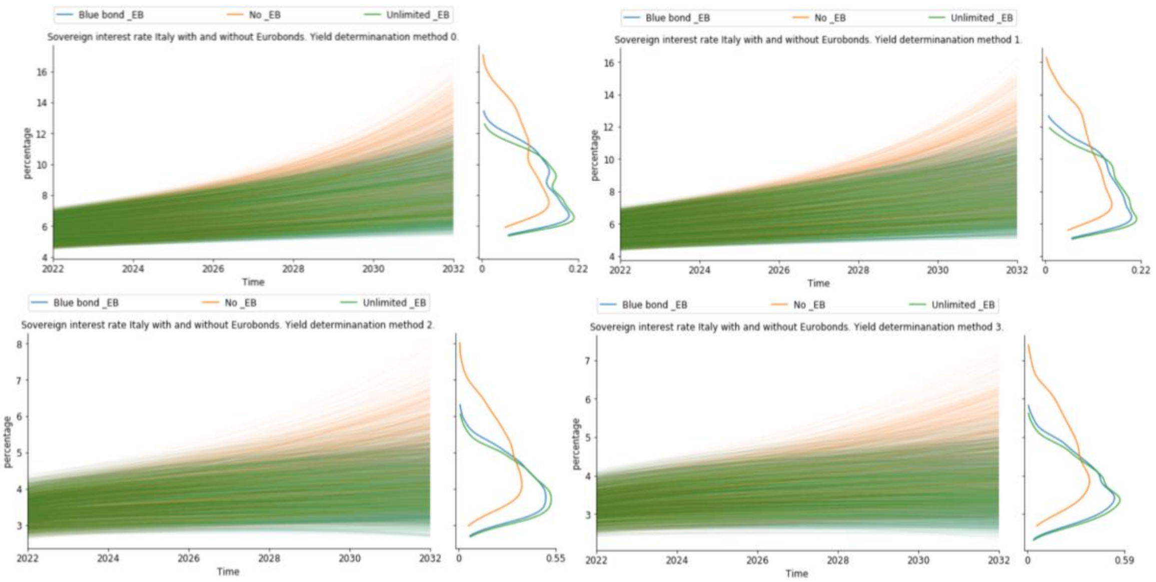


Figure 8.24 Sovereign interest rates Italy. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

D.5. German-Italian bond spreads under level 2 uncertainty

Figure 8.25 shows the spread between the sovereign bond interest rates of Germany and Italy, for all four bond yield determination methods. Note that both Eurobond policies decrease the German-Italian sovereign bond spread, with unlimited Eurobonds providing small additional benefits. Figure 8.26 shows the German-Italian average bond spread, i.e. the average interest rate paid by these countries. This includes the interest paid over Eurobonds, so this better represents the actual fiscal position of both countries in case of introducing Eurobonds. Here, the difference between Blue Bond Eurobonds and unlimited Eurobonds is more noticable, because unlimited Eurobond issuance leads to the average interest rate converging with the Eurobond's interest rate (because Eurobond debt starts making up the majority of both countries' debt).

