THESIS / THÈSE

DOCTOR OF ECONOMICS AND BUSINESS MANAGEMENT

Heterogeneous effects of fiscal policy on sovereign yields

Hubert, Olivier

Award date:
2018

Awarding institution:
University of Namur

Heterogeneous Effects of Fiscal Policy on Sovereign Yields

Olivier Hubert

October 2018

Supervisors
Prof. Dr. Hans Dewachter (National Bank of Belgium, KULeuven)
Prof. Dr. Romain Houssa (University of Namur)

Jury Members
Prof. Dr. Lasse Bork (Aalborg University)
Dr. Stephan Fahr (European Central Bank)
Prof. Dr. Paul Reding (University of Namur)

President
Prof. Dr. Jean-Marie Baland (University of Namur)

PRESSES UNIVERSITAIRES de Namur

Rempart de la Vierge, 13

B - 5000 Namur (Belgique)

Imprimé en Belgique

ISBN : 978-2-39029-016-2

Dépôt légal: D/2018/1881/21

Contents

List of Figures

List of Tables

Preface

Cet ouvrage conclut un chapitre important de ma vie qui aura débuté en fin de Rhéto il y a douze ans, période de doute et d'incertitude partagée par beaucoup quant à la voie à prendre. En définitive, j'aurai eu la chance de mener des études qui m'auront permis de m'épanouir et de devenir un économiste.

En 2011, je démarrais une thèse sous la supervision de Romain Houssa. Je tiens à le remercier tout particulièrement pour ses conseils avisés et son soutien tout au long de ma thèse. Ses qualités de chercheur et de superviseur ont indubitablement contribué à la bonne réalisation de cet ouvrage. Les différentes tâches dont il m'a chargé ont également été extrêmement formatrices pour moi, tant sur le plan professionnel que personnel.

Je tiens à remercier mon second superviseur, Hans Dewachter. Je préfèrerai le terme anglais "*advisor*" plutôt que superviseur dans la mesure où la guidance dont j'ai bénéficié de sa part a été particulièrement bénéfique. Je voudrais aussi souligner la patience dont il a fait preuve avec moi, n'hésitant pas à libérer son emploi du temps chargé pour discuter de mes projets.

Mes remerciements vont également aux membres du Jury, Jean-Marie Baland, Lasse Bork, Stephan Fahr et Paul Reding qui ont su proposer, chacun selon leurs expertises respectives, des suggestions importantes pour améliorer la qualité de mon travail. Je leur dois beaucoup.

J'ai également eu la chance d'être assistant pour toute une série de cours qui m'ont permis de transmettre l'économie et les méthodes quantitatives à plusieurs générations d'étudiants. Cette expérience a été pour moi exceptionnellement enrichissante dans la mesure où elle m'a permis d'assouvir ce besoin de transmettre le savoir. Je souhaiterais ainsi remercier Alain de Crombrugghe, Vincenzo Verardi et Jean-Yves Gnabo. Les assister a été un réel plaisir pour moi.

J'adresse également un clin d'œil à Marcus Dejardin pour sa présence inconditionnelle au sixième étage et sa bonne humeur, de jour comme de nuit, en semaine comme les samedis. Rarement ai-je eu un voisinage si agréable.

La réalisation d'une thèse est loin d'être un travail individuel, et j'ai eu la chance de pouvoir compter sur des collègues compétents, ouverts, et humains. Dans l'euphorie comme dans le doute, ils ont incontestablement été là aux moments nécessaires. Nos activités extra-curriculaires ensemble nous ont certainement permis de tisser des liens forts et durables. Dès lors, chers collègues, chers amis, cher Jolan, je vous remercie du fond du cœur. Jolan mérite assurément une mention particulière car je dois en effet beaucoup à mon compagnon d'échappée dont les connaissances n'ont d'égal que sa disponibilité et sa volonté d'aider. Réduire à un seul mot mes collègues, ancien collègues et amis Nicolas, Alexandre et Jérôme ne leur rendrait pas justice et je préfère leur adresser ma gratitude dans un autre contexte que cette préface.

Je tiens à saluer également Pierrette pour avoir avoir été mon fil d'Ariane dans le dédale des différentes versions du règlement doctoral.

Enfin, je ne peux conclure cette préface qu'en adressant mon entière gratitude à ma famille : mes parents Dominique et Daniel, ma sœur Carole, son compagnon Denis et la petite Johanne. Leur persévérance à essayer de comprendre ce que j'ai fait, durant sept ans, là-haut dans le 622 de la *Fac Eco,* a été une bouffée d'oxygène pour moi. Je suis aussi infiniment redevable envers Laura qui a eu la patience de supporter la distance, et l'intelligence de comprendre à quels moments je voulais son avis, ou le mien dans une autre voix que la mienne.

Heidelberg, le 14 Septembre 2018.

Introduction

In recent years, a lot of effort has been devoted to the understanding of the economic contents of sovereign yields. In a market with free capital mobility, interest rates perfectly represent agents expectations of the future state of the economy. Indeed, economic agents want to smooth their consumption over time and this is only possible with an efficient capital market where savers and borrowers can meet. The resulting interest rate therefore represents the anticipated path of the economy for the years to come. The yield curve – the function that links the interest rate to the time to maturity of a bond – summarizes this information and is therefore a useful tool for policymakers and investors alike. Understanding the drivers of the yield curve is thus particularly relevant as a forecasting device. Additionally, it is possible to decompose the yield curve into several components. Under the assumption that all arbitrage opportunities have been exhausted, long-term interest rates are risk-adjusted expectations of the future short-term interest rate. There is thus, for every long-term interest rate, a risk premium that rewards investors for holding a riskier asset, the long-term bond, over a safe short-term bond.

The yield curve, and in particular the sovereign yield curve, also serves as a basis for the construction of derivatives. In recent years, the size of the derivatives market has exploded, from $80 trillion in 1999 to $544 trillion in 2016. Interest rates derivatives alone represent around 75% of the total derivatives market. Moreover, government bonds of short maturity are usually considered a safe asset such that investment strategies trading risk for yield consider the yield on the short government bond as their benchmark.

The study of the yield curve is also particularly relevant when it comes to debt management policies. In effect, governments make an active decision regarding the maturity of the debt they emit on the primary market. Changing the maturity composition of the debt has an influence on the entirety of the yield curve. For instance, in times of distress, governments have an incentive to emit more short-term debt than long-term debt so as not to lock-in a high interest rate for a long period of time. The increased supply of short-term debt therefore increases the short-end of the sovereign yield curve, provided investors do not see long- and short-term debt as perfect substitutes. The substitution between long and short rates may even cause the long-term yield to decrease. Monetary authorities may also play a decisive role in the relative supply and demand of sovereign bonds. For instance, central banks may buy government bonds of long maturities and sell short-term debt they currently hold as an attempt to bring down long-term yields.[1]

The three reasons presented above point to the marked time-varying properties of the yield curve and its contents. Even more importantly, we have seen that the environment in which market participants, governments, and central banks operate is changing over time, sometimes drastically. It seems therefore incompatible to apply analysis tools that do not take these structural changes into account. Consequently, the argument calls for the development and the application of models that can accommodate changes in the economic environment.

The literature has identified several fundamental drivers of the sovereign yield curve, and I will focus on three key concepts: inflation, economic activity, and fiscal policy. First, if inflation rises, a nominal bond that pays a constant coupon becomes less profitable because the real return drops. As a consequence, the demand for such a bond decreases, driving down its price. As the price drops, its yield mechanically goes up. The yield on the bond has to rise in order to protect investors against the loss of purchasing power caused by inflation. Second, as the economy slows down, individuals and firms are reluctant to make risky consumption decisions or investments. Firms postpone investment and hiring decisions, driving down their share prices because expected profits and dividends are low. As households save more, they are inclined to buy government bonds that offer a higher degree of certainty and security. This behavior pushes the demand for government bonds upwards such that their price increases, driving down their yields. As the economy recovers, inflationary pressures may rise, but at the same time, investment opportunities broaden: with larger expected profits and dividends, investors will choose to invest in the stock market rather than in government bonds. Hence, bond yields rise. Third, the degree of indebtedness of the government may have an influence on the yields. In a market for loanable funds framework, firms and the government compete for available funds from savers. Increasing the sovereign debt level therefore puts pressure on the equilibrium interest rate. At the same time, potential inflationary pressures may surface because the government may temporarily support aggregate demand beyond the equilibrium. Fear of default are also likely to play a role. If the government borrows too much, investors may cast doubt on the capacity of the government to repay its debt burden in the future. This element touches the notion of the sustainability of fiscal policy. If investors fear that the government will have difficulty meeting its debt obligations, they will reduce their demand for the government debt, driving up the interest rate on government debt.

The aim of this thesis is to identify the most relevant determinants of government bond yields and to quantify their effect on the shape of the yield curve. Such an information is relevant for investors and policymakers because it helps them forecast the most likely path of economic indicators relevant for their decisions. The present essays address the general theme of the determinants of sovereign interest rates along three dimensions disseminated

[1] The US Federal Reserve resorted to such a policy in 1961, dubbed "Operation Twist", and between 2011 and 2012.

in three self-contained chapters. As a consequence, the reader may encounter repetitions of concepts. An introductory chapter details the economic mechanisms that are at play in the first two chapters of this dissertation.

In the first chapter of this study, Romain Houssa and I revisit the question whether larger deficits necessarily cause higher sovereign yields. Neither the theoretical nor the empirical literature has reached a consensus in this respect and it seemed important to us to contribute to the empirical debate by applying a dynamic model that accommodates the time-varying properties of debt sustainability. We start by identifying periods in the United States history when fiscal policy was deemed unsustainable. Such a policy is unsustainable if it does not aim at the stabilization of the debt-to-GDP ratio. We have reasons to believe that investors will interpret this signal and revise their expectations concerning inflation developments, prospects of economic growth and potentially default risk. As a second step, we model the fiscal policy rule in conjunction with the monetary policy rule that links the monetary policy rate to inflation and economic activity. Modeling the two processes jointly is crucial because the literature has suggested that the two authorities strategically interact (Leeper and Leith, 2016). The regimes identified lead to different predictions concerning the likely path of the price level and sovereign interest rates. We endeavor to test such predictions by introducing a fiscal policy shock into the model. We also track this shock for 16 quarters to appraise the dynamic responses of inflation, output growth and interest rates on government debt. The local projections method developed by Jordà (2005) are particularly well suited for this purpose given its flexibility and parsimony. We find that US sovereign yields do respond differently whether fiscal policy is considered unsustainable or sustainable. Typically, sovereign yields rise by about 70 basis points at a 6 quarters horizon in the sustainable regime while they decrease by about 35 basis points in the sustainable regime. The *sustainability premium* therefore amounts to one percentage point.

The second chapter of this manuscript, written with Hans Dewachter and Romain Houssa, extends the first chapter along different dimensions. The first improvement is certainly the structural approach to the question whether fiscal policy affects the shape of the yield curve. As mentioned earlier, the yield curve contains information about the expectations of economic agents. In particular, the slope of the yield curve – the difference between long-term rates and short-term rates – is closely linked to economic growth prospects. Indeed, a positive slope is usually associated to a positive outlook while a negative slope often indicates an upcoming recession. The second major modification lies in the way fiscal policy shocks are identified. In this chapter, we identify fiscal policy shocks based on economic theory rather than with statistical tools. The fiscal policy shock, in other words the public demand shock, is identified with sign restrictions together with an aggregate supply and a private demand shock. We develop a regime-dependent term structure model where yield curve factors are supplemented by macroeconomic factors. The latter are unspanned by the yield curve: they do not explain the cross-section of yields but do affect their time series properties. The regimes are taken from the Sustainable/Unsustainable dichotomy developed in the first chapter. This model allows us to appraise the responses of the elements that constitute the shape of the yield curve to a fiscal policy shock depending on the timing of the shock, whether it takes place in the sustainable or unsustainable regime. Results show that while the level of the yield curve rises in both regimes, fiscal shocks in times of unsustainable fiscal policy significantly decrease the slope of the yield curve. The term structure model also allows us to quantify the risk premium embedded in the yield curve. Our specification shows that the risk premium in the unsustainable regime is consistently larger than in the sustainable regime.

The third chapter is single-authored and focuses on the European bond markets. In this chapter, I investigate whether the macroeconomic and financial situation of neighboring countries have a decisive influence on the domestic bond market. The European debt crisis of 2011 revealed salient disparities in the resilience of core and periphery countries to adverse shocks. Of the 76 credit ratings changes recorded by Standard and Poor's, Moody's and Fitch Ratings between the first quarter of 1999 and the last quarter of 2013, 42 took place between the first quarter of 2011 and the last quarter of 2013. Periphery countries were mostly affected, sometimes beyond what could be expected from the deterioration of their fundamentals. I was therefore interested to measure this contagion in the context of a monetary union. To this aim, I devised a spatial Vector Autoregression that is able to capture contemporaneous as well as delayed spatial transmission of shocks from one country of the eurozone to the other members. The model encompasses both macroeconomic and financial variables where the transmission mechanism relies on the exposure of domestic banks to foreign sovereign debt. Banks adjust their loans to the domestic private sector depending on the value of the assets they hold. If the value of their sovereign debt holdings dramatically drop, the banks will reduce their lending to the domestic private sector, thus slowing down the domestic economy. The model shows that not all neighbors are created equal. Unexpected increases in the country's sovereign spread that originate from core countries, whether big or small in terms of economic size, do not propagate beyond their borders. On the contrary, shocks that originate from periphery countries do transmit to other periphery countries, but not to core countries. I find that on average, 10 and 15% of domestic sovereign spreads can be explained by global factors and neighboring countries, respectively. These shares are even larger in the case of periphery countries, indicating that domestic policies in periphery countries can only have a limited impact on their sovereign spreads.

Chapter 1

Methodological chapter

1.1 Introduction

The aim of this introductory chapter is to provide the reader with an analysis of hand-picked influential pieces of research that shaped the way macroeconomics addresses the role of debt for the determination of sovereign interest rates and other macroeconomic aggregates, namely inflation and capital formation. This chapter will cover three topics. The first topic will deal with the role of debt in a general equilibrium model. I will show in that section how the early literature has accommodated debt issuance in their models and I will emphasize the consequences, or absence thereof, of this choice. In the second section I will explain how strategic interactions between the fiscal and monetary authorities can deviate from the conclusions of Robert Barro regarding the neutrality of fiscal policy for aggregate demand, interest rates, and capital formation. The emergence of the Fiscal Theory of the Price Level provides interesting insights in this respect. The third section discusses how the maturity structure can be used to smooth the effects of fiscal policy over time. Finally, I address some limitations of the literature I have presented in Section 1.5.

1.2 The role of debt in a general equilibrium model

I set out first to describe in details the money growth model of Feldstein (1980) who extends to three assets the model of Tobin (1965) where households could only choose to invest in capital or money. In Feldstein's model, however, households face a broader choice of assets: tangible capital, money and government bonds. This essentially turns out to be a question of optimal allocation of assets based on their respective returns. The paper investigates the consequences of an increased deficit on the inflation rate and capital formation. How the deficit is financed, either by printing money or by borrowing, is important. Feldstein then endeavors to analyze four possible predictions from his model regarding the responses of capital formation, inflation and the interest rate to an increased deficit. He concludes that larger deficits cause higher inflation and/or lower capital in the economy. At the same time, it is likely that interest rates increase as a result. At any rate, the investment in tangible capital is lower than in an economy with only capital because part of the households' savings is not invested in real assets but in money and bonds.

I will now cover the main assumptions of the model before turning to its four predictions. The model economy is growing at a constant rate n with a constant labor force such that the economy is at full employment at every period. The economy faces a twice-differentiable concave production function f where the only producing factor is capital k.

There is no central bank in the model, and the government acts as the sole provider of money m. The government thus has three sources of financing: taxes, seignoriage and debt. The government can incur a deficit d, either by printing money and/or by issuing bonds b.

Households can hold three types of assets: real capital, bonds and money, where the sum of the last two corresponds to the total liabilities of the government. The respective return on those assets is the net real return on capital, the real yield on government bonds and zero. The net real return on capital is given by the gross marginal product of capital minus taxes levied on it, taking into account the depreciation rule based on nominal investment. The marginal tax rate is given by τ. The real yield on government bond is the difference between the nominal interest rate on debt i and the inflation rate π.

At steady state, the real per capita growth rate of money is given by the sum of the inflation rate and the growth rate of the population. A similar expression is given for bonds. The real per capita deficit is given by the product of the nominal growth rate of the economy, inflation and growth of population, and the real per capita liabilities of the government, money and bonds.

The demand for bonds over capital depends negatively on the net real return on capital, positively on the interest rate paid on debt and on inflation. Inflation increases the demand for bonds because higher inflation reduces the net real return on capital. The demand for money increases with output but decreases with the interest rate.

The saving rate is a constant share of the real per capita disposable income. As mentioned earlier, government consumption is financed through taxes, money and bonds creation. The share of government consumption over output γ is assumed to be constant such that if expenditures devoted to interest payments increases, other types of expenditures decrease. As such, this implies that the government does not use expenditures as an instrument of fiscal policy. To close the model, all savings must be absorbed in either real capital accumulation, additional real money or real bonds.

Four equations summarize the model:

$$\begin{cases} Deficit & d = (\pi + n)(m + b) \\ Money\, Demand & m = L(i) * f(k) \\ Bond\, Demand & b = \beta \left[(1-\tau) f'(k) + (1-\tau\lambda)\pi - i\right] * k \\ Savings\, allocation & \sigma = \frac{n*[k+m+b]}{[(1-\gamma)*f(k)+n*m+n*b]} \end{cases} \tag{1.1}$$

The government therefore has four instruments at its disposal for the conduct of fiscal policy: (i) the size of the deficits d, (ii) the share of government spending in national income γ, (iii) the nominal interest rate on bonds i and (iv) the tax rates on capital income τ and λ where λ is linked to the depreciation rules in the tax code. Values of n, i, d, γ, τ and λ determine π, k, m and b.

Five main results can be derived from the comparative statics of the model above. First, the government could increase deficits without causing a change in inflation or capital intensity if it can vary all of the remaining instruments. In other words, the government can neutralize the adverse effects of deficits on inflation and capital intensity if it reduces the share of government spending in national income.

However, the model assumes that γ, τ and λ are fixed. An increased deficit therefore leads to higher inflation, reduced capital intensity, or both. I now turn to the comparative statics.

The second result that emerges from the model is the following: an increase in the deficit causes an increase in inflation and a decrease in capital intensity, provided that the real interest rate is maintained or, in other words, if the nominal interest rate moves in lockstep with inflation. To see this, we need to totally differentiate the system in (1.1) subject to the restriction that $\frac{di}{d\pi} = 0$. Feldstein proceeds in two steps. He first shows that higher inflation increases the demand for bonds but reduces the demand for money. If the first effect dominates the second, larger deficits unambiguously reduce k. Since $\frac{\partial K}{\partial d}$ and$\frac{\partial \pi}{\partial d}$ are of opposite signs, the higher deficit also causes higher inflation.

The third result deals with the effect of larger deficits on the nominal interest rate. Following an increase in the deficit, the nominal interest rate has to increase if we want to keep inflation constant. The first equation in (1.1) states that a stable inflation rate requires that $m+b$ increases with the deficit. This larger $m+b$ must be absorbed without larger growth rates of m or b. Therefore, there needs to be a substitution of money for bonds such that it leaves inflation constant. The way to achieve this is to increase the nominal interest rate such that the increased demand for bonds matches the decreased demand for money. In practice, an increase in the ratio $\frac{b}{m}$ means that liquidity in that economy decreases and, therefore, the interest rate rises. Notice also that this higher nominal rate induces a reduction in the capital intensity and a smaller real income.

Fourth, a larger deficit may not cause a lower capital intensity if both inflation and the nominal interest rate rise. The absence of modification in the capital intensity in this economy is equivalent to saying that the variation of the sum of money and bonds must be zero. If $\Delta(m + b) = 0$, then larger deficits can only be financed through larger inflation (first equation of (1.1)). Higher inflation decreases the demand for money and raises the demand for bonds. However, with a constant value of k and i, higher inflation would decrease the demand for bonds. The nominal interest rate must therefore increase to support the demand for bonds.

Finally, it can be shown that a deficit financed through debt emission decreases k and increases π under the restriction that money demand is completely inelastic.

One important assumption that Feldstein makes, though in a footnote, is that government bonds are considered net wealth. That is, households do not consider the corresponding future taxes that they and the future generations will have to bear in order to pay the principal and interests on these bonds. This directly refers to the article of Robert Barro (1974) that addresses what was later called the *Ricardian equivalence*. The Ricardian equivalence, as it was presented, states that the way larger government spending is financed, either through debt or taxes, is irrelevant as optimizing households will internalize that a larger debt today will eventually have to be repaid in the future. Agents therefore increase their savings today in such a way that aggregate demand is left unchanged and public consumption completely crowds out private consumption. As aggregate demand does not change, neither do the interest rate and the capital intensity in the economy. The Ricardian equivalence is, in a sense, the public finances equivalent of the irrelevancy theorem of Modigliani-Miller (1958).

Let me now describe in more details the setup of Barro's article. An economy is populated with n people at each generation. Each individual lives only through two generations such that, at each moment in time, there are only two generations alive. Individuals have the same preferences and productivity within each generation and across generations. Future generations' utility matters for the current generation, however. The young generation works and derives a wage w from it. There is no technological change over time nor is there any change in the wage rate. Assets holdings take the form of physical capital and government bonds. The return on both types of assets is given by the real rate of return r such that both assets are perfect substitutes. Bonds in particular can be bought while young. The interests are paid during the same period while the principal is repaid next period. Production is given by a constant-returns-to-scale production function with capital and labor as inputs. In equilibrium, marginal products of capital and labor are equal to r and w, respectively.

Barro argues that as long as there exists an operative intergenerational transfer (positive bequests or gifts) across generations, there exists no wealth effect of government debt. The line of argumentation of Barro is as follows. He starts by describing the mechanism through which government debt can have wealth effects, provided households perceive larger government debt as net wealth. If they do, consumption increases and savings decrease. This increased consumption pushes Aggregate Demand upwards which leads to a higher interest rate on the market of loanable funds. Finally, this higher interest rate reduces capital accumulation (Modigliani, 1961). Second, he recalls that taxes will have to be levied in the future to finance the interest payments of the newly incurred debt such that the direct positive wealth effect will be (partially) offset. Bailey (1962, pp. 75-77) even suggests that these future taxes will completely offset the new deficit:

> "It is possible that households regard deficit financing as equivalent to taxation. The issue of a bond by the government to finance expenditures involves a liability for future interest payments and possible ultimate repayment of principal, and thus implies future taxes that would not be necessary if the expenditures were finances by current taxation. [...] If future tax liabilities implicit in deficit financing are accurately foreseen, the level at which total tax receipts are set is immaterial; the behavior of the community will be exactly the same as if the budget were continuously balanced."

There is, however, three possible reasons why the offset of future tax liabilities will only be partial, which, essentially, leads to a positive net present value of debt. The first argument suggests that the horizons for tax liabilities and interest payments do no coincide such that the two streams of equal face value have different net present values. Typically, with finite lives, the horizon for tax liabilities is shorter (Thompson: 1967, p. 1200). The second argument considers that different discount rates should be applied to the two streams of value that share the same horizon (Mundell, 1971). Lastly, as is clear from the quote above, the decisions of households who are not able to perfectly forecast and anticipate the extent of future tax liabilities, or those who may not have access to the financial intermediation system may generate wealth effect of government debt.

The argument of Barro regarding the wealth-neutrality of government bonds hinges on the existence of an interior solution regarding the consumption, savings and bequest quantities. Positive values of debt b with a tax levied on future generations make the current generation go insolvent by leaving a debt to its descendant. However, if a member of the old generation had already chosen an optimal consumption, savings and bequests before the new bond issue, it means that the new bond issue does not change the opportunity set. As a consequence, adjusted positive bequests remain optimal. Indeed, the agent has decided that leaving positive bequests was optimal. The corollary to the previous argument means that shifting resources from future generations to her own is sub-optimal. In conclusion, the net present value of of current and future consumption and attained utility will be unaffected, provided that shifts in the debt level will be fully compensated by shifts in bequests. If, however, a member of the old generation is at a corner solution such that bequests for the future generation is zero, then an increase in government debt changes the opportunity set such that the agent will increase her consumption today while potentially leaving zero bequest for the future generation. In that case, government bonds generate wealth effects, similarly to the mechanism set out by Modigliani (1961).

Barro does not therefore completely rule out the possibility of wealth effects of government debt but rather shows that a small set of assumptions can prevent such a situation. Namely, it only requires that current generations care about future generations and that the possibility of bequests exist.

Several criticisms have been addressed to the Ricardian equivalence theorem. Barro (1996) lists the principal: finiteness of life, imperfections of private credit markets, uncertainty about the incidence of future taxes and other variables, and the distortionary effects of taxes.[1] The last point is of particular interest as it hints towards the fact that, since taxes are distortionary, the timing of such taxes may be an additional instrument in the fiscal authority toolkit. Governments, upon incurring new deficits, also have to decide upon a tax schedule for the financing of the deficit. This tax schedule may be spread out across different sources (labor income, consumption, etc) and across time. People want to earn labor income when taxes on labor are low, and consume when taxes on consumption are low. Barro therefore concludes that " variations in the anticipated timing of these levies alters the intertemporal allocations of work effort and consumption." As a consequence, adjustments to the timing of taxes and the source of tax receipts may be the solution to an optimal-tax problem.

Absent from these models, however, is the conduct of monetary policy as a distinct authority. The following section deals with this issue and models the determination of the price level as a joint process between a monetary and a fiscal authority. The effect on the interest rates, however, is not central to the analysis, although parts of it hint at this issue.

1.3 Emergence of the Fiscal Theory of the Price Level

In 1991, Eric Leeper suggested an alternative view regarding the drivers of the price level. His claim was that the monetary and fiscal authorities should not be treated as acting separately but that they jointly determine the price level. Considering strategic interactions between the two entities allows for a richer set of possible equilibria. In particular, he surveys two cases that lead to different conclusions regarding equilibrium prices and interest rates. In the first case, the monetary authority is *active* and the fiscal authority is *passive*. That is to say, fiscal policy acts in such a way that future taxes accommodate debt shocks such that fiscal disturbances do not influence inflation nor the interest rate. These conclusions do not contradict the Ricardian equivalence theorem. In this type of setup, the actions of the fiscal authority are subordinated to the actions of the monetary authority. In the second case, however, the monetary authority is *passive* and the fiscal authority is *active*. With an accommodative monetary authority, incurred deficits generate inflation now or in the future. If the government wants the households to hold the additional nominal debt, it needs to increase the nominal interest

[1] Barro covers most of the rebuttals of Ricardian equivalence in his 1989 paper.

rate. Substitution of assets from money to bonds reduces the liquidity in the economy. Such monetary contractions require higher money growth in the future (interest payments and principal) such that inflation increases. Fiscal shocks can therefore have an impact on inflation.

More recently, Leeper and Leith (2016), based on the works of early *fiscal theorists* (Leeper (1991), Woodford (1996), Sims (1994) among others) provide an in-depth analysis of the two cases highlighted above. In particular, they stress that the fiscal theory of the price level (FTPL) should be not be seen as a substitute for conventional views on the determinants of the price level, but rather as a complement (Leeper and Leith: 2016, p. 106):

> Macroeconomists have an unfortunate history of arguing over whether monetary or fiscal policy in the primary force behind inflation. [...] [T]he fiscal theory and the quantity theory [...] are parts of a more general theory of price-level determination in which monetary and fiscal policies always interact with private-sector behavior to produce the equilibrium aggregate level of prices. Within a certain parametric family of monetary and fiscal rules, the two seemingly distinct perspectives arise from different regions of the policy parameter space, but there is no sense in which one view is "right" and the other is "wrong." Ultimately, it is an empirical question whether we can discern whether and under what circumstances one view is the dominant factor in inflation dynamics.

Leeper and Leith (2016) consider dynamically efficient models with monetary policy, taxes, government expenditures, a budget identity and a maturity structure for nominal government debt in order to detect the differences that can arise between the Monetary and Fiscal dominance regimes. They assert that there are four features that can emerge from those small models in the Fiscal dominance regime. First, surprise changes in inflation and bond prices serve as revaluation tools for the stabilization of nominal government debt. The distinction between real and nominal debt is crucial for the FTPL. On the one hand, real debt is a claim to real goods. If the government wishes to purchase those real goods, it can only do so through taxation. The government therefore has to levy enough taxes to finance its outstanding debt such that its budget constraint is satisfied. On the other hand, nominal debt is a claim to future currency. The government can therefore either levy taxes to acquire this currency, or print new currency if it is allowed to do so. When all the debt of the government is nominal, the government does not face a budget constraint as changes in the price level and bond prices will vary so as to stabilize the real level of debt. Second, some combinations of parameters of the monetary and fiscal policy rules permit nominal government debt expansions or increases in the monetary policy interest rate instrument to generate an increase in nominal private wealth, nominal Aggregate Demand and the price level. Third, expectations of both monetary and fiscal policies matter to determine equilibrium prices and quantities. Fourth, debt management in the form of choosing optimally the maturity structure of nominal debt matters for equilibrium dynamics. This last point amounts to say that the maturity structure could be considered as an additional instrument for policymakers.

Most of the mechanisms at play can be found in a simple endowment economy where households maximize their intertemporal consumption, have access to nominal assets (bonds) and where they interact with the government in the form of lump-sum taxes and transfers. There are two authorities in this economy: a central bank and a government. The first authority sets its policy instrument, the nominal interest rate, as a proportion of the deviation of inflation from its steady state value. The second authority sets its policy instrument, in the form of budget surpluses, as a proportion of the deviation of debt to its steady state value. In equilibrium, the net present value of outstanding debt is given by the discounted future surpluses. The relevant discount factor is given by the real interest rate. Importantly, the two authorities will interact because the government issues nominal debt. As a consequence, the price level will matter for both authorities when computing the equilibrium. As such, the central bank can either respond strongly or weakly to inflation developments and the government can either respond strongly or weakly to debt developments.

Leeper (1991) and Leeper and Leith (2016) show that only two combinations out of the four possible yield a determinate equilibrium. For the rest of the explanation, I will follow their terminology and call the combination of strong response to inflation and strong response to debt *Regime M* while *Regime F* pertains to a weak response to inflation and a weak response of surpluses to debt.[2]

1.3.1 Regime M

One may erroneously think that the conduct of monetary policy is not influenced by fiscal behavior because fiscal aggregates do not enter the policy rule of the central bank. However, fiscal aggregates may have a definitive influence on the price level. In the model of Leeper (1991), the central bank reacts to inflation developments.

In this regime, the government reacts strongly to debt developments (in other words, *passive* fiscal policy) in an environment where the central bank reacts strongly to inflation (*active* monetary policy). Following an increase in the real debt, the price level will increase. This increase will trigger a strong reaction of the central bank such that, by increasing its nominal interest rate more than inflation, the net real interest rate will increase. At the same time, future surpluses will increase sufficiently so as to cover the increased debt service and part of the principal repayment. Real debt will therefore return to its steady state value.

To see clearly the interaction between monetary and fiscal policies in this regime, imagine that there is a surprise monetary expansion at time t such that it raises the

[2] Alternatively, regime M has been referred to as Monetary dominance and Regime F as Fiscal dominance in the literature.

price level P_t. The contemporaneous surplus is not affected but bond holders experience a negative wealth effect. Indeed, in real terms, their holdings are now worth less. As a consequence, the budget constraint of the government needs to be adapted because the market value of its debt issued at time t has declined. If the fiscal authority reduces surpluses by more than the increase in the real rate, the drop in future surpluses has to match the drop in value of debt holdings. This thus eliminates the negative wealth effect on households wealth to make monetary policy expansionary. In conclusion, fiscal policy acts in such a way that it eliminates any monetary effects on households wealth. The corollary to this proposition is the Ricardian equivalence. A decrease in surpluses of one unit (an increase in the deficit) is financed by raising the nominal debt by P_t units. Under the special case that the central bank pegs the interest rate, real debt increases by P_t units. Future surpluses have to increase such that the net present value of those future surpluses equals P_t units.

Notice also that if fiscal policy does not produce sufficient future fiscal adjustments, households wealth would decline, and so would Aggregate Demand. This would therefore counteract the inflationary pressure of monetary expansion. In conclusion, two active authorities do not produce a stable equilibrium.

1.3.2 Regime F

Following an increased deficit financed by debt, nominal households wealth increases due to future income derived from interest payments. Provided that there is not enough tax increases to completely offset the rise in their wealth, households increase their demand for goods, which raises the price level now and in the future. If surpluses do not adjust strongly to real debt, then the debt indefinitely grows, which is inconsistent with equilibrium properties. Monetary policy therefore needs to ensure that real debt is stabilized through non-explosive interest payments. Monetary policy needs to allow surprise inflation to revalue government debt. To understand the mechanism, let me consider the special case where the central bank pegs the nominal rate, that is, the central bank does not respond at all to inflation. A one-time decrease in the time-t surplus financed by new debt increases the price level at time t. Doing so, it keeps the real debt fixed, but a higher price level depresses the value of outstanding debt such that it reduces real interest payments. In conclusion, real debt remains at steady-state. If we assume that the central bank responds weakly to inflation, real debt is still stabilized but inflation can now persist. The persistence of the inflation response increases with the strength of the monetary authority, provided it can still be categorized as *passive*.

1.3.3 Unstable combination of monetary and fiscal stances

When fiscal policy is active, monetary policy cannot be active at the same time. If this were the case, then an increased deficit that increases the price level would have the effect that the nominal interest rate set by the central bank increases more than proportionally. This would result in larger interest payments paid to the households that hold the nominal debt. Their wealth would increase, acting positively on Aggregate Demand and inflation, to which the central bank has to respond more than proportionally. This would lead to a spiral effect inconsistent with equilibrium.

1.4 The role of the maturity structure

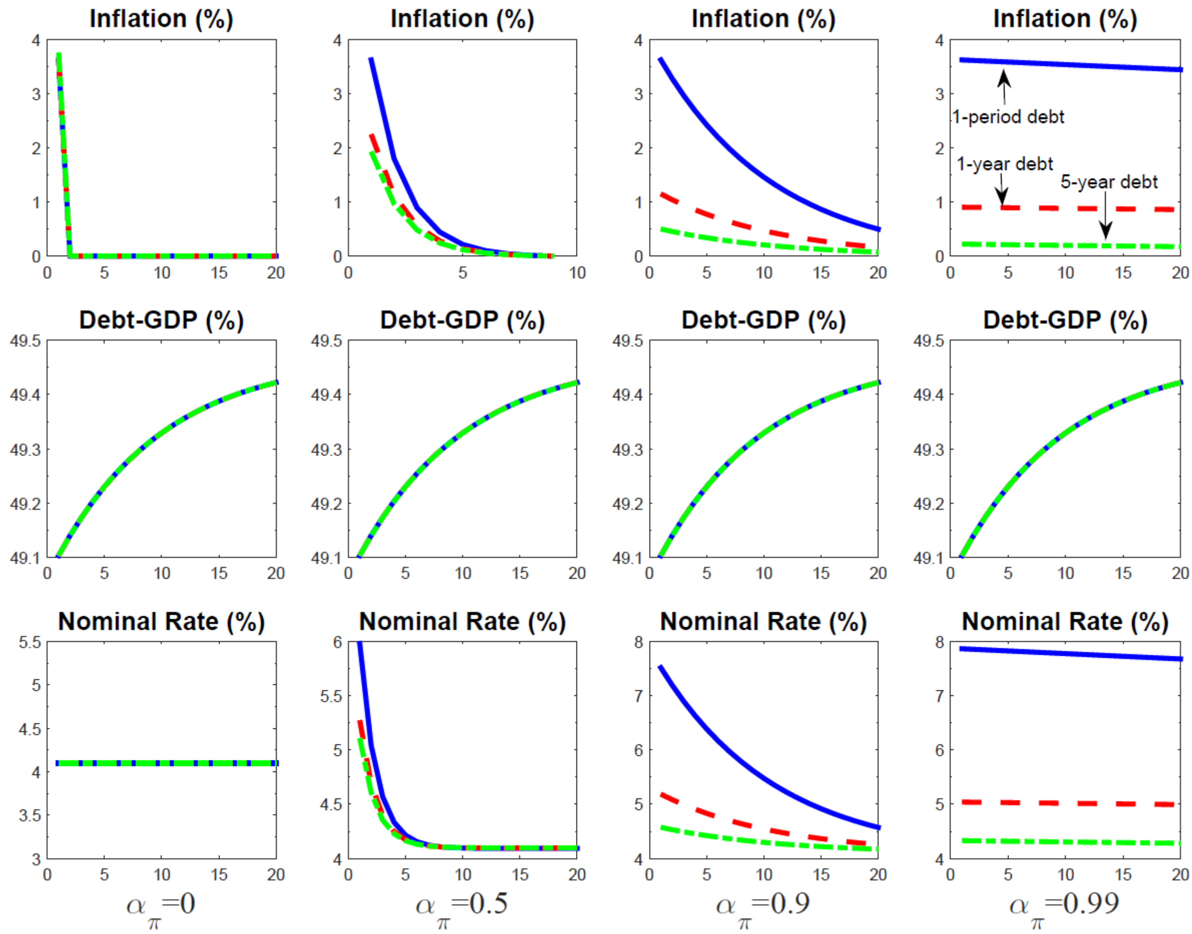
The case for the role of the maturity structure hinges on the type of regime one considers. To see this, let us consider bonds with maturities ranging from one period to an infinity of period. Without loss of generality, let us consider that the maturities decay at a constant rate ρ. The parameter ρ therefore controls the average maturity of the debt. If $\rho = 0$, then all the debt is a one-period debt. If $\rho = 1$, then the debt takes the form of perpetual bonds. For the rest of this section, I will consider an intermediate case where $0 < \rho < 1$. The bonds are priced according to a no-arbitrage condition.

Regime M produces results similar to Barro's conclusion where the maturity of the debt has no influence. In this regime, if the central bank engages in a contractionary policy, the one-period nominal interest rate rises which, in turn, reduces the price of time-t bonds because the net present value of the bond has decreased. Through the no-arbitrage condition, prices of longer maturities bonds also decline. However, future surpluses offset this decrease in bond prices because household will raise their demand for the bonds in order to use the higher interest payments to finance the future surpluses. The government can thus trade smaller surpluses for shorter maturities. In other words, "the government can achieve any path of the nominal term structure and, additionally expected inflation, by adjusting the maturity structure" (Leeper and Leith, 2016 ; p. 21).

In general, one may reformulate the argument of Thompson (1967) highlighted in Section 1.2 in a different way so that maturity can still play a role in regime M: if the stream of surpluses is fixed, shortening the maturity (reducing ρ) will increase the net present value of nominal debt and increase the price level.

Regime F offers a new channel through which fiscal policy generates wealth effects: bond prices that reflect expected inflation over the maturity of the bond. With one-period bonds, the rise in the price level following a decrease in surpluses is direct and only lasts one period. With m-periods bonds, the rise in inflation is spread out across all bonds up to maturity m via a decrease in their prices. How this rise in inflation is distributed across contemporaneous and future inflation depends on the maturity structure of the debt and the parameters in the monetary policy rule. The maturity structure is a tool to shift inflation intertemporally. The total inflationary effect of deficits is the same, but the maturity structure can control which, from current or future inflation, will take most of the change. In essence, the maturity parameter ρ acts as an additional discount factor in the bond valuation equation. If the average maturity of the debt increases,

Figure 1.1 – Responses to an increase in transfers under various monetary policy rules and maturity structures



Note: the figure reports the impulse responses from inflation, debt-to-GDP ratio and the nominal rate from an endowment shock in the calibrated model of Leeper and Leith (2016). The values for the calibrations are found under the third row of plots. The solid line corresponds to a one-period debt, the long dashed line pertains to a debt maturity of 1-year and finally, the dashed and dotted line refers to a 5-years debt.

inflation can be smoothed out on longer horizons such that the contemporaneous rise in inflation decreases at the expense of higher inflation in the future. As a consequence, the price of the short-term bonds will decrease more the longer the debt maturity. As the central bank increases its responsiveness to inflation (while still remaining *passive*), inflation persistence increases and the drop in bond prices is more severe.

I reproduce in Figure 1.1 the responses of inflation, the debt-to-GDP and the nominal interest rate following an increase in transfers in the endowment economy presented by Leeper and Leith (2016) under their calibration.[3]

The graph should be read according to two dimensions: the responsiveness of the cen-

[3]In their calibration, they assume that the steady-state ratio of transfers-to-GDP is 18%, government spending is 21% of GDP and taxes represent 41% of GDP such that the annualized steady-state ratio of debt-to-GDP is 50%. Transfers follow an autoregressive process with persistence 0.9 and variance 0.005 of steady-state value.

tral bank to inflation developments and the average maturity of the debt issued by the government. In the first column, the central bank pegs the nominal rate such that there is no difference across maturity structures. With this type of monetary policy reaction function, the total adjustment occurs through surprise inflation in the first period. As the central bank becomes less passive (columns 2 to 4), the persistence of the responses of inflation and the nominal rate increases. With one-period debt, the initial inflation response is the same than in the first column because it is the jump in inflation consistent with the reduction in the net present value of real debt that follows a reduction in surpluses. Inflation, however, remains higher for a prolonged period of time, although only the initial jump in inflation is needed to reduce the value of debt. The rise in the nominal rate is also persistent. A sustained increase in the nominal rate reduces bond prices such that the bond valuation equation is satisfied at lower initial inflation rates. With longer maturities, it is the inflation path over the life of the bond, rather than the initial drop, that permits the reduction of the value of debt. As a consequence of sustained inflation, bondholders obtain lower real returns.

In conclusion, the present value of a positive transfer shock must be financed with a path of inflation that combines current and future inflation surprises where future inflation surprises are embedded in bond prices to ensure solvency of the government.

1.5 Limitations of the literature presented

The literature presented above suffers from a few limitations that are worth mentioning. The first is that most of the models presented explicitly or implicitly assume that the economy is at full-employment or equilibrium. Out-of-equilibrium scenarios are not presented. The Keynesian view (Keynes, 1936), on the other hand, proposes that Aggregate Demand support by means of larger deficits be expansionary without causing inflation, or very little. This situation happens when the Aggregate Demand and Aggregate Supply schedules intersect in a portion of the AS curve that is (near-) flat.

The second limitation is probably the consideration that taxes are lump-sum. Distortionary taxes may provide richer conclusions. In particular, Traum and Yang (2011) develop a Dynamic Stochastic General Equilibrium model whose parameter values can either be compatible with regime M or regime F and present an unusual conclusion. In regime M, the degree with with which the central bank reacts to output is crucial. If the central bank responds strongly to inflation but relatively weakly to output, a reduction in taxes will cause the interest to fall. The argument is as follows: a reduction in the income tax rate increases labor and output because households want to supply more labor. As labor income increases, so do savings, which leads to higher capital accumulation, raises the marginal product of labor and the demand for labor. This in turn lowers the marginal cost of intermediate products. With a constant markup, goods-producing firms can lower their prices such that the general price level falls. Since, in their model, the monetary authority responds more to falling prices than to the increased output, the nominal interest rate falls.

Thirdly, early applications of the FTPL to open economies have not produced convincing results. Leeper and Leith (2016) present such limitations. In particular, the existence of multiple monetary and fiscal authorities spread across as many countries may lead to indeterminacy concerning the price level in the countries considered. Those early models also had the undesirable property that a single country, even small in comparison to others, determines the price level for all.

Hubbard (2012) lists additional determinants of sovereign interest rates, although his focus is rather on the crowding out of private investment. In a demand and supply of loanable funds framework, he claims that private sector debt could also crowd out private investment as they compete for loanable funds. Indeed, the choice between equity or debt is intrinsically linked to the prevailing risk aversion such that variations in risk aversion may cause interest rates to change. Hubbard (2012) also points to the role of open-market operations by the central bank to determine sovereign interest rates. Typically, if bonds of different maturities are not perfect substitutes, the central bank may alter the shape of the yield curve by targeting specific maturities. A sustained demand for the bonds would therefore increase their price and decrease their yield.

In an open-economy framework and using the national savings identity, Elmendorf and Mankiw (1999) show that public dis-saving must be absorbed either by increased private saving, a reduction in private investment or by a decrease in net foreign investments. If the increase in private saving exactly matches the public dis-saving, we reach the Ricardian conclusion. If, however, private saving does not rise enough to offset the increased deficit, private investment and/or net foreign investments must come into play. If investment decreases for a prolonged period of time, it lowers the capital stock. In turn, a lower capital stock depresses output and income. At the same time, less capital available in the economy raises the marginal product of capital such that the interest rate rises. With small adjustments, one can approximate the current account by the net foreign investments such that the drop in net foreign investments both reduces the capital income of residents, but it also turns the current account in negative territory. With a subsequent trade deficit, the currency appreciates, reducing the competitiveness of the domestic economy in the global market.

1.6 Conclusion

An important consideration regarding the conclusions of the effects of fiscal policy on the economy is probably the question of where in the business cycle such policies take place. During periods of full- (or near full) employment, fiscal policy may generate inflation now and/or in the future. In contrast, Keynesian economics tells us that if the Aggregate Supply schedule is flat or near flat at the intersection with the Aggregate Demand schedule, an increase in the deficit (either increased government spending or reduced taxes) boosts Aggregate Demand such that output increases without causing too much inflation.

The Ricardian equivalence has been put to the test numerous times, both theoretically and empirically under the criticism that crucial assumptions are not realistic. Empirically, the evidence is mixed (see the reviews of Barth et al., 1991 and Gale and Orszag, 2003). Very recently, for instance, Auerbach and Gorodnichenko (2017) empirically find that an increase in the deficit when the state of the economy is low *decreases* the nominal interest rate.

In this respect, the emergence of the Fiscal Theory of the Price Level, although under heavy criticisms as well, serves as a complement to the monetarist view of price level determination.[4] The fiscal theory also stresses that it is the interaction between the monetary and fiscal policy that produce stable equilibria such that one cannot be considered without the other.

Finally, the fiscal theory also addresses the role of the maturity structure to smooth the effects of fiscal policy across time. Typically, a longer debt maturity generates more persistent inflation and a larger drop in bond prices after an increased deficit.

[4] Leeper and Leith (2016, p. 4):

> Accusations against the fiscal theory include: it confuses equilibrium conditions with budget constraints; it violates Walras' law; it treats private agents and the government differently; it is merely an equilibrium selection device; it is little more than a retread of Sargent and Wallace's (1981) unpleasant monetarist arithmetic.

Chapter 2

Macroeconomic Policy Interactions and the Effects of Fiscal Stimulus

2.1 Introduction

Following the 2007 financial and economic crisis, many governments from advanced countries have implemented large-scale fiscal stimulus packages. For instance, the size of the 2009 American Recovery and Reinvestment Act (ARRA) totaled $803 billion in addition to the Economic Stimulus Act of 2008 which had a budget of $152 billion. Similarly, the European Commission launched the European Economic Recovery Plan (EERP) in December 2008 for a budget of €200 billion. These programs were mainly financed through increased government deficits and debt emissions, leading to a surge in the debt stock of the countries involved. As such, renewed concerns about the sustainability of public finances emerged. Indeed, too large a debt raises doubts about the capacity of the government to repay it. As a consequence, investors require a premium for holding more risky sovereign bonds (e.g., Arellano, 2018 ; Eaton and Gersovitz, 1981).[1] Equally important, theory predicts that larger deficits may generate larger inflation such that investors may require a compensation against the loss of value of their investment across time.

Although the preceding mechanisms would suggest a positive impact of deficits on bond yields, we need to isolate its impact from other drivers. Indeed, deficits are likely to rise in recessions due to the effect of automatic stabilizers. At the same time, the central bank often reduces its policy rate in recessions in order to reduce households savings and increase firms production and investment. As a consequence, the overall behavior of yields

[1]Fiscal preferences influence interest rate dynamics through the present value of deficit channel. As the present value of deficit increases, the present value of the consumption available to economic agents rises if prices and interest rates do not increase. In turn, it creates a substantial wealth effect and aggregate demand rises in consequence. To offset the discrepancy between the present value of current government debt and expected government budget surpluses, prices and/or inflation have to adjust in order to restore the equality between the present value of government liabilities and the present value of expected surpluses. Unexpected inflation reduces the real value of debt issued in nominal terms. A drop in the real interest rate paid on government liabilities could also allow the government to service its debt with smaller primary surpluses (Woodford, 1996).

in this scenario is ambiguous.