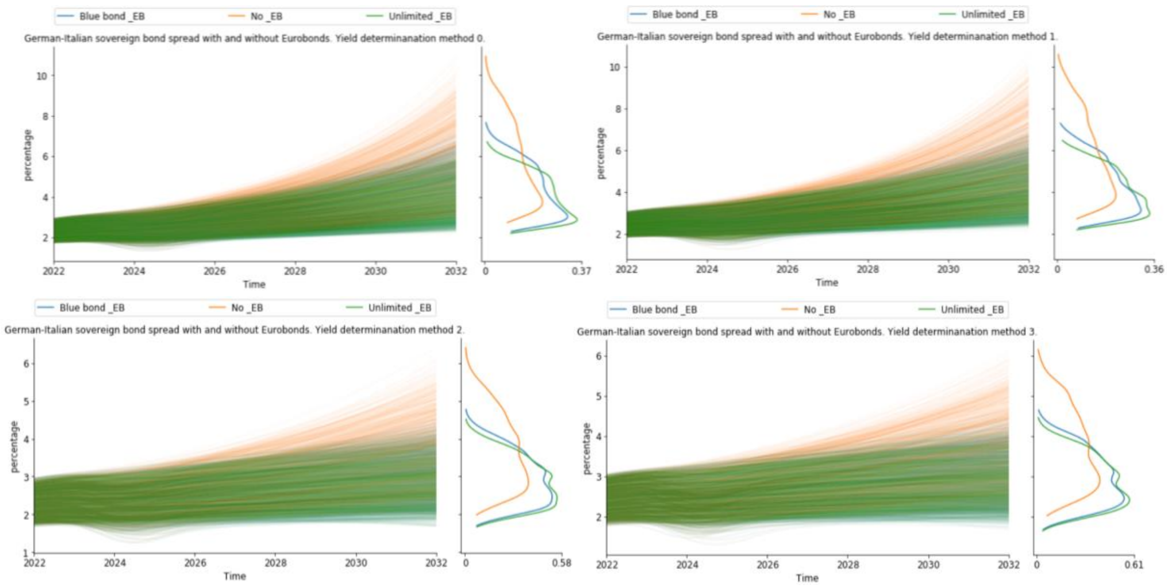


Figure 8.25 German-Italian sovereign bond spread under level 2 uncertainty. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

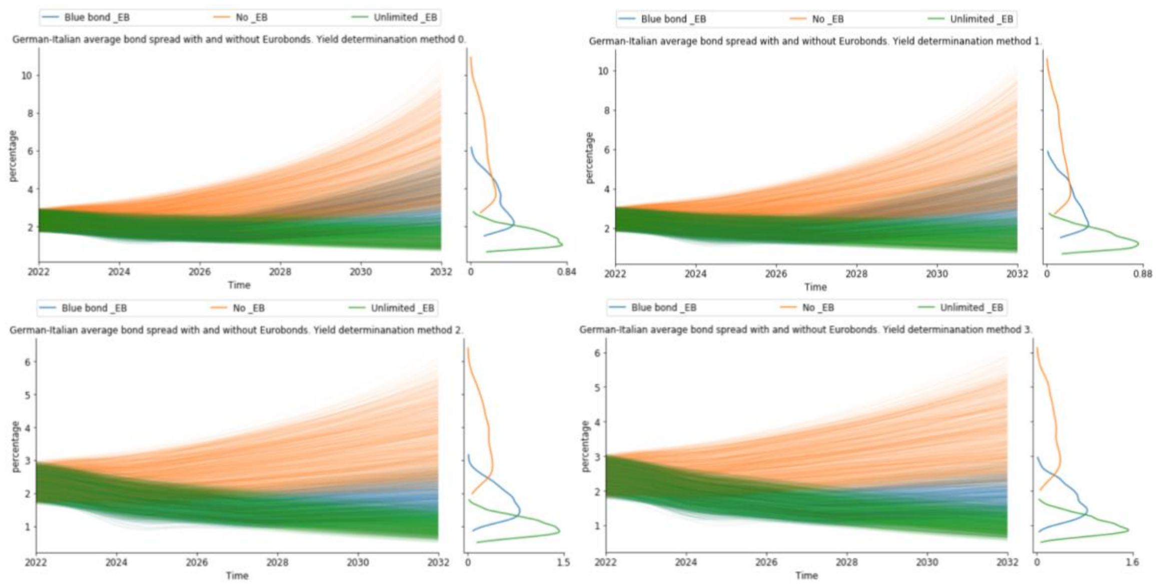


Figure 8.26 German-Italian average bond spread under level 2 uncertainty. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

D.6. Eurobond interest rates in recessions

The following figures show the Eurobond interest rates for all yield drivers. Figure 8.30 are the results for a recession without a change in ECB policy. In figure 8.31, the ECB is lowering rates, and in 8.32 the ECB is increasing rates. Note that for all yield determination methods in all types of recessions, unlimited Eurobonds eventually reach higher interest rates than Blue Bond Eurobonds.