Additionally, the impact of deficit shocks on yields will depend on the intrinsic behavior of demand expressed by bond investors. For instance, if these investors have other motives to hold US bonds (e.g. accumulation of reserves by foreign officials to stabilize their exchange rate, or saving motives) a deficit shock may even coincide with decreasing yields rather than increasing. In line with this intuition, a number of studies show that international bond demand pressure has significantly reduced the US government long term yields in recent years (e.g. Warnock and Warnock, 2009 ; Beltran et al. 2013). This background suggests no clear theoretical relationship between government deficit and interest rates.[2]

Empirical studies are also inconclusive concerning the relationship between the government fiscal position and sovereign yields. For instance, a number of studies using linear regression models have not been able to identify any effect of fiscal positions on interest rates and attribute their results to the Ricardian equivalence theorem (see, for instance, Evans, 1985 ; Evans, 1987 ; Evans and Marshall, 2007). Another part of the literature have used a similar methodology but focused on projected deficits did find positive and significant impacts of deficit on long-term yields (Laubach, 2009). Studies that employ nonlinear techniques also find a positive impact of government deficit on yields (Hamilton, 1988 ; Dillen, 1997 ; Ardagna, 2004 ; Gruss and Mertens, 2009 ; Dewachter and Toffano, 2012. Specifically, Dewachter and Toffano employ a Markov-switching model to identify two fiscal policy regimes: an active regime when debt is unsustainable; and a passive regime when debt is sustainable. They show that the active fiscal policy regime carries a significantly positive premium over the passive regime for US long-term sovereign yields.

The aim of this chapter is to answer the question whether larger deficits always cause higher interest rates. Is is it possible that this relationship depends on the context in which larger deficits are incurred? In particular, do the sustainability of fiscal policy and the stance of monetary policy towards inflation matter to appraise the relationship between deficits and bond yields?

To answer these questions, we proceed in two steps. First, we identify different fiscal and monetary policy regimes in the United States between 1967Q1 and 2012Q1 with Markov-switching regressions of simple feedback rules: a deficit rule and Taylor (1993) rule. These rules model the dynamic behavior of the fiscal and monetary instruments, respectively. We distinguish a Sustainable vs. Unsustainable fiscal policy regime and a

[2]The impact of government deficit on interest rates is also analyzed from the saving-investment identity. In particular, if a rise in government deficit implies a decline in national saving then the interest rate must increase in order to maintain the saving-investment identity (Buiter, 1977). However, if private saving increases by the same amount as government deficit (in anticipation of a future tax burden) then the interest rate will not respond to the increase in government deficit. This is the essence of the Ricardian equivalence theorem presented in Barro (1974). In the same way, if capital inflows are infinitely elastic, then a rise in government deficit will leave the interest rate unaffected but it will cause an appreciation of the domestic currency. Additionally, the interest rate will respond very little to the worsening of the fiscal position if the central bank is ready to buy government debt.

Hawkish vs. Dovish monetary policy regime. The sustainable fiscal policy regime is consistent with debt-stabilization, as opposed to the unsustainable fiscal policy regime. The Hawkish monetary regime corresponds to a regime where monetary policy actively commits to respond more than proportionally to inflation developments whereas the Dovish regime corresponds to a regime where the Taylor principle does not hold. We first estimate the fiscal policy alone before estimating the two rules jointly. The joint estimation gives us four macroeconomic regimes that correspond to different theoretical properties of the fiscal-monetary policy-mix. The combination Sustainable-Hawkish yields Ricardian predictions and corresponds to the common assumption present in Dynamic Stochastic General Equilibrium models. The combination Unsustainable-Dovish corresponds to what the literature has called the Fiscal Theory of the Price Level (Woodford, 1996 ; Chung, Davig and Leeper, 2004 ; Davig and Leeper, 2007 ; Davig and Leeper, 2011). The combinations Sustainable-Dovish and Unsustainable-Hawkish give an indeterminate equilibrium or an explosive path of inflation inconsistent with equilibrium, respectively. Second, we estimate the dynamic responses of output growth, inflation, the primary deficit and nominal yields to a fiscal policy shock with local projections. The methodology easily accommodates regime-specific dynamics. We provide responses from the single regime (linear) estimation, the two-regimes case and the four-regimes case.

In this chapter, we extend the framework of Dewachter and Toffano (2012) along four dimensions. First, we study the response of yields, inflation and output to deficit shocks to provide more insight about the channels of transmission. Second, we use local projections rather than iterating forward a univariate AR(1) process. Local projections are essentially direct forecasts with varying horizons of the variables of interest. Third, we report the effective response to a shock rather than the difference in responses between regimes. Fourth, we also analyze to which extent the stance of monetary policy affects the transmission of fiscal shocks.

Results can be summarized as follows. First, macroeconomic policies exhibit several switches during our sample. The identified periods and their statistical properties correspond to notable economic events and are corroborated by a narrative approach. Fiscal policy has been unsustainable in the years 1973-75, 2002-3 and 2008-10. These periods correspond to sharp drops in tax revenues or large increases in government spending. Monetary policy has been active during two long periods: 1980-1990 and 1994-2000. The first episode of Hawkish policy corresponds to the Volcker-Greenspan Chairmanships of the Fed while the second refers to the fight against inflationary pressures in the mid-90s documented by Goodfriend (2002). Second, regime-dependent impulse responses provide interesting results. Deficit shocks in the unsustainable regime are inflationary and stimulate output. Yields also increase. At the 5 quarters horizon, output, inflation and yields have increased by 40, 50 and 30 basis points, respectively. We should also note that short maturities react much more strongly than long yields such that the slope of the yield curve, that is the difference between long and short rates, decreases. In the sustainable regime, the responses of output, inflation and yields are negative and the slope of the yield curve increases. The difference between the two regimes amounts to 110 basis points for the 5-years yields. Third, the stance of monetary policy has an influence on the effects of deficit shocks on yields and output. For the output in particular, a dovish monetary policy stimulates the economy but an unsustainable fiscal policy provides an additional boost. For the yields, the FTPL and Indeterminate regimes exhibit a Slope effect (i.e. short-term yields react more strongly than long yields) of deficit shocks while the Ricardian regime exhibit a Level effect (i.e. the magnitude of the responses of yields of different maturities is similar).

The remainder of the chapter is structured as follows. The following section describes the methodology. In particular, we cover the identification of fiscal and monetary policy regimes with the Markov-switching framework. We also describe in more details the local projections technique and how we apply it to the research question. The core results can be found in Section 2.3. This section presents the macroeconomic regimes identified and their regime-switching properties as well as the dynamic responses of output growth, inflation, the primary deficit ratio and nominal yields to deficit shocks conditioned on the different regimes. Finally, Section 2.4 concludes.

2.2 Methodology

2.2.1 Markov-switching models

Regime-switching models assumes that the Data Generating Process is nonlinear and consists of a mixture of distributions from which the observed realization is drawn. In other words, observations alternate between discrete states of the world. The aim of regime-switching regressions is therefore to determine, at each point in time, which is the most likely regime from which the observation is drawn. Such models have been put forth by Hamilton (1989) and are now frequent in the literature.

For the majority of the applications, normality of the distribution is assumed in the different regimes. The optimization relies on the Expectations-Maximization (EM) algorithm. The intuition is as follows: the states of the Markov chain are unobserved and are considered as missing data. Those missing data are then replaced by their conditional expectations in the complete data likelihood function. The procedure is as follows:

1. Arbitrarily choose the starting values of the parameters to be estimated

2. Expectations-step: compute the conditional expectations of the missing data as they appear in the complete data log-likelihood function

3. Maximization-step: maximize the likelihood function with respect to the set of parameters to be estimated. Missing data are substituted by their conditional expectations

4. Assess the convergence according to a certain criterion and repeat steps 2 and 3 until convergence is reached.

The optimization produces three outputs. The first is the set of parameters that govern each regime. The second is the probability, at each point in time, of being in a particular regime. The third outcome is the transition probabilities. The latter governs the transition of one regime to and from another.

In the current application, we use a first-order Markov-switching process with transition matrix P, whose elements are $p_{ij} = \Pr[s_{t+1} = i|s_t = j]$. For two states, P takes the form:

$$P = \begin{bmatrix} p_{11} & 1-p_{22} \\ 1-p_{11} & p_{22} \end{bmatrix} \tag{2.1}$$

Elements on the diagonal of Equation (2.1) give the persistence of the regime. The higher the value, the more persistent is the regime. The average duration of the regime is given by $\frac{1}{(1-p_{ii})}$.

2.2.2 Macroeconomic policy rules

2.2.2.1 Fiscal policy rule

We derive the fiscal policy rule and the deficit consistent with debt-stabilization that will be useful to identify the fiscal policy regimes. We start with the standard debt-accumulation equation:[3]

$$B_t = B_{t-1} + i_t^b * B_{t-1} + D_t \tag{2.2}$$

where B_t is public debt, i_t is the average nominal interest rate on bonds and D_t is the primary deficit. Note that positive values of the primary deficit are associated to deficits, negative values to surpluses.

Expressing (2.2) as a ratio of current GDP yields:

$$\frac{B_t}{Y_t} = \left(1 + i_t^b\right)\frac{B_{t-1}}{Y_t} + \frac{D_t}{Y_t} = \frac{\left(1 + i_t^b\right)}{\left(1 + \zeta_t\right)}\frac{B_{t-1}}{Y_{t-1}} + \frac{D_t}{Y_t} \tag{2.3}$$

or expressed in ratios,

$$b_t = \frac{\left(1 + i_t^b\right)}{\left(1 + \zeta_t\right)} b_{t-1} + d_t \tag{2.4}$$

where ζ_t is the growth rate of output between *t-1* and *t*.

An economy naturally decreases its debt ratio if the nominal growth rate is positive and larger than the average interest rate paid on debt.

Stabilizing the debt ratio implies $b_t = b_{t-1}$ in (2.4) such that we can express the primary deficit required to stabilize the debt ratio as:

[3] This equation neglects the seignoriage term which is marginal in the US case.

$$d_t^S = \left(\frac{\zeta_t - i_t^b}{1+\zeta_t}\right) b_{t-1} \tag{2.5}$$

The above expression can be understood as the deficit that the economy can afford, given its output growth and interests paid on its debt. Debt stabilization is achieved either through reduced deficits if $i_t^b > \zeta_t$ or surpluses if $i_t^b < \zeta_t$.

The fiscal policy rule takes the following form (e.g. Favero and Monacelli, 2005 ; Dewachter and Toffano, 2012):

$$d_t = \rho^{s_t^F} d_{t-1} + \left(1 - \rho^{s_t^F}\right) \bar{d}_t + \sigma^{s^F} \epsilon_t^{s_t^F} \tag{2.6}$$

$$\bar{d}_t = c^{s_t^F} + \gamma_y^{s_t^F} (y_t - y_t^*) + \delta^{s_t^F} d_t^S \tag{2.7}$$

where d_t is the government primary deficit-to-GDP ratio and corresponds to the fiscal policy instrument, ρ is the smoothing parameter in the deficit dynamics and captures inertia in fiscal policy, $\bar{d}_t$ is the target deficit and ϵ_t is the error term. In Equations (2.6) and (2.7), c, γ, and δ are parameters, y_t stands for real GDP and y_t^* is the real potential output. The difference $(y_t - y_t^*)$ is the output gap and controls for the counter-cyclical component of fiscal policy in $\bar{d}_t$, and d_t^S is the stabilizing deficit. Is it important to note that the coefficients and the variance in Equations (2.6) and (2.7) are indexed by an indicator variable $s_t^F = \{1, 2\}$ which corresponds to the fiscal policy stance.

In line with the taxonomy of Leeper (1991), we define a *passive* (or Sustainable) fiscal policy a policy that aims at debt-stabilization as opposed to an *active* fiscal policy (Unsustainable) which targets macroeconomic effects, irrespective of the debt-to-GDP dynamics. For the case at hand, we identify the sustainable regime as the regime where the target deficit is compatible with the stabilizing deficit in the long run. In other words, fiscal policy is categorized as sustainable if all the following conditions hold: $|\rho(s_t)| < 1$ (non-explosive deficit dynamics); $c(s_t) = 0$; and $\delta_t = 1$ (e.g. Dewachter and Toffano, 2012). In the empirical estimation, we remove the cyclical component in d_t^S series implied by Equation (2.5) by applying the HP-filter setting a value of $\lambda = 1600$ for quarterly data so as to obtain a smooth long-run trend for the stabilizing deficit.[4]

2.2.2.2 Monetary policy rule

We use a standard Taylor (1993) rule to model the central bank's reaction function (e.g. Leeper, 1991 ; Davig and Leeper, 2007 ; Davig and Leeper, 2011):

$$r_t = a^{s_t^M} + \gamma_\pi^{s_t^M} (\pi_t - \pi^*) + \gamma_y^{s_t^M} (y_t - y_t^*) + \epsilon_t^{s_t^M}, \tag{2.8}$$

[4] We remove one year of observations at the beginning and at the end of the dataset in order to prevent the well-documented end-point bias of the HP-filter contaminating our results (e.g. Mise, Kim and Newbold, 2005).

where r_t is the policy instrument of the central bank, a is a constant, π_t is the realized inflation, π^* is the target inflation rate of the central bank. The difference $(y_t - y_t^*)$ is the output gap. The coefficients and the variance in Equation (2.8) are indexed by an indicator variable $s_t^F = \{1, 2\}$ which corresponds to the fiscal policy stance. In line with Leeper (1991), we define *active* (or Hawkish) monetary policy when the central banks vary the policy rate more than proportionally to inflation, thus respecting the Taylor principle with $\gamma_\pi > 1$. A *passive* monetary policy (Dovish) does not respect the Taylor principle.

2.2.2.3 Combining fiscal and monetary rules

We model the monetary policy rule separately under the assumption that the central bank does not take into consideration whatever policy the government implements.[5]

Such combinations yield, in theoretical models, starkly different outcomes for the price level and interest rates. The combination Sustainable–Hawkish yields Ricardian results in the sense that any increase in government deficit is not perceived as an increased net wealth for households (Barro, 1974). However, agents perfectly anticipate that larger deficits today will have to be repaid by higher taxes in the future. Households therefore save more today in order to be able to be able to pay the increased taxes in the future such that the net present value of their wealth has not changed. Aggregate Demand remains unchanged and so do the price level as well as interest rates. The combination Unsustainable–Hawkish yields, on the other hand, an explosive path for the price level. Indeed, a larger deficit that generates inflation would make the central bank react more than proportionally to inflation, increasing the nominal interest rate. Such an increase in the interest rates would benefit households who would see their wealth increase, thus pushing Aggregate Demand upwards. Keeping Aggregate Supply constant, the price level would increase, to which the central bank must respond more than proportionally. This would therefore have a spiral effect inconsistent with equilibrium (see Leeper and Leith, 2016). Empirically, however, this is not worrisome because agents can anticipate that there will be a switch towards an equilibrium-compatible policy in the future. The combination Sustainable–Dovish yields indeterminate results as no authority anchors the price level. The last combination, Unsustainable–Dovish corresponds to what is called the Fiscal Theory of the Price Level in the literature. If the government increases its deficit by emitting nominal debt, the nominal wealth of households increases due to larger interest payments received. If their net wealth increases, households will consume more, drive Aggregate Demand up and with it the price level. if future surpluses do not adjust strongly to current real debt, then the debt level grows indefinitely, which is inconsistent with equilibrium properties. It is thus the central bank's responsibility to ensure that real debt is stabilized. In fact, the central bank needs to allow inflation to persist such that

[5] Alternatively, we can model the dynamics of both the fiscal and monetary rule in a multivariate framework with four regimes. Doing so, we stress that the determination of macroeconomic aggregates and sovereign yields is a joint fiscal-monetary process. Identified monetary regimes are sensibly similar under both specifications such that results are qualitatively similar to this alternative.

the real burden of debt is non-explosive. As a consequence, surprise inflation depresses the current value of future interest payments. In other words, the government trades surpluses for inflation. As a by-product, interest rates increase due to higher inflation.

2.2.3 Local projections

The local projections technique was first introduced by Jordà and popularized by Auerbach and Gorodnichenko (2012, 2013, 2017) and Owyang et al. (2013) to study the nonlinear impacts of fiscal policy shocks. Technically, the Impulse Response Functions (IRFs) computed with the local projections consist of regressing the dependent variable at $t+h$, where h is the horizon considered, onto a set of explanatory variables at $t-1$ and a *shock* variable at t. Additionally, one can include control variables. The particularity of the technique is that the model is re-estimated for every horizon h considered. The IRFs at horizon h and inference can be read directly in the form of the coefficient in front of the *shock* and its standard error. Indeed, the coefficient for the *shock* is $\frac{\partial dependent_{t+h}}{\partial shock_t}$, which is the general definition of an impulse response function.

Local projections have several advantages over traditional Vector Autoregressions (VAR). First, if an econometric model is ill-specified, a direct forecast will perform better than an iterative forecast. Indeed, the prediction error is exponential in a VAR compared to linear in the local projections. Second, the local projections do not constrain the shape of the IRFs as is the case with VARs. As such, local projections offer more flexibility. This property derives from the direct vs. iterative forecast distinction. Third, the number of parameters to estimate is smaller in the local projections than in the VAR. The last advantage is specific to regime-dependent models. Local projections do not require to model the dynamics of the regimes. That is, the only necessary information is the type of regimes the economy is in at the moment of the shock. VARs, however, need to take into account the likelihood of staying or switching to and from a particular regime when computing IRFs.

Local projections have nonetheless potential shortcomings as well. The first pertains to the identification of the *shock*. In traditional VARs, identification is usually carried out by a triangular factorization of the variance-covariance matrix of the residuals. For the local projections, the *shock* is a time series that needs to have the econometric properties of shocks: centered around zero and i.i.d. Identification is thus performed outside of the regressions. One therefore needs to ensure that the economic content of the series corresponds to the shocks one wants to interpret the responses of. The second caveat is that inference is usually less precise in local projections than in VARs because the model trades off bias for variance.

In this research, we are interested in the responses of output, the price level, deficit and sovereign yields. We estimate the local projections for each dependent variable separately. Equations (2.9) to(2.12) correspond to the linear (or single-regime) version of the local projections for real output growth, inflation, the deficit and sovereign yields.

$$\begin{aligned}\frac{y_{t+h}-y_{t-1}}{y_{t-1}} &= \widehat{\beta_{t+h}^{shock}} \cdot shock_t \\ &+ \Sigma_{j=1}^{J}\left[\beta_{j,t+h}^{y} \cdot g_{t-j} + \beta_{j,t+h}^{\pi} \cdot \pi_{t-j} + \beta_{j,t+h}^{d} \cdot d_{t-j} + \beta_{j,t+h} \cdot q_{j,t+h}^{m}\right] \\ &+ \alpha_{t+h}^{y} + \beta_{t+h}^{X} X_t + deterministics_t + \eta_{t+h}\end{aligned} \tag{2.9}$$

$$\begin{aligned}\frac{z_{t+h}-z_{t-1}}{z_{t-1}} &= \widehat{\beta_{t+h}^{shock}} \cdot shock_t \\ &+ \Sigma_{j=1}^{J}\left[\beta_{j,t+h}^{y} \cdot g_{t-j} + \beta_{j,t+h}^{\pi} \cdot \pi_{t-j} + \beta_{j,t+h}^{d} \cdot d_{t-j} + \beta_{j,t+h} \cdot q_{j,t+h}^{m}\right] \\ &+ \alpha_{t+h}^{P} + \beta_{t+h}^{X} X_t + deterministics_t + \eta_{t+h}\end{aligned} \tag{2.10}$$

$$\begin{aligned}d_{t+h} &= \widehat{\beta_{t+h}^{shock}} \cdot shock_t \\ &+ \Sigma_{j=1}^{J}\left[\beta_{j,t+h}^{y} \cdot g_{t-j} + \beta_{j,t+h}^{\pi} \cdot \pi_{t-j} + \beta_{j,t+h}^{d} \cdot d_{t-j} + \beta_{j,t+h} \cdot q_{j,t+h}^{m}\right] \\ &+ \alpha_{t+h}^{d} + \beta_{t+h}^{X} X_t + deterministics_t + \eta_{t+h}\end{aligned} \tag{2.11}$$

$$\begin{aligned}q_{t+h}^{m} - q_{t-1}^{m} &= \widehat{\beta_{t+h}^{shock}} \cdot shock_t \\ &+ \Sigma_{j=1}^{J}\left[\beta_{j,t+h}^{y} \cdot g_{t-j} + \beta_{j,t+h}^{\pi} \cdot \pi_{t-j} + \beta_{j,t+h}^{d} \cdot d_{t-j} + \beta_{j,t+h} \cdot q_{j,t+h}^{m}\right] \\ &+ \alpha_{t+h}^{q} + \beta_{t+h}^{X} X_t + deterministics_t + \eta_{t+h}\end{aligned} \tag{2.12}$$

where α is a constant, z is the price level, q^m is the yield of maturity m, X_t is a vector that contains exogenous variables and $deterministics_t$ can contain temporal trends and seasonal dummies. The equations above accommodate up to J lags. All coefficients are indexed by $t{+}h$ because they vary with the horizon of the regressions.

The left-hand side of Equations (2.9) and (2.10) aim to determine the growth rate of output and prices due to a deficit shock while Equation (2.12) determines the yield difference due to a deficit shock. Equation (2.11) resembles an AR(1) process and provides information about the persistence of the deficit shocks.

In their nonlinear forms, Equations (2.9) to (2.12) read:

$$\begin{aligned}\frac{y_{t+h}-y_{t-1}}{y_{t-1}} &= \Sigma_{k=1}^{K} I_k \cdot \widehat{\beta_{t+h}^{shock}} \cdot shock_t \\ &+ \Sigma_{k=1}^{K}\Sigma_{j=1}^{J} I_k \cdot \\ &\qquad \left[\beta_{j,t+h}^{y} \cdot g_{t-j} + \beta_{j,t+h}^{\pi} \cdot \pi_{t-j} + \beta_{j,t+h}^{d} \cdot d_{t-j} + \beta_{j,t+h} \cdot q_{j,t+h}^{m}\right] \\ &+ \Sigma_{k=1}^{K} I_k \cdot \alpha_{t+h}^{y} + \beta_{t+h}^{X} X_t + deterministics_t + \eta_{t+h}\end{aligned} \tag{2.13}$$

$$\begin{aligned}\frac{z_{t+h}-z_{t-1}}{z_{t-1}} &= \Sigma_{k=1}^{K} I_k \cdot \widehat{\beta_{t+h}^{shock}} \cdot shock_t \\ &+ \Sigma_{k=1}^{K}\Sigma_{j=1}^{J} I_k \cdot \\ &\quad \left[\beta_{j,t+h}^{y} \cdot g_{t-j} + \beta_{j,t+h}^{\pi} \cdot \pi_{t-j} + \beta_{j,t+h}^{d} \cdot d_{t-j} + \beta_{j,t+h} \cdot q_{j,t+h}^{m}\right] \\ &+ \Sigma_{k=1}^{K} I_k \cdot \alpha_{t+h}^{P} + \beta_{t+h}^{X} X_t + deterministics_t + \eta_{t+h}\end{aligned} \tag{2.14}$$

$$\begin{aligned}d_{t+h} &= \Sigma_{k=1}^{K} I_k \cdot \widehat{\beta_{t+h}^{shock}} \cdot shock_t \\ &+ \Sigma_{k=1}^{K}\Sigma_{j=1}^{J} I_k \cdot \\ &\quad \left[\beta_{j,t+h}^{y} \cdot g_{t-j} + \beta_{j,t+h}^{\pi} \cdot \pi_{t-j} + \beta_{j,t+h}^{d} \cdot d_{t-j} + \beta_{j,t+h} \cdot q_{j,t+h}^{m}\right] \\ &+ \Sigma_{k=1}^{K} I_k \cdot \alpha_{t+h}^{d} + \beta_{t+h}^{X} X_t + deterministics_t + \eta_{t+h}\end{aligned} \tag{2.15}$$

$$\begin{aligned}q_{t+h}^{m} - q_{t-1}^{m} &= \widehat{\beta_{t+h}^{shock}} \cdot shock_t \\ &+ \Sigma_{k=1}^{K}\Sigma_{j=1}^{J} I_k \cdot \\ &\quad \left[\beta_{j,t+h}^{y} \cdot g_{t-j} + \beta_{j,t+h}^{\pi} \cdot \pi_{t-j} + \beta_{j,t+h}^{d} \cdot d_{t-j} + \beta_{j,t+h} \cdot q_{j,t+h}^{m}\right] \\ &+ \Sigma_{k=1}^{K} I_k \cdot \alpha_{t+h}^{q} + \beta_{t+h}^{X} X_t + deterministics_t + \eta_{t+h}\end{aligned} \tag{2.16}$$

where I_k is an indicator for the regime k. The specifications above ensure that the dependent and the independent are stationary. In terms of explanatory variables, Auerbach and Gorodnichenko (2017) also use the growth rates of output and inflation, the fiscal policy variable in level and the interest rate in level.

In the application, temporal lags are set to 1 and deterministics include temporal trends up to the second power. The chosen maturity for the yield is three years. The vector X_t contains the oil price and is treated as exogenous. We choose as indicator I_k the smoothed probabilities from the Markov-switching regressions (2.6) and (2.8). We believe that this corresponds more closely to agents assessment of the current state of the economy.[6] As the *shock* series, we use the residuals ϵ_t from Equation (2.6) in its single, two and four regimes form.[7]

[6]We could also create as many dummy variables as there are regimes that take the value 1 if the probability of being in that specific regime is above .5. While this choice would help clarify the regime-specific responses by setting the influence of all other regimes to zero, it is nevertheless a simplification. However, in our case, probabilities are generally very close to 0 and 1 such that the distinction makes little difference on the results. If anything, using dummy variables make the dynamic responses less smooth.

[7]Alternatively, one can use the residuals per regime as shock series. This choice, however, does not affect our results.

2.2.4 Data sources and transformations

The data come from publicly available databases. Primary deficit is defined as Federal Government Expenditures (line 23 of NIPA Table 3.2) minus Government Receipts (line 1 of NIPA Table 3.2) minus Interest Payments (line 32 of NIPA Table 3.2). A positive value therefore indicates a deficit. While nominal GDP is provided in line 1 of NIPA Table 1.1.5, the potential nominal GDP series is provided by the Bureau of Economic Analysis. The output gap is computed as the annual rate log difference between real GDP and potential real GDP. Output growth is the yearly growth rate of real GDP. The price level is given by the seasonally-adjusted Consumer Price Index. Inflation is computed as a yearly rate. The debt series comes from the Dallas Fed and is available at a monthly frequency. We select the privately held gross federal debt at market value as a measure of debt so as to remove holding by the Central Bank and governmental institutions. We then divide the debt stock at the end of the quarter by the current nominal GDP series. Finally, the yields come from the Board of Governors of the Federal Reserve System (H15) and cover the nominal Treasury constant maturities of the US government for the maturities of 1-, 3-, 5- and 10-years. Yields are available at a daily frequency, so we take the last value of the quarter when transforming the data to quarterly series.

2.3 Empirical results

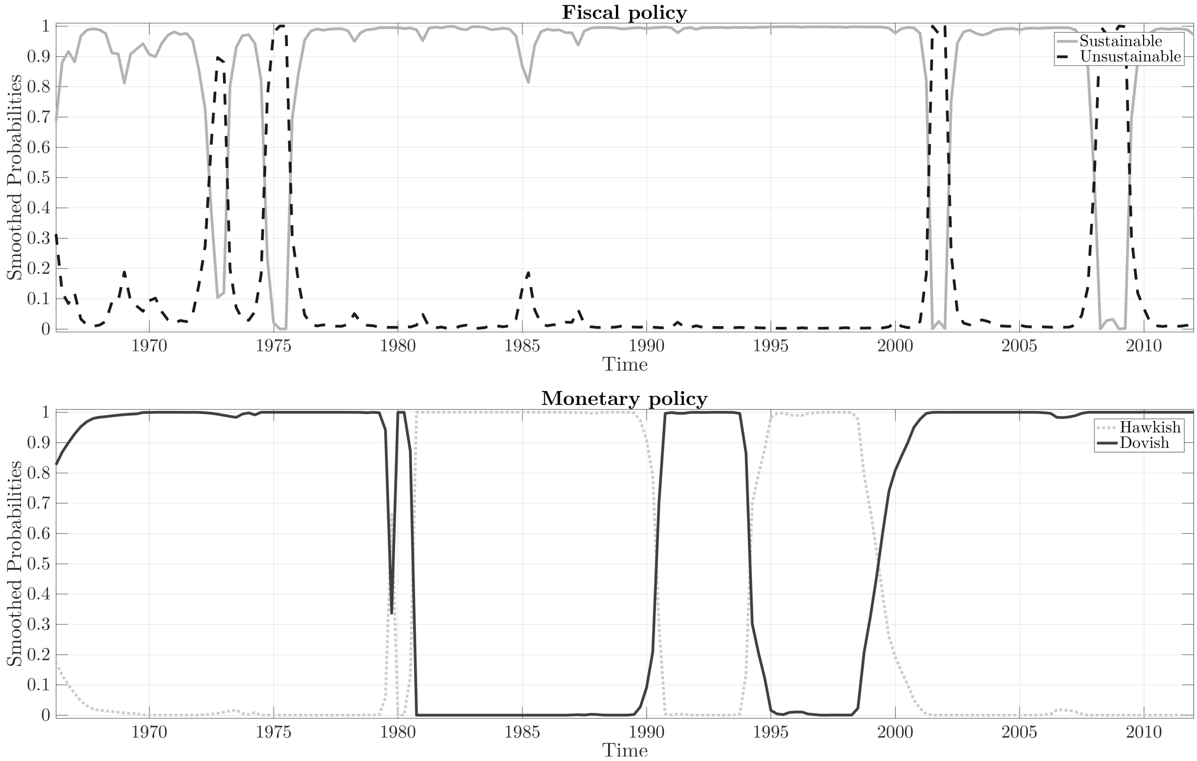
2.3.1 Fiscal and monetary policy stances

Figure 2.1 summarizes the estimation of historical episodes of fiscal and monetary policy switches in the United States between 1967Q1 and 2012Q1. Tables 2.1 and 2.3 report details on the rules where we also include estimation results for the single-regime reaction functions for benchmark analysis.

Our historical episodes of fiscal policy regimes displayed in Figure 2.1 (top panel) are in line with the literature (see for example Chung, Davig and Leeper, 2004 ; Davig and Leeper, 2007 ; Davig and Leeper, 2011 ; Favero and Monacelli (2005) ; Dewachter and Toffano, 2012). We find that fiscal policy has mostly been passive during the whole sample with a handful of short bursts of fiscal activism. We identify four passages of unsustainable fiscal policy. The first and second episodes match the years 1973 and 1975 and correspond to the fiscal policy program initiated by the Ford administration in hope of restoring economic prosperity in the US. The third event of active fiscal policy occurred between 2001 and 2003 and is linked to the successive tax cuts under the Bush presidency. Finally, the last occurrence of fiscal activism started in late 2008 following the financial crisis and lasted up until 2010.

Second, US monetary policy has been active during two major periods: the first period ranges from the beginning of the 1980s till 1992 and corresponds to the Volcker-Greenspan era. The second episode of active monetary policy took place between the

Figure 2.1 – Smoothed probabilities for fiscal and monetary regimes



Note: the figure reports the estimated smoothed probabilities from the fiscal policy rule (2.6) in the top panel and from the monetary policy rule (2.8) in the bottom panel.

mid-1990s and 2000. Goodfriend (2002) observed that the Fed needed to operate without challenging the credibility it had built with its efficient preemptive fight against inflation in 1994-1995 when it was confronted with an economic boom and potential inflationary pressures. Since 2000 onward, the Fed has accommodated inflation, reacting less than proportionally to the rise in prices. Following the recession of 2001, the Fed reduced its policy rate from 6.5 percent at the beginning of 1991 to reach 1.75 percent in December 2001. The inflation rate did not follow the same path, resulting in negative real rates. Hofmann and Bogdanova (2012) reach the same conclusion, claiming that US monetary policy has been loose since 2000.

Panel (a) of Table 2.2 reports that fiscal policy evolves in a counter-cyclical way as was expected. It is also clear that the stabilizing deficit does significantly influence the current deficit-to-GDP ratio. The last feature could in fact conceal evidence of a succession of *active* and *passive* fiscal stances where the dominant regime is the sustainable regime. We therefore allow the fiscal policy rule to swing across regimes using our Markov-switching setup. It appears that the Markov-switching regression offers a better fit as indicate the Log-Likelihood values. Notice that it is not possible to test the null hypothesis of a single regime against the alternative of several regimes with Likelihood ratios because there are parameters that are only identified under the alternative (Cho and White, 2007). It is, for instance, the case of the transition probabilities.

Table 2.1 – Estimates of fiscal policy rule

	Estimates of fiscal policy rule (1967Q1:2012Q1)						
	c	ρ	γ	δ	p_{SS}	p_{UU}	*Log Lik.*
Panel (a)	Single-regime model						
	-0.003***	0.862***	-0.135***	1.032***			674.60
	(0.0004)	(0.02)	(0.016)	(0.099)			
Panel (b)	Markov-switching model: $\lvert\rho^{s_t^F=Sust}\rvert < 1,\ c^{s_t^F=Sust.} = 0,\ \delta^{s_t^F=Sust.} = 1,\ \delta^{s_t^F=Unsust.} < 0$						
Sustainable	*0*	0.945***	-0.036***	*1*	0.97		704.58
		(0.00)	(0.00)				
Unsustainable	-0.001***	0.657***	-0.301***	-0.006		0.72	
	(0.00)	(0.00)	(0.00)	(0.00)			

Note: The table reports the estimates of the feedback policy rule in Equation (2.6). We report the estimates for each regression separately together with their standard errors in parenthesis. Superscripts ***, **, * indicate significance levels of 1, 5 and 10%, respectively. Numbers in italic are fixed parameters.

Passive fiscal policy experiences a large persistence (expected duration of 30 quarters), small innovations, and a primary deficit dynamics consistent with debt stabilization as per restrictions. The active fiscal regime is typically characterized by smaller inertia (its expected duration is estimated at around 4 quarters) and larger variance innovations. Most importantly, an active fiscal policy is inconsistent with debt stabilization (the coefficient δ is not significant) and hence fiscal policy does not take the stabilizing deficit into account in the unsustainable regime.

Table (2.2) presents the results of the single-regime and Markov-switching estimation of Equation (2.8). We can observe that monetary policy would be categorized as passive throughout the sample in the single-regime case. However, this hides periods when the Taylor principle holds and periods when it does not. The Hawkish regime (strong response to inflation) is characterized by a higher Federal Funds rate on average, and a countercyclical response of the policy rate. The Dovish regime (feeble response to inflation) exhibits a positive co-movement with economic activity and lower interest rates.

Table 2.2 – Estimates of monetary policy rule

	Estimates of monetary policy rule (1967Q1:2012Q1)					
	a	γ_π	γ_y	$p_{NT,NT}$	$p_{T,T}$	*Log Lik.*
Panel (a)	Single-regime model					
	-0.024***	0.89***	0.137*			386.47
	(0.002)	(0.042)	(0.078)			
Panel (b)	Markov-switching model: $\gamma_\pi^{s_t^M=Taylor} > 1$; $\gamma_\pi^{s_t^M=Non-Taylor} < 1$					
Dovish	0.017**	0.756***	0.443***	0.97		476.76
	(0.00)	(0.00)	(0.00)			
Hawkish	0.04***	1.071***	-0.434***		0.95	
	(0.00)	(0.00)	(0.00)			

Note: The table reports the estimates of the Taylor rule in Equation (2.8). We report the estimates for each regression separately together with their standard errors in parenthesis. Superscripts ***, **, * indicate significance levels of 1, 5 and 10%, respectively. Numbers in italic are fixed parameters.

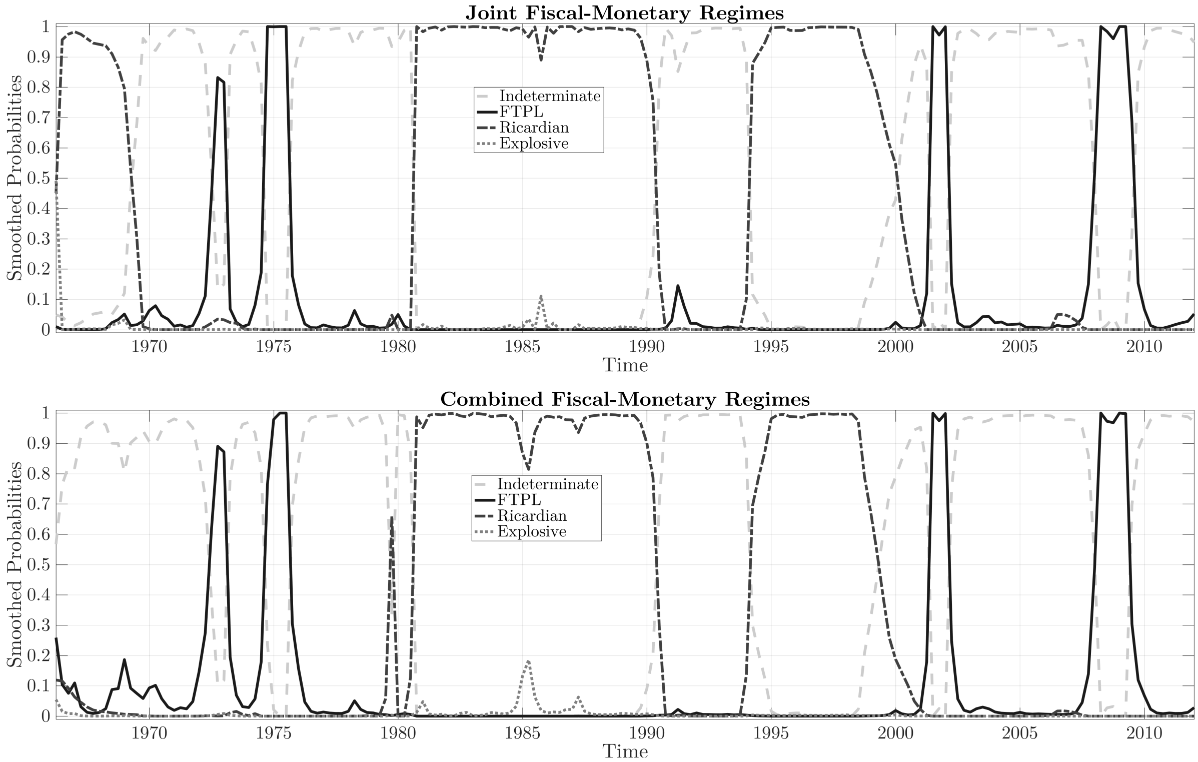
2.3.2 Macroeconomic policy mix

We provide the estimation results from the policy mix in Figure 2.2. The top panel reports the joint estimation of Equations (2.6) and (2.8). First, we can observe that the Explosive regime (Unsustainable-Hawkish) never occurs during our sample. Second, the joint regimes usually inherit the properties of the individual regimes, with the notable exception of the period at the end of the sixties. Indeed, monetary policy is categorized as active in the joint estimation whereas it was passive when estimated individually. In the bottom panel, we compute the combined smoothed probabilities. In other words, we report the Hadamard product of the smoothed probabilities of the fiscal and monetary rules taken separately. For the rest of the analysis, we use the combined version of the rules.[8]

Panel (a) of Table 2.3 provides the estimates of (2.6) and (2.8) jointly estimated in the Markov-switching framework. In the estimation procedure, we group the regimes two by two such that they share the same characteristics from the fiscal rule and the monetary rule, respectively. In other words, coefficients for the fiscal rule are the same between regimes 1 and 2, and between regimes 3 and 4 whereas coefficients for the monetary rule

[8]Impulse response functions from the joint estimation can be found in Appendix A.2.1. Results are qualitatively similar.

Figure 2.2 – Combining fiscal and monetary policy rules



Note: the figure reports the estimated smoothed probabilities from the joint estimation of fiscal policy rule (2.6) and monetary policy rule (2.8) in the top panel and the combined probabilities of (2.6) and (2.8) in the bottom panel.

are the same between regimes 1 and 3, and between regimes 2 and 4. Consequently, the transition matrix P has 16 elements.[9] Notice that the Taylor principle has been enforced in the Ricardian (Sustainable-Hawkish) and Explosive regimes but that this constraint is not binding. The properties of the fiscal rule in the 4-regimes framework are generally in accordance with the coefficients presented in Table 2.1. For the monetary policy rule, the regime-switching regressions correctly disentangle periods when the Taylor principle holds from those when it does not hold. In the former, the central bank behaves counter-cyclically, raising its policy rate when output growth is low, while it behaves pro-cyclically in the latter.

Panel (b) provides useful information about the transition probabilities and the fit of the model. First, the two longer-lasting regimes are the Indeterminate and the Ricardian regimes (11 quarters), with the FTPL regime following at 4 quarters. The Explosive regime is, of course, not persistent. The diagonal elements give the probability of staying in the considered regime. Since the Explosive regime is non-persistent and does not occur in our sample, we will focus our comments on the first three regimes. In particular, it

[9]We chose this specification rather than letting the coefficients in the four regimes be different because the number of parameters to estimate would become very large, jeopardizing the convergence of the Maximum Likelihood estimation. As a comparison, we estimate 26 parameters against 48 if coefficients were free across all four regimes.

Table 2.3 – Estimates of fiscal and monetary policy rules

	Estimates of fiscal and monetary policy rules (1967Q1:2012Q1)				
Panel (a)	Markov-switching model: $\lvert\rho\rvert < 1$, $c^{Indeterminate.,Ricardian} = 0$, $\delta^{Indeterminate,Ricardian} = 1$, $\gamma_\pi^{Ricardian,Explosive} > 1$, $\gamma_\pi^{Indeterminate,FTPL} < 1$				
Fiscal rule	c	ρ	δ	γ	
Indeterminate / Ricardian	*0*	0.936***	*1*	–0.042***	
		(0.00)		(0.00)	
FTPL / Explosive	-0.003***	0.64***	-0.0001	-0.363***	
	(0.000)	(0.00)	(0.00)	(0.00)	
Monetary rule	a	γ_π	γ_y		
Indeterminate / FTPL	0.017***	0.824***	0.538**		
	(0.000)	(0.00)	(0.00)		
Ricardian / Explosive	0.03***	1.191***	-0.538***		
	(0.000)	(0.00)	(0.00)		
Panel (b)	Transition probabilities				
	Indeterminate	FTPL	Ricardian	Explosive	*Log Lik.*
Indeterminate	0.91	0.27	0.06	0.00	1194.48
FTPL	0.06	0.73	0.00	0.00	
Ricardian	0.04	0.00	0.91	1.00	
Explosive	0.00	0.00	0.03	0.00	

Note: the table reports the results from the joint regime-switching estimation of the fiscal and monetary policy rules (2.6) and (2.8). The standard errors can be found in parenthesis below the value of the coefficient. The superscripts *, **, *** indicate significance at the 10%, 5% and 1% level, respectively.

is almost as likely to switch to the FTPL or Ricardian regime from the Indeterminate regime (6% vs. 4% chance of switching, respectively). However, starting in the Ricardian regime, we have a 6% chance of switching to the Indeterminate regime. Interestingly, we have a 27% chance of switching from the FTPL regime to the Indeterminate regime. We can conclude from the analysis of both the bottom graph of Figure 2.1 and Panel (b) of Table 2.3 that fiscal and monetary policies do not switch synchronously. This would have been the case had larger values been found at the crossroad between the FTPL and Ricardian regimes. Second, the log-likelihood value from the regime-switching regressions is higher than the sum of the log-likelihoods of the two single-regime rules, indicating that regime-switching models are better suited for the analysis. This is confirmed by comparing Information Criteria in Table 2.4. The advantage of Information Criteria is that they penalize the number of parameters estimated.

Table 2.4 – Information criteria for fiscal and monetary rules

Rule	Case	AIC	BIC	HQIC
Fiscal rule	Single-regime	-7.278	-7.191	-7.243
	Regime-Switching	-7.500	-7.233	-7.389
Monetary rule	Single-regime	-4.339	-4.280	-4.315
	Regime-Switching	-5.041	-4.813	-4.949
Fiscal and	Single-regime	-12.070	-11.910	-12.000
Monetary rules	Regime-Switching	-12.400	-11.453	-12.014

Note: the table reports Information Criteria for the different rules under the single regime or regime-switching specification. We report the Akaike (AIC), Bayes-Schwarz (BIC) and Hannan-Quinn (HQIC) Information Criteria. Information Criteria have been re-scaled by the number of observations. A lower value of the Information Criterion indicates a better fit, taking into consideration the number of parameters estimated.

2.3.3 Dynamic responses to government deficit shocks

In what follows, we present the responses of output growth, inflation, deficit and nominal yields to a deficit shock. The shock has been re-scaled such that, on impact, the deficit-to-GDP ratio rises by one percentage point. This re-scaling ensures that we can compare the responses of the variables of interest across the different regimes.[10] We also present the 90% Newey-West confidence interval obtained from the local projections. Jordà (2005) suggests that the Newey-West lag correction be increasing with the horizon of the impulse response. We therefore set the Newey-West lag to h. The horizontal axis corresponds to the number of quarters after the shock while the vertical axis gives the response of the variable considered in percentage points.

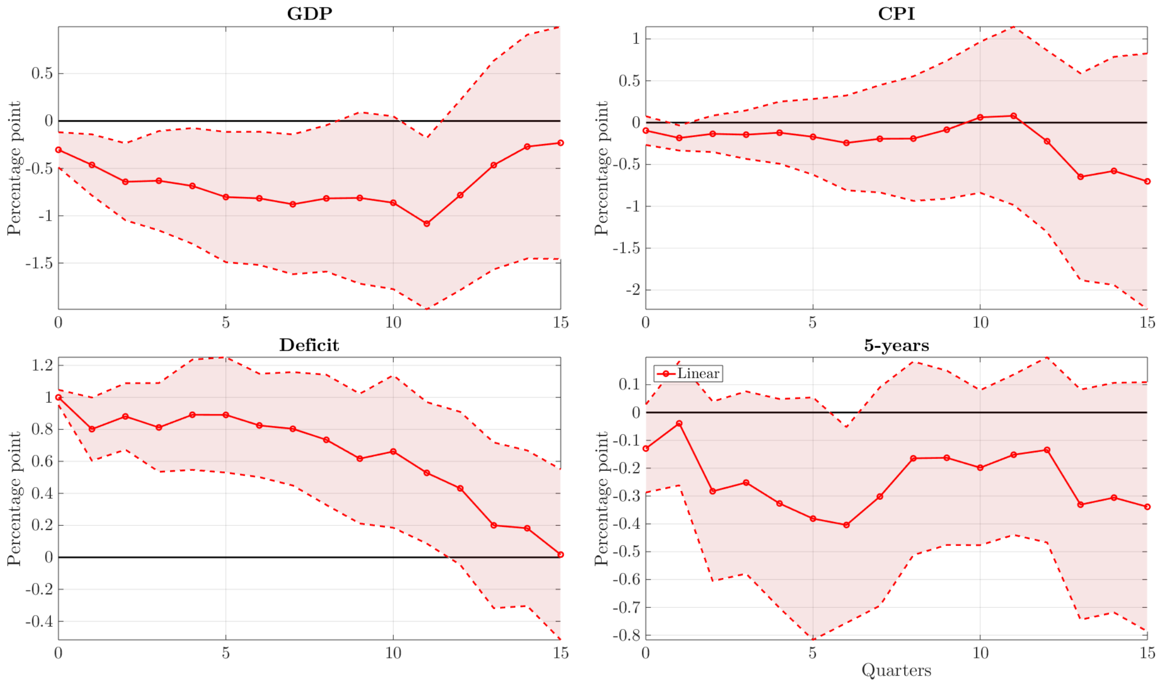
2.3.3.1 Benchmark analysis - single regime

We report the IRFs to a deficit shock in the single regime case in Figure 2.3. Results indicate that deficit shocks in the single regime are persistent. GDP and CPI exhibit a counter-intuitive negative response for a few quarters. Indeed, conventional theory predicts that larger deficits lead to higher inflation. However, negative inflation responses have also been found in the literature (see, for instance, Auerbach and Gorodnichenko, 2017). A deficit shock does not significantly reduce the 5-years nominal yield. A similar exercise for other maturities (1-year, 5-years, 10-years) presented in Figure 2.4 indicates that the yields responses are generally uniform across maturities, though the negative tendency in the responses is stronger for long maturities.[11]

[10] This re-scaling has little influence on the conclusions drawn from the exercise because the coefficient $\widehat{\beta_{t+0}^{shock}}$ ranges from 0.94 to 1.02 without re-scaling for the different regimes considered.