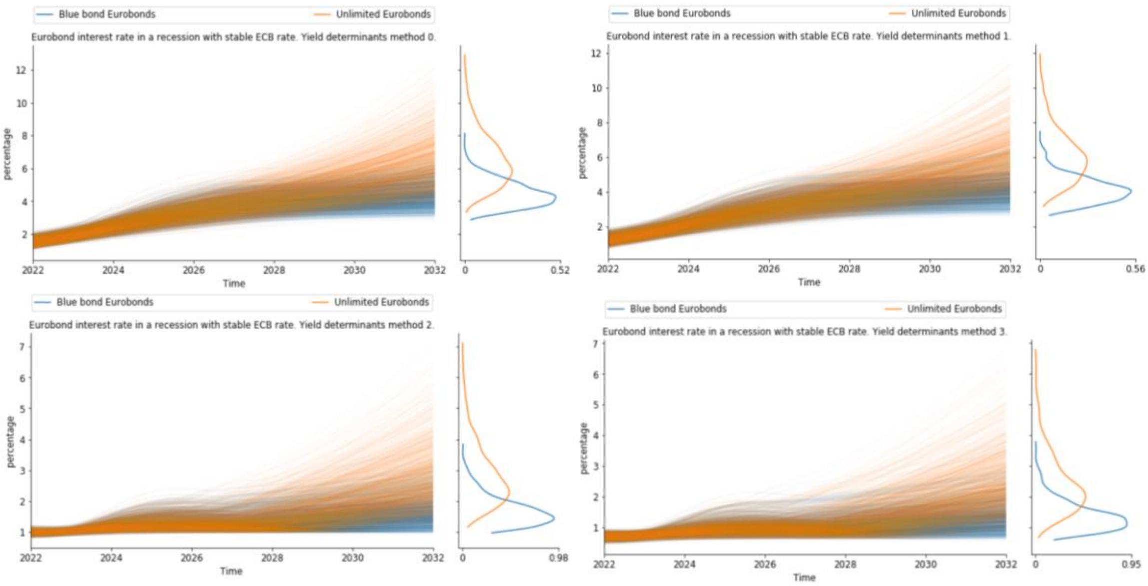


Figure 8.27 Interest rate Eurobonds under level 3 uncertainty in a recession with no ECB policy change. From top left to bottom right: yield determination methods 0, 1, 2 and 3. 1000 runs per policy.

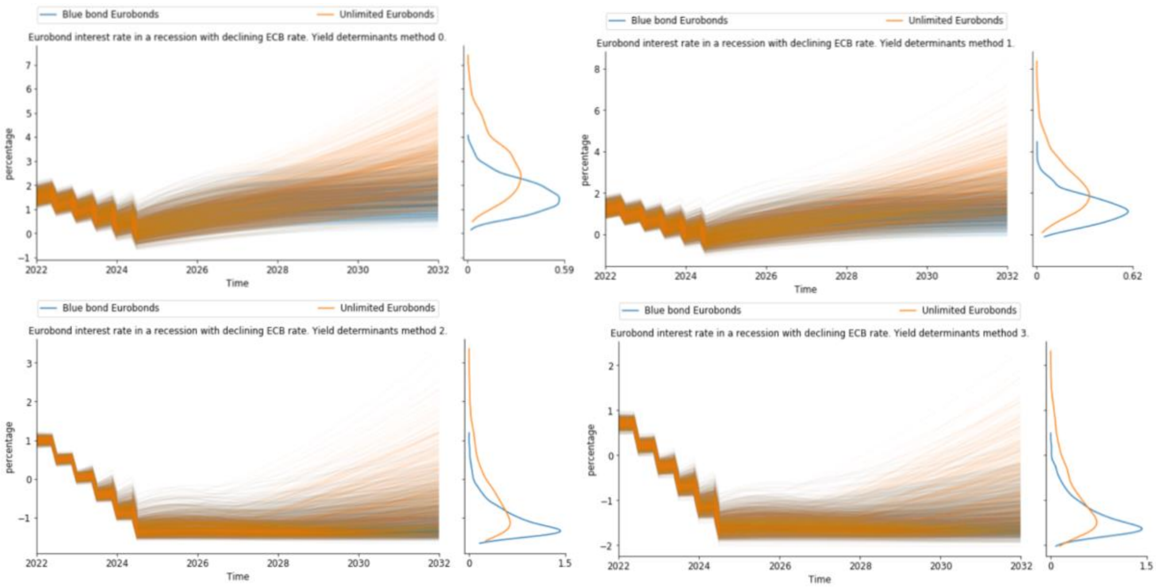


Figure 8.28 Interest rate Eurobonds under level 3 uncertainty in a recession with the ECB lowering rates. From top left to bottom right: yield determination methods 0, 1, 2 and 3. 1000 runs per policy.