[11] Paul Krugman also notices this negative relationship and provides interesting insights in a few of his blog posts. See, for instance, https://krugman.blogs.nytimes.com/2009/08/14/deficits-and-interest-rates/ and https://krugman.blogs.nytimes.com/2013/07/25/deficits-and-interest-rates-the-history/.

Figure 2.3 – Impulse responses of dependent variables to deficit shocks – single regime

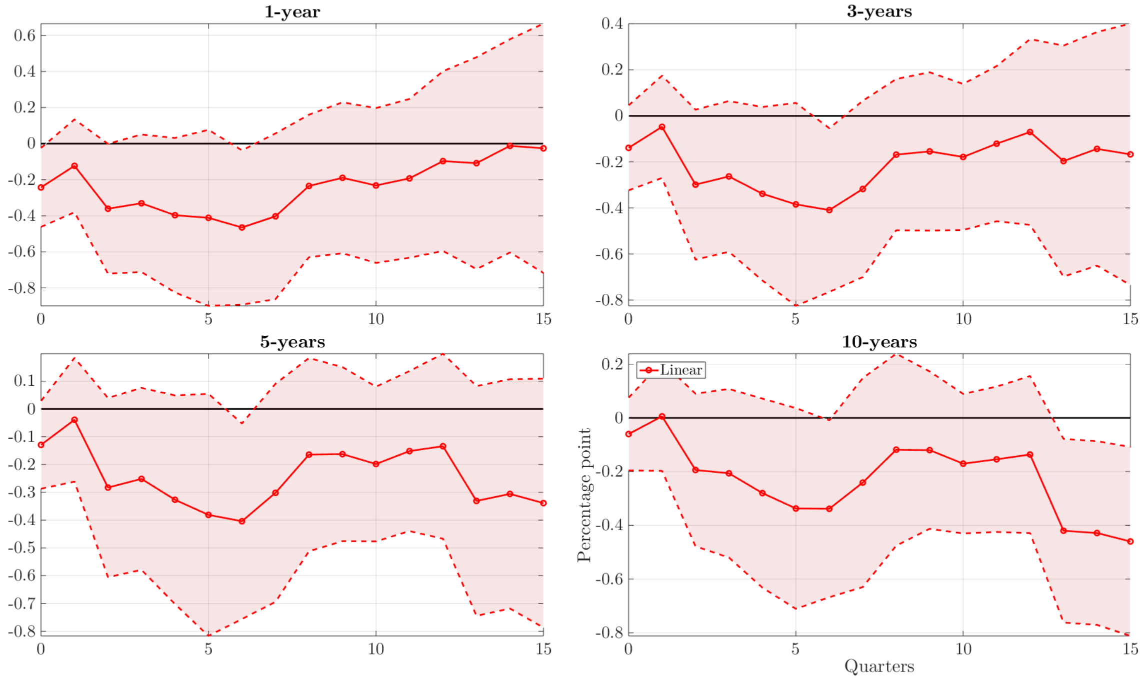


Note: the figure presents the responses of output growth, inflation, deficit and the 5-years nominal yield to a 1 percentage point increase in the deficit-to-GDP ratio. The solid line represents the point estimate and is derived from the local projections (2.9) to (2.12). The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h.

2.3.3.2 Fiscal policy regimes

We now consider the responses of our four dependent variables to a one percentage point deficit shock in Figure 2.5 depending on the Sustainable/Unsustainable regimes. To facilitate reading, only one set of confidence bands are plotted at a time. On the top row, the shaded area corresponds to the confidence bands of the unsustainable fiscal policy regime, while the bottom row plots the confidence interval from the sustainable regime. Several conclusions can be drawn from Figure 2.5. First, the responses of output growth, inflation and interest rates are of opposite signs in the two regimes. While a deficit shock in the unsustainable regime increases output and inflation, a shock in the sustainable regime depresses output and slightly reduces the prices. As a consequence, a deficit shock raises the price level by about 1 percentage point after 4 years. Second, turning to the deficit we can see that shocks in the unsustainable regime are much less persistent than in the sustainable regime. Finally, the 5-years yield increases by 30 basis points at a 5 quarters horizon whereas it decreases by around 85 basis point in the sustainable regime. The decrease is significant from impact to the 6th quarter. There is therefore more than a one percentage point premium between the two regimes. These findings show that, on average, the government will have to pay a higher debt service cost to finance additional deficit if its debt is not sustainable.

Figure 2.4 – Impulse responses of nominal yields to deficit shocks – single regime



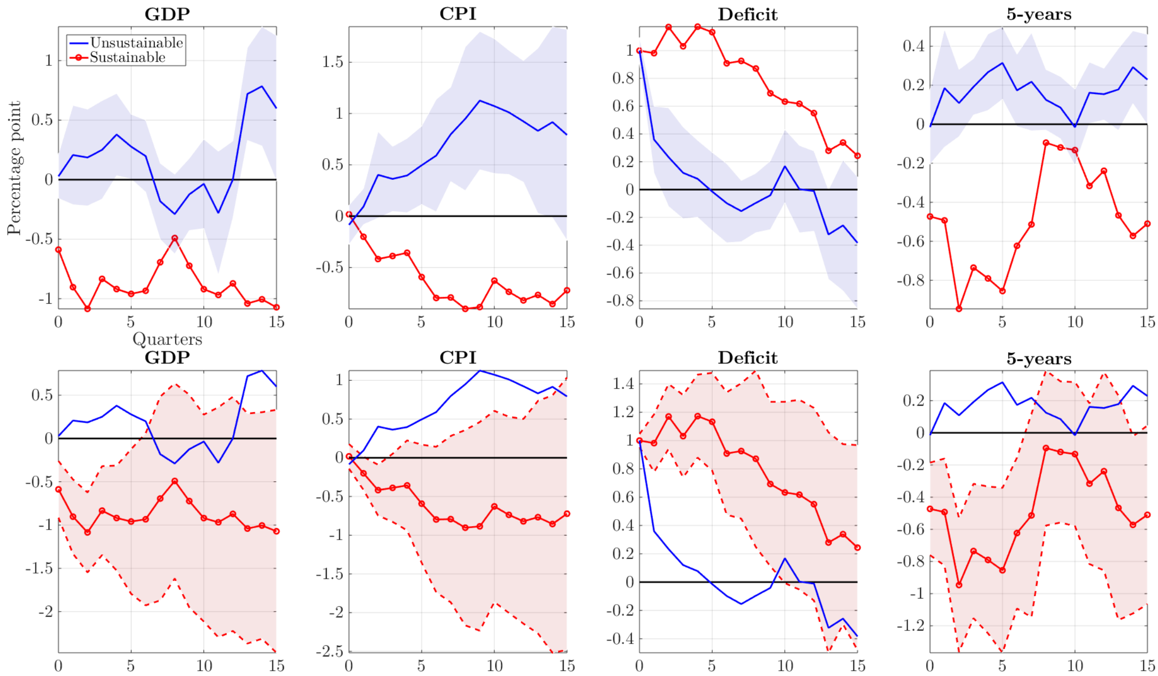
Note: the figure presents the responses of nominal yields of maturities 1-, 3-, 5-, 10-years to a 1 percentage point increase in the deficit-to-GDP ratio. The solid line represents the point estimate and is derived from the local projections (2.12) with the corresponding maturity. The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h.

The responses of the four maturities considered inherit the properties described above. Nevertheless, it is interesting to assess the influence of deficit shocks on the maturity spectrum. In the unsustainable regime, short-maturity yields respond much more, both economically and statistically, that long-maturity yields. At the peak response at quarter 5 of about 40 basis points for the 1-year yield, the 10-years yield only rises by 20 basis point, and this increase is barely significant. In the sustainable regime, all the responses are negative and significant up until the 7th quarter after the shock. Though the response of yields turns significant after the 12th quarter, we suggest that these results be taken with a grain of salt. Ramey (2012) points that local projections may become unreliable for large horizons. In fact, due to the nature of the local projections, the dataset is iteratively reduced as the horizon increases.

2.3.3.3 Combining fiscal and monetary rules

Figure 2.7 presents the impulse response functions in the four-regimes case. Under this specification, the responses of output and the price level highly depend on the regime considered. A deficit shock in the Fiscal Theory of the Price Level (FTPL – Unsustainable-Dovish) or Indeterminate (Sustainable-Dovish) regime significantly raises output while the opposite holds for the Ricardian regime. Notice that the response of output in the FTPL

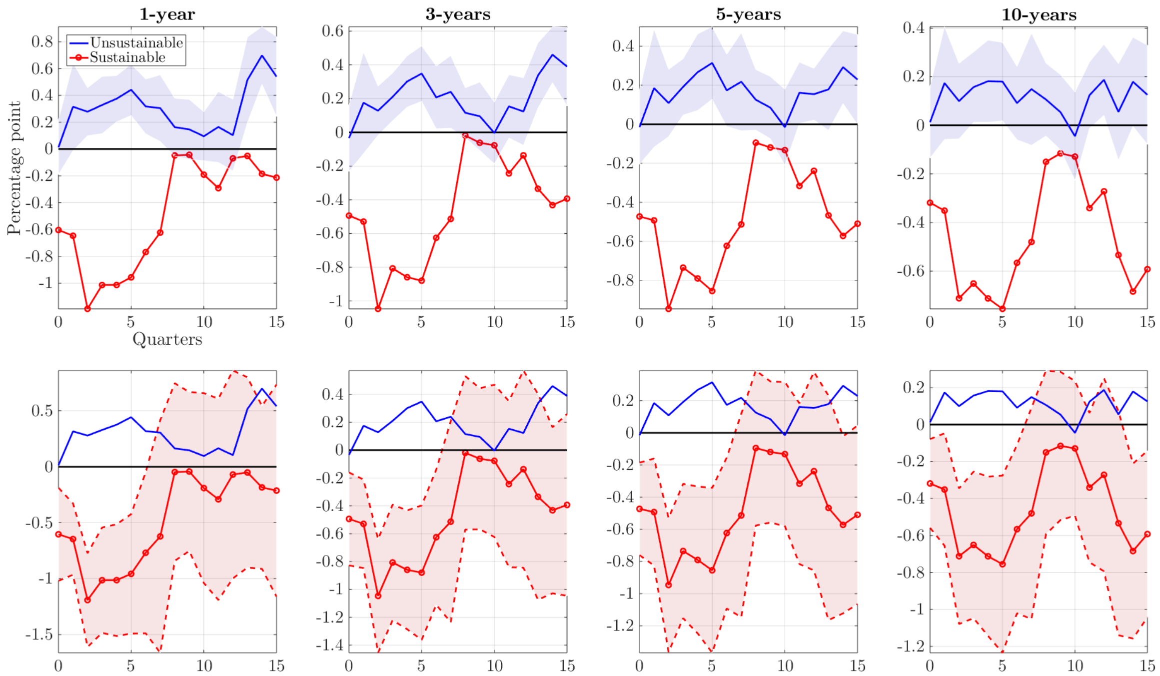
Figure 2.5 – Impulse responses of dependent variables to deficit shocks – sustainable vs. unsustainable fiscal policy regimes



Note: the figure presents the responses of output growth, inflation, deficit and the 5-years nominal yield to a 1 percentage point increase in the deficit-to-GDP ratio. The solid lines represent the point estimate and are derived from the multi-regimes local projections (2.13) to (2.16). The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h. The first row reports the confidence bands from the unsustainable regime while the second row reports the confidence bands from the sustainable regime.

is positive while it is negative in the other regimes. We posit that the stance towards inflation of the central bank plays an important role. As the central bank expects the price level to rise following a positive deficit shock, it raises its policy rate to dampen the inflationary effects of deficits. Since this rise in the policy rate is more than proportional to inflation developments, the real interest rate increases. As a consequence, households save more and enterprises produce less. Output therefore exhibits a negative response. It should be noted that deficits significantly create inflation only in the FTPL regime. Lastly, the responses for yields remain different across regimes. Yields in the FTPL regime rise by about 30 basis points until the fifth quarter while the yields responses in the Indeterminate or Ricardian regime are negative. Notice that the stance of monetary policy plays a role in addition to the fiscal policy. Indeed, we can clearly see that the positive sign of the response of yields is due to the sustainability of fiscal policy because the Ricardian and Indeterminate regimes share the same features for fiscal policy. However, a central bank that responds more strongly to inflation decreases the yields even further. Auerbach and Gorodnichenko (2017) posit that negative response for yields are still plausible because “markets may view fiscal stimulus as a way not only to accelerate the economy but also to reduce risks associated with a prolonged slump”. They also note the importance of monetary policy that can accommodate or offset fiscal policy. The authors also advance

Figure 2.6 – Impulse responses of nominal yields to deficit shocks – sustainable vs. unsustainable fiscal policy regimes



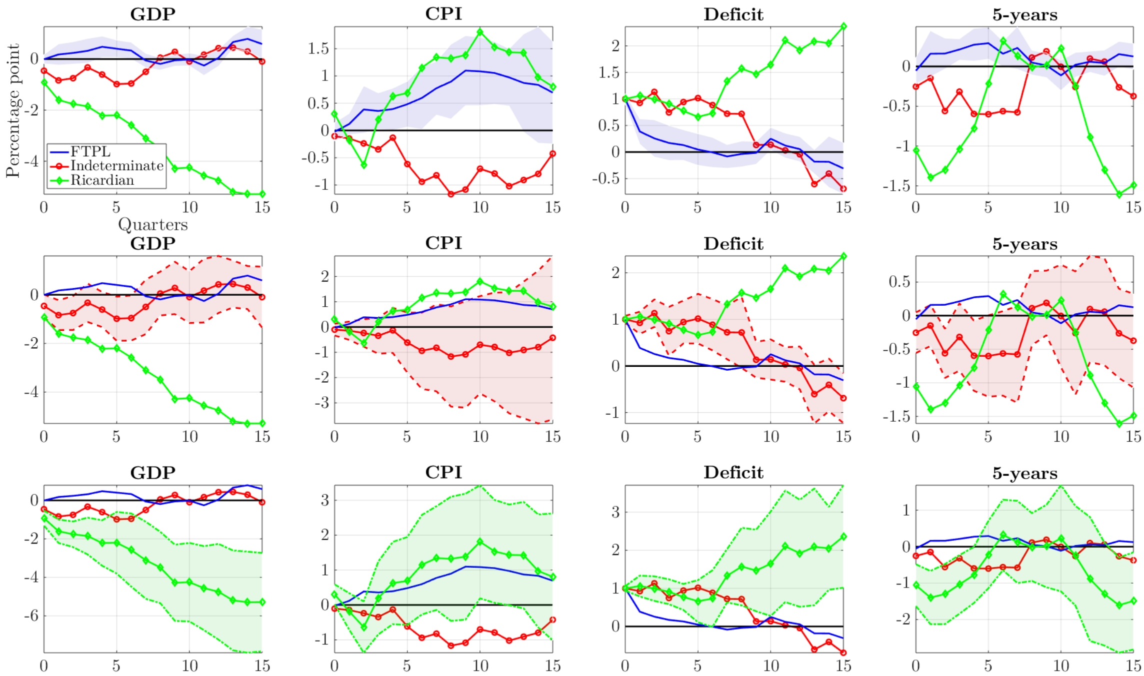
Note: the figure presents the responses of nominal yields of maturities 1-, 3-, 5-, 10-years to a 1 percentage point increase in the deficit-to-GDP ratio. The solid line represents the point estimate and are derived from the multi-regimes local projections (2.12) with the corresponding maturity. The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h. The first row reports the confidence bands from the unsustainable regime while the second row reports the confidence bands from the sustainable regime.

that fiscal stimulus in a slump may still stimulate the economy such that a larger crisis is averted.

We can see from Figure 2.8 that the effects of a deficit shock on the yields are not homogeneous across maturities or regimes. In particular, it seems that short maturities are more responsive than long maturities, both in terms of values and statistical significance. We can remark that the regime does have an influence on the response of the shape of the yield curve. Indeed, deficit shocks in the Ricardian regime make all yields vary by roughly the same amount, indicating a Level effect (in the sense of Litterman and Scheinkman, 1991). Deficit shocks in the Indeterminate and FTPL regimes mostly affect the Slope of the curve because short maturities respond much more strongly than long maturities. Deficit shocks in the FTPL regime flattens the yield curve while deficit shocks in the Indeterminate regime steepens the yield curve.

These results indicate that a more thorough analysis of the effects of fiscal policy shocks on the shape of the yield curve is needed to confirm whether the shape of the yield curve is affected by the type of regimes we consider. In particular, the government may use the average maturity of marketable debt outstanding as another policy instrument to weather the negative outcome of larger deficit. In periods of distress, the government is better off emitting short-term debt so as to avoid locking-in a higher interest rate for a long

Figure 2.7 – Impulse responses of dependent variables to deficit shocks – fiscal-monetary policy mix



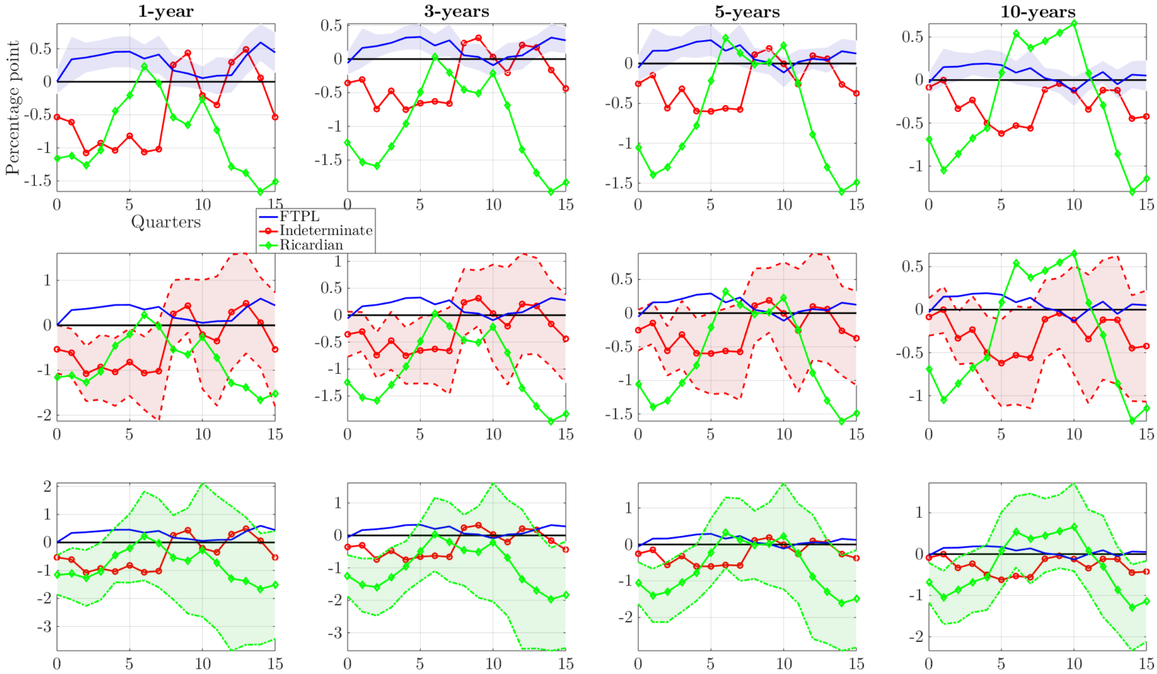
Note: the figure presents the responses of output growth, inflation, deficit and the 5-years nominal yield to a 1 percentage point increase in the deficit-to-GDP ratio. The solid lines represent the point estimate and are derived from the multi-regimes local projections (2.13) to (2.16). The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h. The first row reports the confidence bands from the FTPL regime, the second row the confidence bands from the Indeterminate regime and the third row from the Ricardian regime.

period of time. Figure 2.9 shows that the average maturity has changed substantially across time (see, for instance, Greenwood and Vayanos, 2008).[12] The dip in 2008-9 is particularly interesting in this respect. It is possible that the responses presented above reflect not only the effect of deficits but also the ripples of debt management policies.

The framework presented above could be further developed to include a more structural approach. For instance, the current model presented here cannot disentangle the contents of the yields responses between expectations regarding output growth or inflation and default risk due to larger debt. However, this is not the central question in this chapter. We provide a tool to assess the likely path of government debt financing costs after a fiscal policy shock depending on the regime in which the shock takes place. In addition to this, the model could take the shape of the yield curve into account. An efficient and deep bond market ensures that arbitrage opportunities are exhausted such that bond prices at each moment in time reflect both the time series dynamics and cross-sectional relations. We could, for instance, jointly estimate the different maturities under the restriction that there is a Level, Slope and Curvature factor (Litterman and Scheinkman, 1991). This

[12]The document is accessible at: https://www.treasury.gov/resource-center/data-chart-center/quarterly-refunding/Documents/Q12017CombinedChargesforArchives.pdf

Figure 2.8 – Impulse responses of nominal yields to deficit shocks – fiscal-monetary policy mix



Note: the figure presents the responses of nominal yields of maturities 1-, 3-, 5-, 10-years to a 1 percentage point increase in the deficit-to-GDP ratio. The solid lines represent the point estimate and are derived from the multi-regimes local projections (2.16). The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h. The first row reports the confidence bands from the FTPL regime, the second row the confidence bands from the Indeterminate regime and the third row from the Ricardian regime.

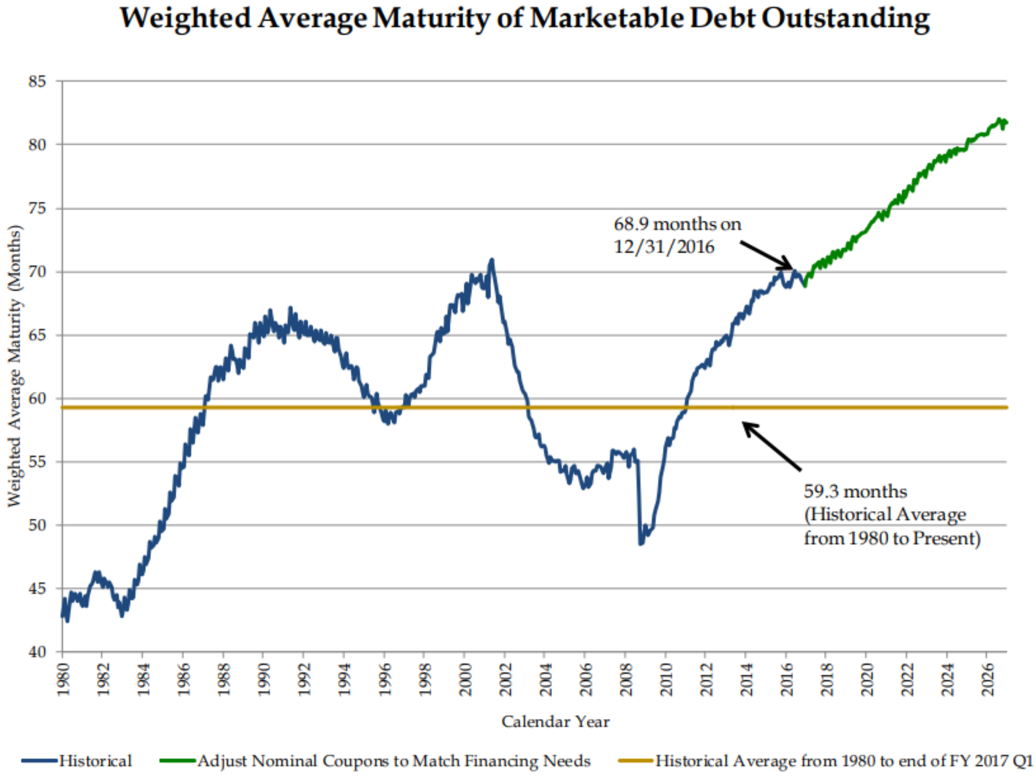
would, however, require Maximum Likelihood estimation rather than OLS.

Another potential extension would be to use the bond yields to improve the identification of the regimes. The yields dynamics would be jointly modeled together with the fiscal and the monetary policy rules. We expect that high levels and volatility of yields would match episodes of fiscal activism. This would in turn precise the environment in which the government operates.

2.4 Conclusion

We have presented an empirical framework that aims to answer the question whether larger deficits always cause higher inflation and sovereign yields. We have applied regime-dependent local projections to US data and have shown that larger deficits do not always lead to higher debt servicing costs. In fact, the sign of the relationship depends on the level of sustainability of fiscal policy. When debt is unsustainable, larger deficits do cause higher inflation, output and nominal yields. Interestingly, larger deficits are associated with smaller output, inflation and yields in the sustainable regime. Additionally, larger deficits in the unsustainable fiscal policy regime reduce the slope of the yield curve because

Figure 2.9 – Weighted average maturity of marketable debt outstanding



Source: US Treasury, Office of Debt Management in the Fiscal Year 2017 Q1 Report.

the 1-year rate rises by 30 basis points at the 5 quarters horizon when the 10-years only rises by 20 basis points. The difference between the response of the yields in the unsustainable regime and the response of the yields in the sustainable regime can be as large as 110 basis points. Taking into account the monetary policy stance brings another light on the issue. Monetary policy can either fight or accommodate inflation. When monetary policy accommodates inflation, deficit shocks have a tendency to raise output. The response of the yield curve exhibits regime-dependence. While yields in the Ricardian regime (Sustainable-Hawkish) respond negatively by about the same value, indicating a Level effect, the yield curve in the FTPL (Unsustainable-Dovish) and Indeterminate (Sustainable-Dovish) regimes flatten and steepen the yield curve, respectively. These new findings thus contribute to the debate about the macroeconomic impacts of government deficit shocks. However, a definitive answer on the effects of fiscal policy on the yield curve requires a more structural approach.

Chapter 3

Nonlinear Impacts of Fiscal Policy on the Yield Curve

3.1 Introduction

The theoretical literature has proposed several channels through which fiscal policy can affect the economy, but different theories proposed have reached starkly different conclusions. On the one hand, the New Keynesian theory predicts that an expansionary fiscal policy creates a shift in Aggregate Demand and a change in the composition of Aggregate Demand, either through a direct increase in goods purchases if the government raises its consumption without changing taxes, or via an improvement in households' disposable income via taxes which will increase private consumption and therefore Aggregate Demand. If the government finances its deficit by issuing debt it competes with private borrowers for loanable funds. The demand for loanable funds increases and, if the supply for loanable funds remains the same, so does the interest rate. This rise in the interest rate crowds out part of private investment. In the short run, enterprises increase the use of the factors of production to face the increased demand. However, prices and wages are sticky, such that national income rises. Since there is less private investment in the economy, the long run stock of capital decreases. As a consequence, the marginal product of capital rises, and with it the interest rate. As the interest rate is higher than before, the local currency appreciates.

On the other hand, forward-looking Ricardian households understand that an increase in the stock of debt today, via a reduction of taxes, for example, induces higher interest payments in the future that would be financed through higher taxes. These households may thus decide to save in order to support higher future taxes. Thus, the increase in private savings will exactly match the decrease in public savings such that the equilibrium interest rate on the market for loanable funds will remain unchanged. These arguments, however, rest on the assumption that government consumption does not vary. If a tax reduction today is met by a decrease in government spending tomorrow, it can still generate wealth effects and would stimulate consumption and reduce national saving.[1]

In line with these ambiguous predictions empirical studies have not been able to reach a consensus regarding the effects of fiscal policy on interest rates. Gale and Orzsag (2003) and Barth et al. (1991) provide extensive reviews of empirical results. The latter surveyed 42 empirical studies and report that 17 studies found a "predominantly significant, positive" effect of deficits on interest rates, 6 found mixed results and 19 found "predominantly insignificant or negative" results (Barth et al., 1991). More recent studies suggest a significant link between deficits and interest rates (e.g. Canzoneri, Cumby and Diba, 2002 ; Dai and Philippon, 2005 ; and Laubach, 2009). For instance, Dai and Philippon (2005) show that a one percentage point increase in the deficit ratio increases the 10-year rate by 25 basis points after three years. Laubach (2009) produces similar estimates for the US using projected budget deficits.

Another strand of the literature has assumed a nonlinear relationship between fiscal policy and bond yields. For instance, Davig and Leeper (2007) and Davig and Leeper (2011) identify *Active* and *Passive* fiscal and monetary policies, in the words of Leeper (1991), and show that the response of the short-rate in a calibrated model differs greatly in sign and magnitude across the two regimes. Nonlinearities are particularly relevant in this context because it conditions the behavior of households, the government and the central bank. In particular, whether the monetary or the fiscal authority dominates the other has different implications for the price level dynamics. In the case of investors, whether fiscal policy is compatible with debt stabilization or not is crucial for their decisions.

Dewachter and Toffano (2012) investigate the link between fiscal deficits and bond yields across fiscal policy regimes in the USA. Using regression techniques, they show that unsustainable deficits are associated with higher bond yields whereas no statistical relationship is found between government deficit and bond yields in periods when debt is sustainable. In a related study, Houssa and Hubert (2015) use local projections to analyze the dynamic impact of government deficit shocks on bond yields in the United States. They find that a primary deficit shock in the United States significantly increases bond yields in the unsustainable fiscal regime as opposed to a significant decrease in bond yields in the sustainable fiscal regime but that this effect lasts around 8 quarters.

One important insight from the literature discussed above is that nonlinearity is important in uncovering the link between fiscal policy and interest rates. However, these studies are not able to bind different maturities in a consistent manner and this is the reason why models of the term structure are needed. Term structure models are capable of decomposing long rates into expected future short rates and risk premia. Bond risk premia represent the compensation demanded by investors for exposures associated

[1] In a related literature, Woodford (1996) pioneered the Fiscal Theory of the Price Level. This theory predicts that an increase in debt that is not is offset but future changes in taxes or spending generates a wealth effect for households and increase Aggregate Demand. If Aggregate Supply does not change, both goods market and government's budget clearing conditions require that the price level increases enough to match future real debt with its initial value.

to fundamental risks. As such, understanding movements in bond risk premia provides valuable information on market participants' valuation of risks.

The seminal paper of Ang and Piazzesi (2003) extends a latent yield curve term structure model with macro factors such that the relevant state vector for bond pricing consists of both latent and observable factors. In their setup, they impose independence between latent and macro factors. As a result, macro variables determine bond yields, but not the reverse. Ang, Dong and Piazzesi (2005) and Diebold and Li (2006) allow for bidirectional macro-finance linkages and show that macro factors are much more important when bidirectionality is enforced. This framework has been successfully applied and extended in subsequent studies (e.g. Dewachter and Lyrio, 2006).

Recently Joslin, Priebsch and Singleton (2014) have challenged the assumption that macroeconomic factors can be recovered from a collection of bond yields. They assert that this restriction can lead to a misspecified model and could bias the estimation of the term premium. They therefore relax what they call the "macro-spanning condition": macroeconomic factors do not enter the pricing kernel of bonds, but determine expectations of future short rates.

In this chapter, we investigate the nonlinear impact of fiscal policy on the yield curve. To achieve this, we propose a regime-dependent term structure model that incorporates the three standard yield curve factors (level, slope and curvature) and three macroeconomic factors (inflation, economic activity and government primary deficit). We proceed in two steps. First, we do not impose no-arbitrage conditions in the vein of Martins (2012). This model free of no-arbitrage conditions allows the macroeconomic variables to have a contemporaneous impact on the yield curve. We distinguish between two economically-grounded fiscal policy regimes: a sustainable versus an unsustainable path of government debt. The regimes are identified through a regime-switching feedback fiscal policy rule similar to Favero and Monacelli (2005), Dewachter and Toffano (2012) and Houssa and Hubert (2015). In order to assess the quantitative response of yields to fiscal policy shocks, we identify deficit shocks with sign restrictions. In a second step, we quantify the risk premium embedded in US zero-coupon yields under the two regimes. We therefore follow Joslin, Priebsch and Singleton (2014) and impose that the macro factors are unspanned by the yield curve. The literature has shown that there is additional information in macroeconomic factors that is not included in bond yields and risk premia (see, for instance, Duffee, 2002, 2011, 2012 ; Cooper, 2009 ; Ludvigson and Ng, 2009).

We show that accounting for fiscal policy regime changes is economically meaningful to understand the dynamics of bond yields and risk premia. A one percentage point increase in the primary deficit-to-GDP raises interest rates by between 50 to 100 basis points at the 12-quarters horizon, depending on the regime and maturity considered. If we decompose the total effect on yields into their components, we can see that the bulk of the movement in yields is due to the level and, to a lesser extent, the slope factor, with a more pronounced decrease in the slope of the yield curve in the unsustainable regime.

Variance decomposition indicates that fiscal policy shocks are mostly important in the unsustainable regime, where its share can be twice as large as in the sustainable regime. Risk premia associated with the unsustainable regime are consistently larger than their sustainable counterparts, indicating that investors demand a premium to hold bonds of a government that runs an unsustainable fiscal policy.

The remainder of this chapter is structured as follows. Section 3.2 covers the methodology and describes the features of the model. In particular, we cover the identification of the economic regimes and we present the regime-dependent term structure model without imposing the no-arbitrage conditions. We also explain in this section how the impulse response functions take into account the history of regime switches. Section 3.3 presents the data collection and treatment for the analysis. The fiscal regimes uncovered, impulse response functions and variance decompositions are found in Section 3.4. We devote Section 3.5 to the quantification of the risk premium. Finally, Section 3.6 concludes.

3.2 Methodology

3.2.1 Fiscal policy

We follow the strategy of Favero and Monacelli (2005) and Dewachter and Toffano (2012) to identify fiscal policy regimes. We proceed in three steps. First, we define the standard debt accumulation equation:[2]

$$b_t = \left(\frac{1+i_t^b}{1+\zeta_t}\right) b_{t-1} + d_t, \tag{3.1}$$

where b_t denotes the debt-to-GDP ratio at time t, i_t^b is the average interest rate paid on the outstanding stock of debt at $t-1$, and ζ_t represents the growth rate of nominal GDP between $t-1$ and t.

Second, stabilizing the debt-to-GDP ratio implies that $b_t = b_{t-1}$. Hence, we obtain the debt-stabilizing deficit measure d_t^S by substituting the equality $b_t = b_{t-1}$ in Equation (3.1):

$$d_t^S = \left(\frac{g_t - i_t^b}{1+\zeta_t}\right) b_{t-1}. \tag{3.2}$$

Stabilization is achieved via primary surpluses in the case where $i_t^b > \zeta_t$ or via restricted deficits if $\zeta_t > i_t^b$.

Third, we reproduce the analysis of Dewachter and Toffano (2012) and Houssa and Hubert (2015) to identify fiscal policy regimes. We assume that fiscal policy follows a fiscal rule similar to Favero and Monacelli (2005) where the current primary deficit-to-GDP ratio d_t can be expressed as:

[2]This equation neglects the seignoriage term which is marginal in the US case.

$$d_t = \rho^{s_t^F} d_{t-1} + \left(1 - \rho^{s_t^F}\right) \bar{d}_t + \sigma^{s^F} \epsilon_t^{s_t^F} \tag{3.3}$$

$$\bar{d}_t = c^{s_t^F} + \gamma_y^{s_t^F} (y_t - y_t^*) + \delta^{s_t^F} d_t^S \tag{3.4}$$

where d_{t-1} is the first lag of the primary deficit ratio and captures inertia in fiscal policy, $\bar{d}_t$ is the target deficit and is composed of a constant c, the output gap $(y_t - y_t^*)$ to control for the natural counter-cyclical behavior of fiscal policy, and the stabilizing deficit d_t^S. The error term $\epsilon_t^{s_t^F}$ is assumed to be i.i.d.

Each of the coefficients is indexed by the superscript s_t^F that gives the stance of fiscal policy at time t. For the empirical estimation, s_t^F can take two values. The stance of fiscal policy and the values of the coefficients are uncovered by estimating expression (3.3) in a first-order Markov-switching framework with transition matrix P whose elements p_{ij} represents the probability of being in regime i at time t if the data generating process was in regime j at time $t-1$. Formally, this gives $p_{ij} = \Pr\left[s_t^F = i | s_{t-1}^F = j\right]$.

The main advantage of Markov-switching regressions over linear regressions with dummy variables is that the identification of regimes is determined by the data and not *a priori* by the researcher. Another advantage is that Markov-switching regressions give a probability rather than a 0/1 distinction. The ratio $\frac{1}{p_{ii}}$ gives the average duration of regime i, enabling the researcher to gain knowledge about the probable regime several periods in the future.

This reaction function allows the government to react differently to debt developments depending on the value of the stabilizing deficit. Following the taxonomy of Leeper (1991), we define *passive* (or sustainable) fiscal policy if the government aims at stabilizing the debt-to-GDP ratio whereas *active* (or unsustainable) fiscal policy targets macroeconomic variables, irrespective of the debt-to-GDP dynamics. Empirically, it corresponds to the question whether the target deficit $\bar{d}_t$ aims towards the stabilizing deficit d_t^S in the long run. That is, if $\left|\rho^{s_t^F}\right| < 1$ (the relation is non-explosive), $c^{s_t^F = Sustainable} = 0$ and $\delta^{s_t^F = Sustainable} = 1$. We identify the Active regime as a regime where $\delta^{s_t^F = Unsustainable} < 1$. A coefficient $\delta < 1$ implies that government does not increase surpluses as much as would be necessary to stabilize the debt. A negative sign for δ indicates that the government increases the deficit when a reduced deficit or a surplus is required.

In the empirical estimation, we remove the cyclical component of the raw stabilizing deficit d_t^S series implied by Equation (3.2) using the Hodrick-Prescott filter setting a value of $\lambda = 1600$ for quarterly observations so as to obtain a smooth long-run trend for the stabilizing deficit. Doing so, we stress that debt sustainability is a long-run goal and actual fiscal policy is allowed to deviate from it in the short run. In this respect, this is a small deviation of the rule set forth by Favero and Monacelli (2005).

3.2.2 A term structure model without no-arbitrage conditions

In this section, we lay out the empirical term structure model with macroeconomic factors where the no-arbitrage conditions are not imposed. The setup closely follows Afonso and Martins (2012). The model consists of two distinct parts that include yield curve factors on the one side, and macro variables on the other. The yield curve factors are computed separately from macroeconomic information. Yields are collected in the vector Y_t which contains rates for J different maturities. We summarize these yields by means of portfolios $\mathcal{P}_t$ such that $\mathcal{P}_t = WY_t$ where W is a full-rank weighting matrix that transforms observed yields into portfolios of yields. For our analysis, we take W as the loadings coming from the eigenvector-eigenvalue decomposition of the variance-covariance matrix of observed yields. We therefore select the first three principal components and call them *Level*, *Slope*, and *Curvature* given the effect a shock on each of these principal components has on the yield curve (Litterman and Scheinkman, 1991). The decomposition is regime-specific because a different combination of the latent factors may better explain yields in times when fiscal policy is unsustainable.

Diebold and Li (2006, pp. 361-362) and Diebold, Rudebusch and Aruoba (2006, p333) have stated that it is not clear whether no-arbitrage conditions are necessary or desirable for macro-finance modeling. Their argument is that if the data is consistent with the no-arbitrage assumption, then imposing such restrictions should not greatly improve the statistical properties of the model. If, however, the data is not consistent with no-arbitrage restrictions, then imposing it would decrease the forecasting ability of the model.

We augment the yields factors by including macroeconomic variables collected in the vector M_t. We include yearly core inflation, the output gap and the primary deficit over GDP. We chose the primary deficit as the fiscal policy instrument for two reasons. One, the primary deficit is the combination of decisions regarding taxes and government spending. Part of the literature uses taxes as the fiscal instrument (e.g. Davig and Leeper, 2007 ; Davig and Leeper, 2011) whereas others consider government spending as the main fiscal instrument (see, for example, Auerbach and Gorodnichenko, 2013). However, tax collection may depend on the business cycle, on which the government may not have a definitive influence. Government spending, on the other hand, stems from a direct decision of the government. There is also evidence that governments jointly use taxes and spending as instruments (Devries et al., 2011). Second, primary deficits do not include interest payments. We believe that it is an important consideration when dealing with the interplay between deficits and sovereign interest rates. Using deficits that include interest payments would be detrimental to the quality of the analysis. Indeed, if deficit shocks influence the cost of debt financing, future deficits may rise or fall solely because the average interest rate paid on debt has risen or fallen, and not because of an action of the government.

We gather the yield curve factors and the macroeconomic variables in the vector $Z_t = \left[M_t', \mathcal{P}_t'\right]$ such that the number of factors is $\mathcal{N} = L + \mathcal{M}$, where L is the number of principal components and $\mathcal{M}$ the number of macroeconomic factors. Our model thus contains six observable risk factors. In the single-regime case, we set up a Vector Autoregression model of order 1 that takes the form:

$$Z_t = \mu + \Phi Z_{t-1} + \epsilon_t, \quad \epsilon_t \sim N\left(0, \Sigma_{\mathcal{N}}\right) \tag{3.5}$$

where Z_t represents the new information that market participants obtain at time t. The parameters μ represent the constant terms, Φ is the feedback matrix that stacks the coefficients of the regressions together, ϵ_t is the vector of residuals, and Σ is the variance-covariance matrix of the residuals. Though longer lags could be informative for the dynamic responses, we chose to remain parsimonious and as close as possible to most of the literature on term structure models that enforce the no-arbitrage conditions.

In more details, Equation (3.5) gives:

$$\begin{aligned} Z_t &= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix} + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix} Z_{t-1} + \epsilon_t \\ &= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix} + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix} \begin{bmatrix} M_{t-1} \\ \mathcal{P}_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{M_t} \\ \epsilon_{\mathcal{P}_t} \end{bmatrix} \end{aligned} \tag{3.6}$$

and

$$\Sigma = E[\epsilon_t, \epsilon_t] = \begin{bmatrix} \Sigma_{MM} & \Sigma_{M\mathcal{P}} \\ \Sigma_{\mathcal{P}M} & \Sigma_{\mathcal{P}\mathcal{P}} \end{bmatrix}. \tag{3.7}$$

The variables in the VAR are ordered by decreasing order of exogeneity. In particular, we set up the yield curve factors after the macroeconomic variables such that the yield curve can respond to macro news contemporaneously. However, shocks stemming from the yield curve do not affect macroeconomic variables contemporaneously. Within the macro block, we order inflation first, then the output gap and finally the fiscal policy instrument. This ordering supposes that the fiscal policy instrument may be directly affected by inflation and output development through automatic stabilizers, for instance. The primary deficit is found in third position to fit the documented policy lag implementation (Blanchard and Perotti, 2002). When we compute impulse response functions, the responses of the yields are obtained by multiplying the responses of the yield curve components by the first three columns of W.

3.2.3 Regime-dependent dynamics

In the subsequent empirical application we allow the dynamics to be regime-dependent. In this sub-section, we precise how the regime-dependence feature enters the empirical estimation.

Equations (3.6) and (3.7) become:

$$\begin{aligned} Z_t &= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix}^k + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix}^k Z_{t-1} + \epsilon_t^k \\ &= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix}^k + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix}^k \begin{bmatrix} M_{t-1} \\ \mathcal{P}_{t-1}^L \end{bmatrix} + \begin{bmatrix} \epsilon_{M_t} \\ \epsilon_{\mathcal{P}_t^L} \end{bmatrix}^k \end{aligned} \tag{3.8}$$

and

$$\Sigma^k = \begin{bmatrix} \Sigma_{MM} & \Sigma_{M\mathcal{P}} \\ \Sigma_{\mathcal{P}M} & \Sigma_{\mathcal{P}\mathcal{P}} \end{bmatrix}^k \tag{3.9}$$

where the superscript k stands for the regime one considers.

We base the regimes on Equation (3.3) such that they carry a clear economic interpretation. The regimes therefore represent periods during which the economic environment has specific properties. As an alternative, one could estimate a regime-switching VAR directly, but it would be difficult to assert what are the driving forces behind the regimes switches.

We estimate the VAR by Maximum Likelihood (Hamilton, 1989 ; Kim, 1994) where stationarity of both regimes is imposed. The stationarity criterion states that the modulus of the largest eigenvalue should be strictly inferior to one. In order to overcome the difficulty to reach the global optimum, we start the optimization procedure from a hundred sets of random parameter values that respect the stationarity criterion centered around the OLS coefficients. We then select the best parameter values combination based on the value of the log-likelihood of the VAR.

We estimate Equation (3.5) by interacting the constant and the six factors M_t and $\mathcal{P}_t$ with a dummy variable that takes the value 1 if the probability that fiscal policy is unsustainable is larger than 0.5. An alternative would be to use the smoothed probabilities of each regime as such. We choose the first option because the probabilities are, in general, either close to 1 or close to 0, making the distinction dummy variable/probabilities nil. Secondly, interpretation is clearer since the other regime does not contaminate the first in the way model parameters are estimated. Log-Likelihood ratio tests indicate that the improved fit of the dependent variables between the single- and multi-regimes cases is statistically significant. Table B.1 in Appendix B.2 provides the results of the tests.

3.2.4 Impulse response functions

3.2.4.1 Algorithm

In order to identify economic shocks, one needs to transform the estimated residuals ϵ_t into structural shocks $v_t = SR\epsilon_t$, where S is a unique decomposition of the variance-covariance matrix Σ and R is a rotation matrix. For the recursive identification strategy,

S is the Cholesky decomposition of the variance-covariance matrix, and R is the identity matrix. For the sign restrictions identification scheme, the matrix R is replaced by a rotation matrix that preserves orthogonality of the structural shocks but rotates them such that the responses of some of the variables respect certain conditions set *a priori* by the researcher and grounded in economic theory. The shocks are therefore set-identified such that only the rotations that are consistent with the restrictions established *a priori* are kept.

The algorithm is as follows:

1. An orthogonal rotation matrix is randomly selected from the uniform distribution (see, among others, Rubio-Ramirez, Waggoner and Zha, 2010 ; Baumeister and Hamilton, 2015).

2. Compute the impulse response functions for that particular rotation.

3. If the draw respects the restrictions, it is stored whereas if it fails to respect the criteria, it is discarded.

4. Repeat steps 1 through 3 until the number of accepted draws is large enough (500 in this case).

We later summarize the collection of accepted draws by its median value and a confidence interval around the median. Fry and Pagan (2011) have proposed an alternative measure for the summary of the impulses response functions on the grounds that the median response may not be a response produced by the model. They suggest reporting the impulse responses closest to the median instead.