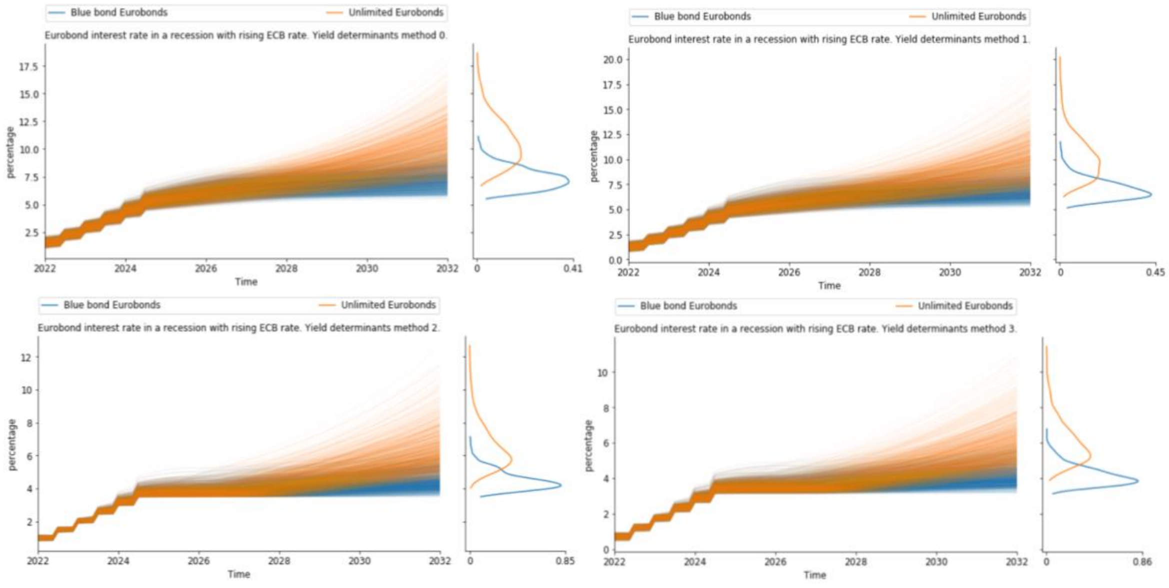


Figure 8.29 Interest rate Eurobonds under level 3 uncertainty in a recession with the ECB increasing rates. From top left to bottom right: yield determination methods 0, 1, 2 and 3. 1000 runs per policy.

D.7. Debt-to-GDP eurozone in recessions

Figure x shows the eurozone's debt-to-GDP ratio in a recession without any ECB policy change, for all four yield determination methods. Figure x and figure x show the same, but with an ECB rate decrease and a rate increase respectively. The results indicate that both Eurobond policies are robust for all yield determination methods to lower the debt-to-GDP ratio of the eurozone, in all three types of recessions. The additional debt sustainability benefits provided by unlimited Eurobonds, compared to Blue Bond Eurobonds, are insignificant.

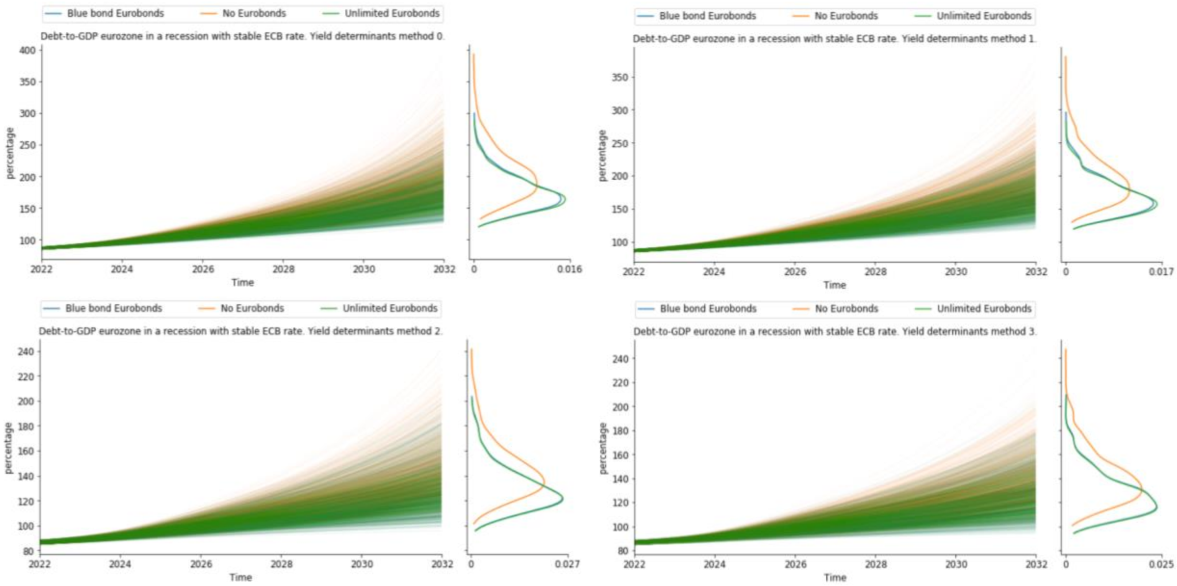


Figure 8.30 Debt-to-GDP ratio eurozone under level 3 uncertainty in a recession with stable ECB rate. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