We can thus rewrite Equation (3.6) for the single regime as:[3]

[3]We omit the superscript k for ease of exposition. The regime-dependent version of the model would read:

$$
\begin{aligned}
Z_t &= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix}^k + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix}^k Z_{t-1} + SR\epsilon_t^k \\
&= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix}^k + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix}^k \begin{bmatrix} M_{t-1} \\ \mathcal{P}_{t-1} \end{bmatrix} + SR \begin{bmatrix} \epsilon_{M_t} \\ \epsilon_{\mathcal{P}_t} \end{bmatrix}^k \\
&= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix}^k + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix}^k \begin{bmatrix} M_{t-1} \\ \mathcal{P}_{t-1} \end{bmatrix} + \begin{bmatrix} \nu_{M_t} \\ \nu_{\mathcal{P}_t} \end{bmatrix}^k
\end{aligned}
$$

$$\begin{aligned}
Z_t &= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix} + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix} Z_{t-1} + SR\epsilon_t \\
&= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix} + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix} \begin{bmatrix} M_{t-1} \\ \mathcal{P}_{t-1} \end{bmatrix} + SR \begin{bmatrix} \epsilon_{M_t} \\ \epsilon_{\mathcal{P}_t} \end{bmatrix} \\
&= \begin{bmatrix} M_t \\ \mathcal{P}_t \end{bmatrix} = \begin{bmatrix} \mu_M \\ \mu_{\mathcal{P}} \end{bmatrix} + \begin{bmatrix} \Phi_{MM} & \Phi_{M\mathcal{P}} \\ \Phi_{\mathcal{P}M} & \Phi_{\mathcal{P}\mathcal{P}} \end{bmatrix} \begin{bmatrix} M_{t-1} \\ \mathcal{P}_{t-1} \end{bmatrix} + \begin{bmatrix} \nu_{M_t} \\ \nu_{\mathcal{P}_t} \end{bmatrix}
\end{aligned} \tag{3.10}$$

Following Hamilton (1994), expresssion (3.10) can be written as a $MA(\infty)$ process such that:

$$Z_t = \mu + v_t + \Psi_1 v_{t-1} + +\Psi_2 v_{t-2} + \cdots = \Psi(L)\, v_t \tag{3.11}$$

where $\Psi_h = \Phi^h$ and L stands for the lag operator.

Consequently, element (i, j) of the matrices Ψ_h can be interpreted as the impulse response function of variable i to a shock in variable j at time $t + h$ since $\frac{\partial Z_{t+h}}{\partial v_t} = \Psi_h$.

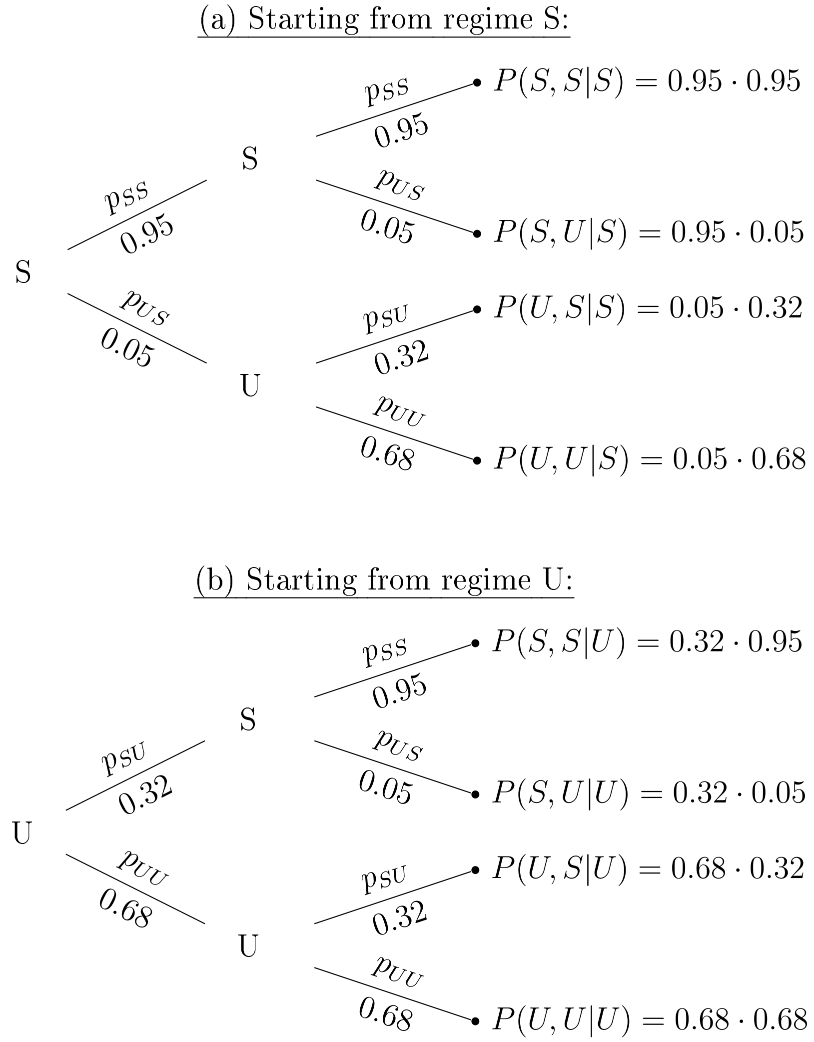
3.2.4.2 Taking regime persistence into account

We compute the impulse response functions in a way that preserves the information contained in the transition matrix P. Impulse response functions of shock j are essentially the difference between a forecast of Z_t at horizon h where a shock occurred in variable j and a forecast where no shock occurred. When forecasting the VAR, we need to take into account that the coefficients of the VAR differ by regimes and that the one period forecast between $h-1$ and h will depend on the coefficients of regime 1 or regime 2 according to the transition matrix P. Therefore, a forecast h periods ahead should take into account the history of switches from one regime to the other.

The transition matrix P is extremely informative about the likelihood of occurrence of the k-regime h periods ahead. If there are no absorbing regimes (i.e. a regime in which the data-generating process is locked), the diagonal elements of $(P)^h$ will tend to the long-term likelihood of occurrence of the regimes. Let us call $\bar{H}$ the number of periods necessary for the transition matrix P to converge to its long-term likelihood of occurrence of each regime.

Figure 3.1 presents the method for $h = 2$. Panels (a) and (b) give the history of switches if the shock occurs in the sustainable or unsustainable regime, respectively. At each horizon $h = 1, \ldots, H$ one can observe a switch or a non-switch. This feature is represented by the straight lines between the nodes. We also associate a probability to each straight line that corresponds to the probability p_{ij} in P. In order to compute the impulse response functions, we iterate forward using the dynamics pertaining to the previous node. For instance, the top-right branch is computed as $\left[\Phi^S\right]^2$ whereas the bottom-right branch

Figure 3.1 – Regime-switching impulse response functions



Note: U and S stand for the Unsustainable and Sustainable regimes, respectively.

is computed as $\Phi^U \cdot \Phi^S$. Those branches have a likelihood of occurrence of 0.9025 and 0.034, respectively. We compute $2^{\bar{H}}$ possible histories of switches (i.e. at each horizon $h = 1, \ldots, \bar{H}$ one can observe a switch or a non-switch) for $h \leq \bar{H}$. We then weight the different paths by their likelihood of occurrence such that highly unlikely histories carry little weight in the final value of the IRF. For $h > \bar{H}$ we consider that the regime occurring at horizon $\bar{H}$ will last indefinitely.[4]

[4] Because of computational limits from the statistical software, the highest $\bar{H}$ achievable is 19 periods. However, choosing $\bar{H} = 10$ or $\bar{H} = 15$ makes little difference. To circumvent this physical limitation, we can compute the histories of switches by simulation. We draw from the uniform distribution at each horizon h and compare the value of the draw to the probability of switching to another regime. If the value of the draw is smaller than the probability of switching, the data-generating process remains in the regime it was in and switches otherwise. Taking $10 * 2^H$ draws, where H is the maximum horizon of the computed IRFs, and averaging gives similar results to the analytical method.

3.3 Data

We use the same yields dataset as Joslin, Priebsch and Singleton (2014) (JPS henceforth). The final dataset ranges from the first quarter of 1972 to the last quarter of 2011. To express monthly yields at a quarterly frequency we take the last observation of the quarter. The maturities used are 6 months, 1 through 5 years, 7 years and 10 years.

The principal components are extracted by decomposing the variance-covariance matrix of the eight standardized observed maturities into eigenvalues and eigenvectors as in Litterman and Scheinkman (1991). Consistent with previous estimates (e.g. Cochrane and Piazzesi , 2005 ; Cochrane and Piazzesi, 2009) the first three principal components explain 97.9, 1.9 and 0.14% of the total variance of observed yields, respectively. The literature (e.g. Litterman and Scheinkman, 1991) coined them level, slope and curvature. The level factor evenly loads on all maturities, the slope factor loads negatively on short maturities and positively on long maturities while the curvature factor is U-shaped and thus loads positively on short and long maturities but negatively on medium maturities. These results are standard in the literature (see, for instance, Ang and Piazzesi, 2003 ; Afonso and Martins, 2012). Although the first principal component captures almost all the variation, we found it important to consider three principal components due to their economic content put forth by the literature. For instance, the slope of the yield curve is a good predictor for business cycle turning points (Keen, 1989 ; Estrella and Mishkin, 1998). Note, however, that the loadings have been rescaled according to the following rules as in JPS such that the scores of the principal components have the same scale:[5,6]

$$Loading^{new}_{Level} = \frac{Loading^{old}_{Level}}{\Sigma^{8}_{i=1} Loading^{old}_{Level}} \tag{3.12}$$

$$Loading^{new}_{Slope} = \frac{Loading^{old}_{Slope}}{Loading^{old}_{Slope}(10y) - Loading^{old}_{Slope}(6m)} \tag{3.13}$$

$$Loading^{new}_{Curv.} = \frac{Loading^{old}_{Curvature}}{Load.^{old}_{Curv.}(10y) - 2 \cdot Load.^{old}_{Curv.}(2y) + Load.^{old}_{Curv.}(6m)} \tag{3.14}$$

Figure 3.2 presents the empirical loadings from the single, sustainable, unsustainable regimes and compares them to those obtained by imposing no-arbitrage. Several conclu-

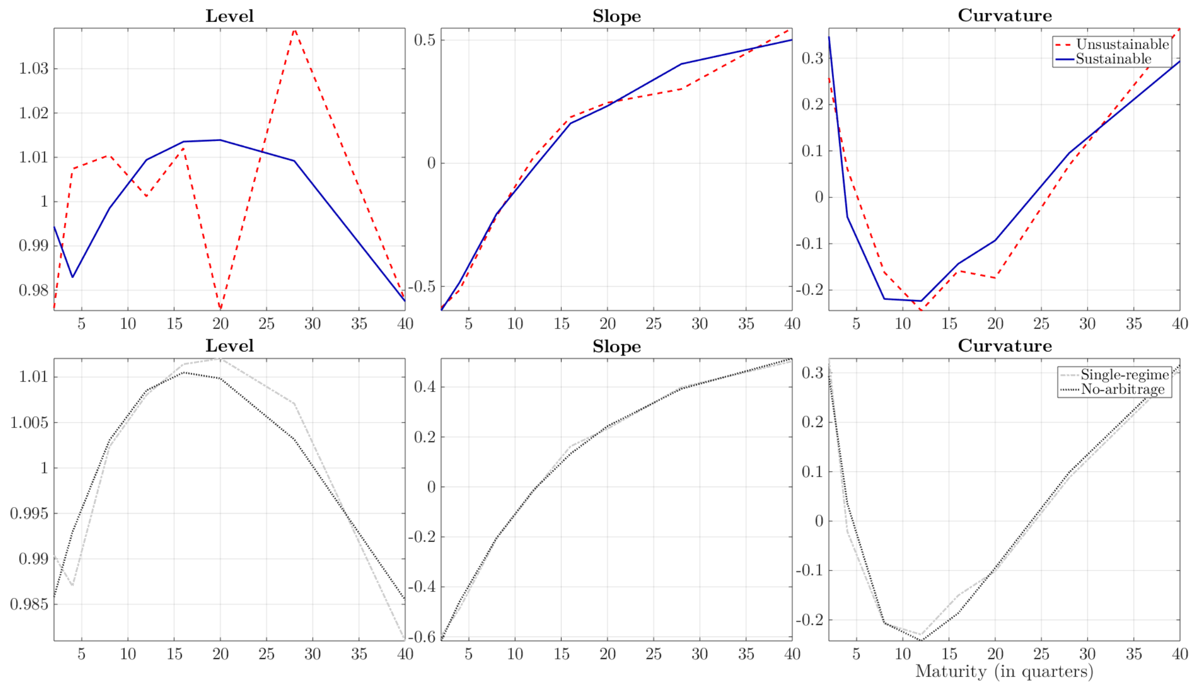
[5]Since principal components are, by construction, independent from each other, a rescaling of one of the principal components has no impact on the others.

[6]We also used an alternative measure for yield curve factors, as in Afonso and Martins (2012), results are robust to this specification:

$$\begin{aligned} Level_t &= \left[y_t^{(6m)} + y_t^{(2y)} + y_t^{(10y)}\right]/3 \\ Slope_t &= \left[y_t^{(10y)} - y_t^{(6m)}\right] \\ Curvature_t &= \left[y_t^{(10y)} - 2 * y_t^{(2y)} + y_t^{(6m)}\right] \end{aligned}$$

sions can be drawn from the exercise. First, loadings generally respect the shape presented in the literature. Second, the loadings in the unsustainable regime are more erratic than in the other configurations. However, the loadings of the level factor broadly remain around 1. Third, the difference between the empirical loadings and their no-arbitrage counterparts is small, although the difference with the unsustainable regime is more pronounced. Using empirical loadings or no-arbitrage loadings would therefore make little difference for the results.

Figure 3.2 – Comparison of empirical and no-arbitrage loadings



Note: the figure presents the empirical and no-arbitrage level, slope and curvature components of the US yield curve between 1972Q1 and 2011Q4. The no-arbitrage loadings come from the model presented in section 3.5. The regime-specific empirical loadings are obtained by extracting the principal components of the yields observed during the two distinct regimes.

Economic activity is captured by the CBO output gap calculated as the log difference between actual nominal GDP and nominal potential GDP. Inflation is the yearly growth rate of Consumer Price Index less Energy and Food prices. Bauer and Rudebusch (2015) stress that the use of core CPI inflation is supported by the statements of monetary policymakers. Typically, very volatile series do not greatly influence inflation expectations.

To estimate the fiscal feedback rule in Equation (3.3) we compute the primary deficit-to-GDP ratio as total government expenditures minus total taxes and interest payments, divided by nominal GDP. A positive value indicates deficit while a negative value indicates surplus. See Appendix B.1 for details on the computation of the data.

Table 3.1 – Estimates of fiscal policy rule

	Estimates of fiscal policy rule (1972Q1:2011Q4)							
	c	ρ	γ	δ	σ_ϵ	p	q	LL
Panel (a)	Single-regime model							
	0.0004	0.862***	-0.157***	0.652***				584.07
	(0.0005)	(0.021)	(0.0179)	(0.103)				
Panel (b)	Markov-switching model: $\lvert\rho_{s_t=S}\rvert < 1$, $c^{s_t=S} = 0$, $\delta^{s_t=S} = 1$, $\delta^U < 0$							
Sustainable	*0*	0.937***	-0.043***	*1*		0.97		615.37
		(0.00)	(0.00)					
Unsustainable	-0.0006***	0.608***	-0.226***	-0.005			0.67	
	(0.00)	(0.00)	(0.00)	(0.01)				

Note: The table reports the estimates of the feedback policy rule presented in section 3.2.1 between 1972Q1 and 2011Q4. We report the estimates for each regression separately together with their standard errors in parenthesis. Superscripts ***, **, * indicate significance levels of 1, 5 and 10%, respectively. Numbers in italic are fixed parameters.

3.4 Empirical results

3.4.1 Fiscal policy regimes

We estimate Equation (3.3) from 1971Q4 until 2011Q4. Panel (a) of Table 3.1 provides some interesting features. First, fiscal policy is quite persistent, as the autoregressive coefficient indicates. Second, fiscal policy behaves in a counter-cyclical manner as expected. Notice also that the stabilizing deficit enters with a positive sign in the single-regime case. However, the magnitude of the coefficient is smaller than one, indicating that the government does not react strongly enough to developments in the stabilizing deficit. The fit is significantly improved when fiscal policy is allowed to switch from a sustainable to an unsustainable regime and vice-versa as indicates the Information Criteria in Table 3.2. Moreover, the non-stabilizing regime is characterized by a negative δ coefficient. Such negative coefficient implies that the government increases its deficit when larger surpluses are needed. We also see that fiscal policy reacts much stronger to economic developments in the unsustainable regime than in the sustainable regime.

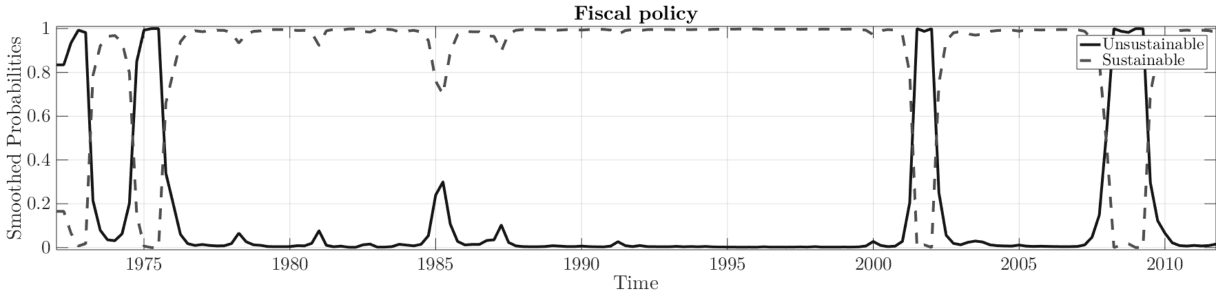
The literature on fiscal preferences shifts is extensive and different fiscal policy reaction

Table 3.2 – Information criteria for fiscal policy rule

Case	AIC	BIC	HQIC
Single-regime	-7.238	-7.142	-7.200
Regime-Switching	-7.530	-7.280	-7.428

Note: the table reports Information Criteria for the different rules under the single-regime or regime-switching specification. We report the Akaike (AIC), Bayes-Schwarz (BIC) and Hannan-Quinn (HQIC) Information Criteria. Information Criteria have been re-scaled by the number of observations. A lower value of the Information Criterion indicates a better fit, taking into consideration the number of parameters estimated.

Figure 3.3 – Fiscal policy regimes



Note: The figure reports the smoothed probabilities of occurrence of the two regimes presented. For the rest of the analysis, the regime is considered unsustainable if the smoothed probability of being in the unsustainable regime is larger than 0.5.

functions have been proposed (see, for example, Bohn, 1998 ; Davig and Leeper, 2007, 2011 ; Favero and Monacelli, 2005) ; Afonso and Martins, 2012). In line with Dewachter and Toffano (2012), we find that fiscal policy has been predominantly passive except for four short-lived episodes of unsustainable fiscal policy. Those episodes match documented discretionary fiscal policy decisions. The first episode is matched with the 1973 recession that saw a drop in tax revenue while the second episode corresponds to the President Ford's tax cuts following the oil shock and the 2-years long recession of 1973-1975. US government has generally run positive primary deficits throughout the sample with the exception of the nineties that saw a strong buildup of surpluses. This trend was put to an halt and even reversed with the successive tax cuts of the Bush administration in 2002 and 2003. The fiscal stimulus packages of 2008 and 2009 (Economic Stimulus Act ($152 billions) and the American Recovery and Reinvestment Act ($803 billions) complete the set of unsustainable fiscal episodes. Those periods correspond to extreme events: either large increases in spending, or sharp decreases in government revenue.

Our estimates of unsustainable fiscal policy compare well against the fiscal policy rule developed by Davig and Leeper (2007, 2011). They estimate a regime-switching fiscal policy rule for the United States between 1949 and 2004 where the government adjusts taxes as a function of government debt, output, and the level of government spending. The authors estimate the following rule:

$$\tau_t = \gamma_0^{s_t^F} + \gamma_b^{s_t^F} b_{t-1} + \gamma_y^{s_t^F} (y_t - y_t^*) + \gamma_g^{s_t^F} g_t + \sigma_\tau^{s^F} \epsilon_t^{s_t^F} \tag{3.15}$$

where τ is tax revenues less transfer payments, b_t is the debt held by the public divided by GDP, $(y_t - y_t^*)$ is the output gap and g_t is current government purchases. The superscript s_t^F stands for the fiscal policy regime. Notice that the variance is regime-dependent. Removing transfers from tax revenues partly removes the natural movement of tax revenue due to automatic stabilizers.

The identification of sustainable and unsustainable fiscal policy hinges on the sign of the response of tax revenues to the lagged value of debt. A positive co-movement indicates a sustainable fiscal policy while a negative sign indicates an unsustainable fiscal policy. Davig and Leeper (2007, 2011) identify fiscal policy as unsustainable in 1955-67, 1969-1971, 1975, 1979-86, and 2002-2004.[7] The start of these periods broadly correspond to the start of the periods we uncover, although their regimes are more persistent.

There are two main differences between Equations (3.3) and (3.15). The first is that Davig and Leeper consider that the principal fiscal policy instrument are taxes and that they react to developments in government spending. The rule of Favero and Monacelli (2005), on the other hand, considers the final outcome of developments in both taxes and government spending and removes the effect of borrowing on the budget. Secondly, recall that $d_t^S = \frac{(\zeta_t - i_t^b)}{(1+\zeta_t)} * b_{t-1}$. The multiplying factor in front of the lagged value of the debt is time-varying and oscillates around 1, whereas it is fixed to 1 in the rule of Davig and Leeper. In some sense, we relax this embedded assumption in Davig and Leeper's rule.

3.4.2 Impulse response functions

An alternative identification strategy is to impose *a priori* the sign of the response of some variables of the VAR. Those restrictions are dictated by economic theory. We slightly adapt the identification strategy of Forni and Gambetti (2010). A positive aggregate demand shock raises both output and the price level, but decreases the deficit-to-GDP ratio whereas a positive aggregate supply shock raises output but reduces the price level. The response of the deficit is left unrestricted. A positive deficit shock raises the primary deficit to GDP ratio as well as inflation and output. With this identification, we can disentangle private aggregate demand shocks from public aggregate demand shocks. We impose such restrictions from impact to three quarters after the shock. We summarize the restrictions in Table 3.3.

One advantage of the sign restrictions is that shocks identified through this method do not suffer from doubts about the timing and exogeneity of variables included in the VAR. The identification, however, is not exact as is the case with the Cholesky decomposition.

[7] Additional information can be found in Appendix B.6.

Table 3.3 – Sign restrictions

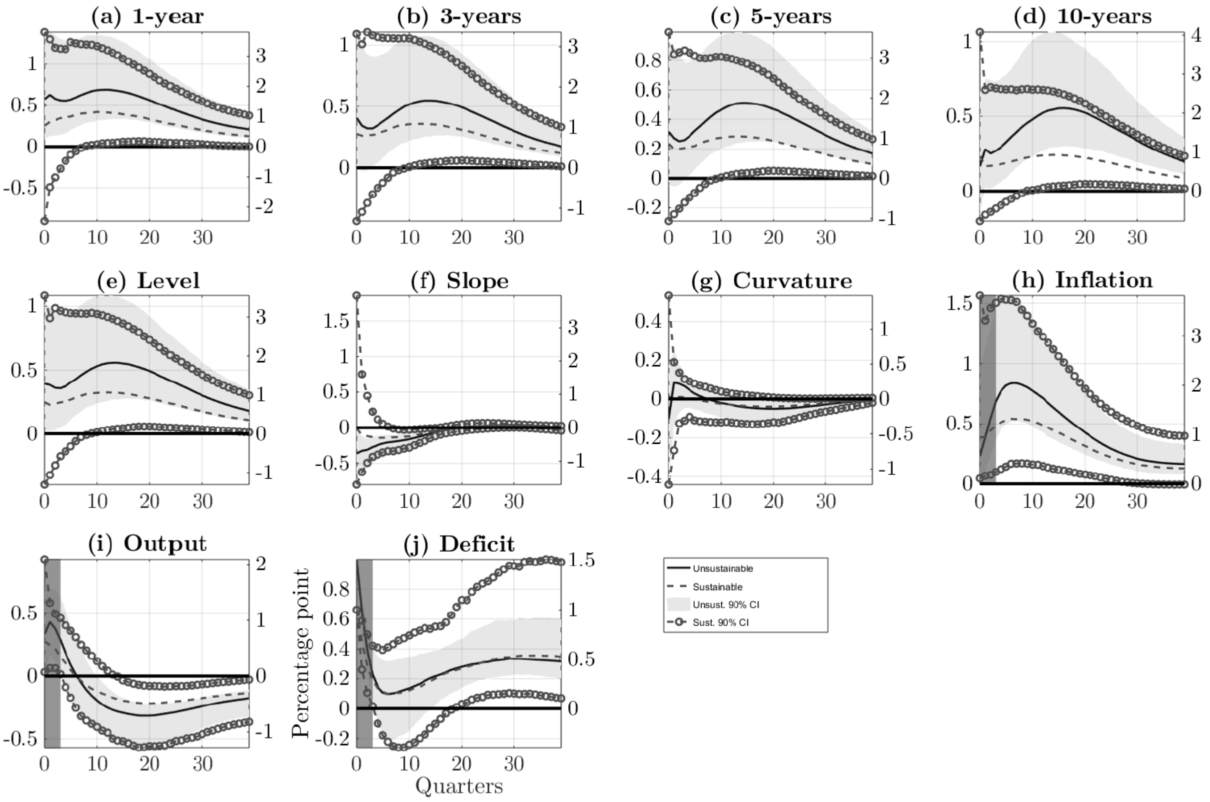
Variable\Shock	Aggregate Supply	Aggregate Demand	Deficit
Inflation	-	+	+
Output	+	+	+
Deficit/GDP	?	-	+

Note: A question mark indicates that the response is left unrestricted. The longest horizon up until which the sign restrictions apply is fixed at three quarters after the shock.