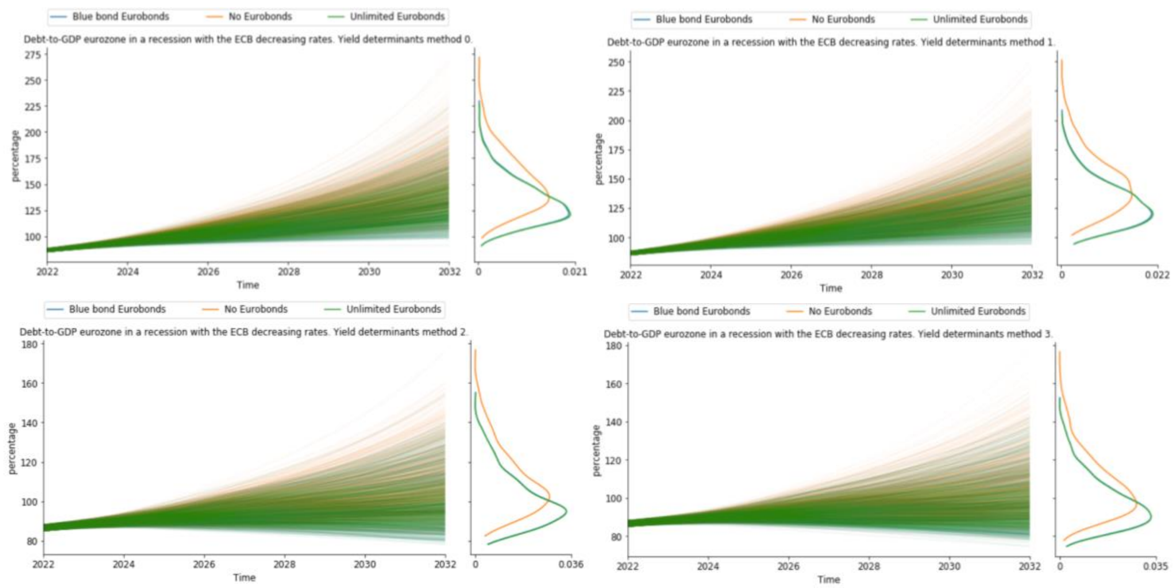


Figure 8.31 Debt-to-GDP ratio eurozone under level 3 uncertainty in a recession with decreasing ECB rate. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.

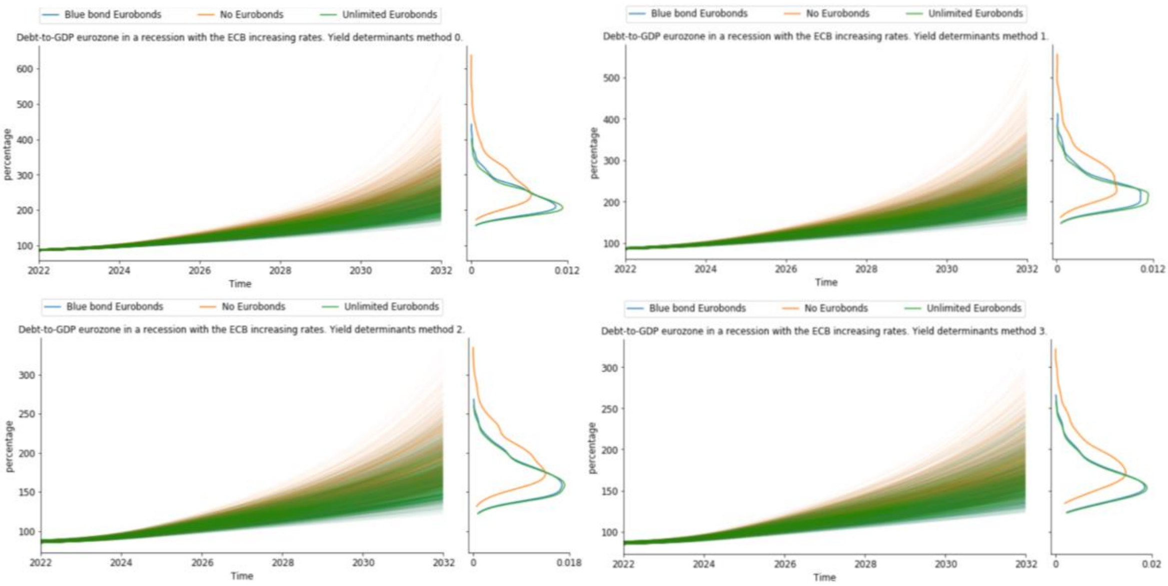


Figure 8.32 Debt-to-GDP ratio eurozone under level 3 uncertainty in a recession with decreasing ECB rate. From top left to bottom right: yield determination methods 0 to 3. 1000 runs per policy.