Figure 3.4 presents the impulse responses from a one percentage point deficit shock identified with sign restrictions together with its corresponding 90% confidence bands based on 500 accepted draws. Panel (j) presents the response of the primary deficit to a public demand shock. The persistence of the shock differs greatly across regimes, although both are extremely persistent. A deficit shock raises inflation and output, as per the restrictions. However we can see that the positive response of output is short-lived and even turns negative after twelve quarters. The response on inflation is, however, undoubtedly positive and persistent for both regimes. Turning to the yields responses, we can detect a difference between regimes. In the sustainable case, yields increase with a delay of ten quarters, whereas the response of yields in the unsustainable regime is much quicker. In fact, all yields in the unsustainable regime significantly increase after the third quarter. In particular, the 1-year rate increases by 53 basis points on impact while the increase for the 10-years is only 16 basis points and is not significant. At the 12-quarters horizon, yields in the unsustainable regime have increased by 68 basis points for the 1-year, and 50 basis points for the other maturities. The yields in the sustainable regime, in contrast, increase by 1 percentage point for the 1-year, and 80 basis points for the 10-years. Though the increase in sovereign interest rates is larger in the sustainable regime, the confidence bands markedly differ across the two regimes. Public demand shocks are identified much more precisely in the unsustainable regime. If we decompose the variation of yields into their principal components, we can see that it is mostly the level factor that drives the responses, as was expected. However, it is interesting to see that the slope decreases from impact up until the 12th quarter when fiscal policy is unsustainable while the response in the sustainable regime exhibits a delay.

Our results are larger than what the literature has presented. Dai and Philippon (2005), for example, report that a shock of 1 percentage point to the deficit increases the 10-years bond by about 25-35 basis points. Their identification is different, as they use the identification strategy presented in Blanchard and Perotti (2002). Laubach (2009) uses the projected deficit/GDP and reach a similar magnitude as Gale and Orszag (2003) in their survey. We posit that this difference is due to the identification strategy. Indeed, the sign restrictions identification allows public demand shocks to have a larger influence on the variables included in the VAR than would be allowed by a Cholesky decomposition where the deficit variable is ordered last. Indeed, a large share of the effect of fiscal policy on output would already be captured by the output shock because the output shock appears before in the ordering.

Figure 3.4 – Impulse response functions



Note: The figure presents the responses of the yields and variables included in the VAR to a one-percentage increase in the deficit. The shocks are identified with sign restrictions. The horizon of the restrictions corresponds to the dark shade. The light shade gives the 90% confidence bands of the unsustainable regime (left axis) around its median in solid line while the dashed and circled lines pertain to the sustainable regime (right axis). Both axes give the response of the variables in percentage points.

3.4.3 Forecast error variance decomposition

We present the median variance decomposition of shocks in Tables 3.4 and 3.5 at horizons of 1, 4, 20 and 40 quarters. Variance decomposition gives the share of the response that can be attributed to each shock, at a specific horizon. We group the unidentified shocks under the term Others.

Generally speaking, identified shocks explain between 30 and 45% of the variance of yields. Aggregate Supply shocks are generally not informative as their share remains stable but under 10% irrespective of maturity, regime or horizon. Most of the explained share of yields variance therefore hinges on private and public demand shocks. Notice that the single regime and the sustainable regime are generally in accordance such that the comments that pertains to the sustainable regime are also valid for the single regime. Two principal conclusions can be drawn from the variance decomposition. First, the importance of deficit shocks increases with the horizon considered. It therefore appears that deficit shocks matter more at long horizons than at short horizons. In parallel, the influence of Aggregate Demand shocks decreases with the horizon in the unsustainable regime while the opposite holds for the sustainable regime. There is therefore a substitution between private and public demand shocks. Second, It is interesting to see that the shares of the Aggregate Demand and deficit shocks do differ across regimes. In particular, the importance of deficit shocks in the unsustainable regime can be twice as large as the importance of the deficit shocks in the sustainable regime. The analysis of the unsustainable regime is informative because the total share of explained shocks is consistently larger in the unsustainable regime than under the sustainable regime. Forecast Error Variance Decomposition for the sign restrictions identification therefore stresses the importance of considering fiscal policy regimes as well as deficit shocks. With deficit shocks identified with sign restrictions, our estimates of the importance of deficit shocks fall between Ang and Piazzesi (2003) and Dai and Philippon (2005). Typically, the former find that their macro factors explain up to 85% of the total variance of impulse response functions for short bonds and 50% for long bonds while the latter estimate that fiscal policy shocks explain up to 12% of the variance in yields from 1 quarter to 10-years at a 40 quarters horizon.

3.5 Risk premium accounting

3.5.1 A dynamic term structure model with unspanned macro risks

The model above is silent about the quantification of the risk premium embedded in the US term structure of interest rates. Indeed, the risk premium is the difference between a

Table 3.4 – Median variance decomposition for yields (1-year, 3-years)

Shock to:	**Others**	**Supply**	**Demand**	**Deficit**
		1-year		
Single				
Horizon: 1	73	7	12	**8**
4	70	6	15	**9**
20	57	6	19	**19**
40	56	5	19	**20**
Unsustainable				
Horizon: 1	62	3	10	**24**
4	62	3	10	**24**
20	55	3	9	**34**
40	56	4	7	**34**
Sustainable				
Horizon: 1	75	7	10	**8**
4	74	6	11	**8**
20	58	6	21	**16**
40	55	6	23	**17**
		3-years		
Single				
Horizon: 1	68	7	15	**10**
4	67	6	17	**10**
20	59	4	19	**18**
40	55	5	19	**21**
Unsustainable				
Horizon: 1	70	5	16	**9**
4	68	4	16	**12**
20	55	3	12	**29**
40	56	4	10	**31**
Sustainable				
Horizon: 1	73	5	13	**9**
4	70	6	15	**10**
20	58	5	21	**16**
40	56	5	20	**18**

Note: The table reports the variance decomposition for yields of maturity 1- and 3-years. The rows may not sum to 100 due to rounding. The shocks are identified with sign restrictions. Unidentified shocks are grouped under the label *Others*.

risk-averse and a risk-neutral world. The model in Section 3.2.2 still suffers from potential arbitrage opportunities. This section fills this gap and presents a multi-regime dynamic

Table 3.5 – Median variance decomposition for yields (3-years, 5-years)

Shock to:	**Others**	**Supply**	**Demand**	**Deficit**
		5-years		
Single				
Horizon: 1	68	6	15	**11**
4	69	6	16	**10**
20	59	4	18	**19**
40	57	4	17	**22**
Unsustainable				
Horizon: 1	74	6	15	**5**
4	71	5	16	**8**
20	56	3	12	**29**
40	55	4	10	**31**
Sustainable				
Horizon: 1	71	6	13	**10**
4	70	7	12	**11**
20	59	5	19	**16**
40	57	5	20	**18**
		10-years		
Single				
Horizon: 1	76	5	11	**9**
4	75	4	10	**10**
20	59	5	15	**21**
40	57	5	15	**23**
Unsustainable				
Horizon: 1	70	7	18	**5**
4	67	7	18	**8**
20	55	4	11	**30**
40	54	4	10	**33**
Sustainable				
Horizon: 1	71	7	13	**9**
4	70	7	13	**10**
20	59	5	17	**18**
40	57	5	18	**20**

Note: The table reports the variance decomposition for yields of maturity 1- and 3-years. The rows may not sum to 100 due to rounding. The shocks are identified with sign restrictions. Unidentified shocks are grouped under the label *Others*.

term structure model with unspanned factors. As a consequence, we need to slightly modify the model presented in Section 3.2.2. Joslin, Singleton and Zhu (2011) have proved that, from a collection of J yields, there exists a rotation of $L < J$ latent factors that is observationally equivalent to observed yields portfolios, provided zero measurement error is assumed for the latent factors. We can therefore treat our observable level, slope and curvature factors as latent in the dynamic term structure model (DTSM).

We depart from the usual view predominant in term structure modeling that all relevant information about the state of the economy is embedded in the yield curve, what Joslin, Priebsch and Singleton (2014) have called the "macro-spanning condition". As a consequence, variation in macro variables is not perfectly correlated with the yield curve. Evidence suggests that there is indeed unspanned macroeconomic variation (see Joslin, Priebsch and Singleton, 2014 ; Duffee 2002, 2011, 2012 ; Cooper, 2009 ; Ludvigson and Ng 2009).[8]

Any no-arbitrage term structure model is fully described by three elements: a time series representation of the risk factors under the real-world, risk-neutral probability measures and an equation that links the short-rate to the priced risk factors. In our DTSM with unspanned macro risks, the first element is given by re-organizing Equation (3.6) such that yield factors are ordered first. Although this has no influence on the values of the parameters Φ, it does have an influence on the Cholesky decomposition of $\Sigma_{\mathcal{P}\mathcal{P}}$ which is used to compute the scaled market prices of risk (see Equations (3.18) and (3.19)). Placing the yields portfolios first ensures that $(\Sigma_{\mathcal{P}\mathcal{P}})^{-1/2}$ does not contain information about macroeconomic innovations.

The risk factors under the real-world probability measure $\mathbb{P}$ therefore follow a Vector Autoregression (VAR) of order 1 of the form:

$$\begin{aligned} Z_t &= \begin{bmatrix} \mathcal{P}_t \\ M_t \end{bmatrix} = \begin{bmatrix} \mu_{\mathcal{P}} \\ \mu_M \end{bmatrix} + \begin{bmatrix} \Phi_{\mathcal{P}\mathcal{P}} & \Phi_{\mathcal{P}M} \\ \Phi_{M\mathcal{P}} & \Phi_{MM} \end{bmatrix} Z_{t-1} + \epsilon_t \\ &= \begin{bmatrix} \mathcal{P}_t \\ M_t \end{bmatrix} = \begin{bmatrix} \mu_{\mathcal{P}} \\ \mu_M \end{bmatrix} + \begin{bmatrix} \Phi_{\mathcal{P}\mathcal{P}} & \Phi_{\mathcal{P}M} \\ \Phi_{M\mathcal{P}} & \Phi_{MM} \end{bmatrix} \begin{bmatrix} \mathcal{P}_t \\ M_t \end{bmatrix} + \begin{bmatrix} \epsilon_{\mathcal{P}_t} \\ \epsilon_{M_t} \end{bmatrix} \end{aligned} \tag{3.16}$$

and

$$\Sigma = E[\epsilon_t, \epsilon_t] = \begin{bmatrix} \Sigma_{\mathcal{P}\mathcal{P}} & \Sigma_{\mathcal{P}M} \\ \Sigma_{M\mathcal{P}} & \Sigma_{MM} \end{bmatrix}. \tag{3.17}$$

Assuming no-arbitrage, there exists a risk-neutral probability measure $\mathbb{Q}$ that can be used to price government bonds. The stochastic discount factor m_{t+1} that defines the change of probability measure between $\mathbb{P}-$ and $\mathbb{Q}-$measures is exponentially affine and takes the form:

[8] See also Appendix B.5 for an application of the several tests of the macro-spanning condition set forth by the literature.

$$m_{t+1} = \exp\left(-r_t - \frac{\lambda_t^{'}\lambda_t}{2} - \lambda_t^{'}\epsilon_{\mathcal{P},t+1}\right) \tag{3.18}$$

where the scaled market prices of risk are given by:

$$\lambda_t = (\Sigma_{\mathcal{P}\mathcal{P}})^{-1/2}(\lambda_0 + \lambda_1 Z_t) \tag{3.19}$$

with $\lambda_0 = \left[\lambda_0^{\mathcal{P}}\right]_{LxL}$, $\lambda_1 = \left[\begin{array}{cc} \lambda^{\mathcal{P}}_{1\,LxL} & \lambda^{M}_{1\,Lx\mathcal{M}} \end{array}\right]$.

Second, for unspanned macro risk term structure models, it is important to make a distinction between the total set of risk factors and the set of priced risk factors. The whole set of risk factors is denoted by Z_t and includes both macro and yield curve risk factors while the priced factors only include the yield curve risk factors. The priced risk factors under the risk-neutral probability measure $\mathbb{Q}$ follow a VAR that is independent of the macro factors because macro risk factors are not spanned by the yield curve:

$$\mathcal{P}_t = \mu_{\mathcal{P}}^{\mathbb{Q}} + \Phi_{\mathcal{P}\mathcal{P}}^{\mathbb{Q}}\mathcal{P}_{t-1} + \epsilon_{\mathcal{P},t}^{\mathbb{Q}}, \quad \epsilon_{\mathcal{P},t}^{\mathbb{Q}} \sim N\left(0, \Sigma^{\mathbb{Q}}\right) \tag{3.20}$$

The only way macro factors enter the model is as additional predictors in the VAR in Equation (3.5). The macro factors will therefore affect real-world expectations of future yields. The bottom-left corner of expression (3.6) is crucial as it determines the effects of macro variables on expectations of yields. If this part of the feedback matrix Φ is restricted to zero, macro variables completely drop out of the model. They can neither affect bond pricing under the risk-neutral probability measure nor the real-world factors dynamics. In that case, we end up with a yields-only model, where only $\mathcal{P}_t$ are the risk factors.

Third, the one-period interest rate is an affine function of the priced risk factors (i.e. the risk factors that enter the bond pricing equation) and is given by:

$$r_t = \rho_0 + \rho_1^{'}\mathcal{P}_t. \tag{3.21}$$

As opposed to spanned macro risks, the one-period interest rate only loads on the first L principal components and not on the macroeconomic factors. Joslin, Priebsch, and Singleton (2014) argue that having macroeconomic factors determine the short-rate in the risk-neutral measure would bias the estimation of the risk premium.

The specification of the prices of risk in expression (3.19) corresponds to the essentially-affine class of Duffee (2002) such that the prices of risk have a constant component λ_0 and a time-varying component λ_1. They measure the additional expected return required per unit of risk in each of the shocks in ϵ_t (Bauer and Rudebusch, 2015). Notice that there are as many rows as there are priced risk factors, and as many columns are there are risk factors. Since macro factors are not priced factors, there are only L rows in λ_0 and λ_1 but $\mathcal{M} + L$ columns. As noted by JPS, the market prices of risk are an affine function of the whole set of risk factors Z_t despite the fact that the only priced risks are the $\mathcal{P}_t$. It follows that agents are sensitive to broader information than just yield curve factors.

Equations (3.19) to (3.21) imply that the log price $p_t^{(n)}$ of an n-period bond at time t is determined by an affine function that links the log bond price to the priced risk factors:

$$p_t^{(n)} = -\left(A_n + B_n^{'}\mathcal{P}_t\right) \tag{3.22}$$

The no-arbitrage condition is written as:

$$p_t^{(n+1)} = E_t\left[m_{t+1}\left(p_{t+1}^{(n)}\right)\right] \tag{3.23}$$

and states that longer bonds are risk-adjusted expected shorter bonds.

To obtain no-arbitrage loadings A_n and B_n one needs to solve the following difference equations:

$$\begin{cases} A_{n+1} & = A_n + B_n^{'}\mu^{\mathbb{Q}} + \frac{1}{2}B_n^{'}\Sigma_{\mathcal{P}\mathcal{P}}\Sigma_{\mathcal{P}\mathcal{P}}^{'}B_n + A_1 \\ B_{n+1}^{'} & = B_n^{'}\Phi_{\mathcal{P}\mathcal{P}}^{\mathbb{Q}} + B_1 \end{cases} \tag{3.24}$$

with initial conditions $A_1 = \rho_0$ and $B_1 = \rho_1$ so as to satisfy $r_t = p_t^{(1)}$.

Once we have solved the difference equations for bond prices, yields can be computed as:

$$y_t^{(n)} = -\frac{p_t^{(n)}}{n} = a_n + b_n^{'}\mathcal{P}_t \tag{3.25}$$

where $a_n = -A_n/n$ and $b_n = -B_n/n$ for $n = 1, 2, 3, \ldots$

3.5.2 Regime-dependence of the DTSM

The second adaptation to our term structure model pertains to the dynamics of the risk factors under the $\mathbb{P}-$measure. We restrict the top-left corner of Φ and Σ to be the same across regimes because the regime-switching feature should only matter for the expectations of future yields and should not enter the bond-pricing equation. As such, the regime-switching feature is not priced by market participants (see, for instance, Dai, Singleton and Yang (2007) for a term structure model where regime shifts are priced) but does influence their expectations. In some sense, the regime-switching properties are not spanned by the yield curve. These restrictions are consistent with the unspanned macro risks attribute of the model: yields factors matter for the characterization of the cross-section of yields while both yields factors and macro factors determine the expectations of the state of the economy.

Equations (3.6) and (3.7) become:

$$
\begin{aligned}
Z_t &= \begin{bmatrix} \mathcal{P}_t \\ M_t \end{bmatrix} = \begin{bmatrix} \mu_{\mathcal{P}} \\ \mu_M \end{bmatrix}^k + \begin{bmatrix} \Phi_{\mathcal{P}\mathcal{P}} & \Phi^k_{\mathcal{P}M} \\ \Phi^k_{M\mathcal{P}} & \Phi^k_{MM} \end{bmatrix} Z_{t-1} + \epsilon_t \\
&= \begin{bmatrix} \mathcal{P}_t \\ M_t \end{bmatrix} = \begin{bmatrix} \mu_{\mathcal{P}} \\ \mu_M \end{bmatrix}^k + \begin{bmatrix} \Phi_{\mathcal{P}\mathcal{P}} & \Phi^k_{\mathcal{P}M} \\ \Phi^k_{M\mathcal{P}} & \Phi^k_{MM} \end{bmatrix} \begin{bmatrix} \mathcal{P}_t \\ M_t \end{bmatrix} + \begin{bmatrix} \epsilon_{\mathcal{P}_t} \\ \epsilon_{M_t} \end{bmatrix}^k
\end{aligned} \tag{3.26}
$$

and

$$
\Sigma^k = E[\epsilon_t, \epsilon_t] = \begin{bmatrix} \Sigma_{\mathcal{P}\mathcal{P}} & \Sigma^k_{\mathcal{P}M} \\ \Sigma^k_{M\mathcal{P}} & \Sigma^k_{MM} \end{bmatrix}. \tag{3.27}
$$

where the superscript k stands for the regime one considers.

We see that despite the identical top-left corner of the Φ matrix, the complete Φ is regime-dependent. As a consequence, the variance-covariance matrix is also regime-dependent. Notice that the top-left corner of Σ^k is especially important as it enters the no-arbitrage model and thus determines the no-arbitrage loadings A, B_n, a, b_n as well as the market prices of risk and excess returns. Typically, as $\Sigma_{\mathcal{P}\mathcal{P}}$ does not depend on the regime considered, it enters the recursive differential equations in (3.24) equally for both regimes. Consequently, the short-rate loadings in (3.21) are also unaffected.

We select the best parameter values based on the procedure described in Section 3.2.3.

3.5.3 Market prices of risk

The market prices of risk transform the risk factors dynamics under $\mathbb{P}$ into the risk factors dynamics under $\mathbb{Q}$ and vice-versa. More specifically,

$$
\mu^{\mathbb{Q}}_{\mathcal{P}} = \mu_{\mathcal{P}} - \Sigma_{\mathcal{P}\mathcal{P}}\lambda_0 \tag{3.28}
$$

$$
\Phi^{\mathbb{Q}}_{\mathcal{P}} = \Phi_{\mathcal{P}\mathcal{P}} - \Sigma_{\mathcal{P}\mathcal{P}}\lambda_1 \tag{3.29}
$$

Scaled market prices of risk are thus given by:

$$
\begin{cases} \Sigma_{\mathcal{P}\mathcal{P}}\lambda_0 &= \mu_{\mathcal{P}} - \mu^{\mathbb{Q}}_{\mathcal{P}} \\ \Sigma_{\mathcal{P}\mathcal{P}}\lambda_1 &= [\Phi_{\mathcal{P}\mathcal{P}}\ \Phi_{\mathcal{P}M}] - \left[\Phi^{\mathbb{Q}}_{\mathcal{P}\mathcal{P}}\ \mathbf{0}_{L\mathrm{x}M}\right] \end{cases} \tag{3.30}
$$

The largest difference in bond risk premia will presumably come from the market prices of risk in Equation (3.30) because $\Phi^k_{\mathcal{P}M}$ can greatly differ. Similarly, most of the differences across regimes of the responses of the dependent variables will be due to different parameter values in Φ^k and Σ^k.

3.5.4 Excess returns

Recall that the price of a bond of maturity n at time t is given by:

$$P_t^{(n)} = \exp\left(-\left(A_n + B_n \mathcal{P}_t\right)\right) \tag{3.31}$$

The Expected Excess Returns are therefore computed as:

$$\begin{aligned} rx_t^{(n)} &= E_t\left[\log\left(P_{t+1}^{(n-1)}\right) - \log\left(P_t^{(n)}\right)\right] - r_t && (3.32) \\ &= E_t\left[-A_{n-1} - B_{n-1}\mathcal{P}_{t+1} - \left(-A_n - B_n\mathcal{P}_t\right)\right] - r_t && (3.33) \end{aligned}$$

Notice that only $\mathcal{P}_{t+1}$ is unknown at time t. Reworking expression (3.33) yields:

$$\begin{aligned} rx_t^{(n)} &= (A_n - A_{n-1}) + (B_n\mathcal{P}_t - B_{n-1} * \mathrm{E_{t+1}}\left[\mathcal{P}_t\right]) - r_t && (3.34) \\ &= (A_n - A_{n-1}) + (B_n\mathcal{P}_t - B_{n-1} * \mathcal{P}_t * \left[\Phi_{\mathcal{P}\mathcal{P}}\ \Phi_{\mathcal{P}M}\right]) - r_t && (3.35) \end{aligned}$$

Table 3.6 provides information about the scaled market prices of risk. The price of risk gives the compensation required by bondholders to be exposed to this risk. The prices of risk should be understood as the sensitivity of risk premia to the exposure of shocks. A positive value in column i implies a positive co-movement of the risk premium with the exposure to risk i. Conversely, a negative value should be considered as a hedge.

First, although JPS impose some zero-restrictions on the prices of risk motivated by improvement in Information Criteria, we obtain the same signs of the co-movements between the exposures to level, slope, curvature shocks and the expected excess returns on the yields portfolios level, slope and curvature as JPS, whether we consider the single, sustainable or unsustainable regime. Exposures to deficit shocks have ambiguous effects on the level, slope and curvature portfolios depending on the regime one considers. Indeed, while the sign and magnitude of the pro-cyclicality of the risk premium associated to the curvature portfolio induced by exposure to deficit shocks is the same for the three cases, we can see that the sensitivity to deficit shocks is markedly larger in the unsustainable regime for the slope portfolio. It is also worth nothing that the exposure to deficit shocks has a positive co-movement with the level risk premium in the unsustainable regime, as compared to a negative co-movement for the single and sustainable regime.

We present the one-period expected excess returns for a selection of maturities in Figure 3.5. Similarly to the IRFs, we consider that expectations h periods ahead take into account the history of switches until h. With one-period forecast and two regimes, this amounts to:

$$\begin{aligned} \mathcal{P}_t^{*,k=i} = &\left[\mu_{\mathcal{P}}^{k=i} + \left[\Phi_{M\mathcal{P}},\, \Phi_{\mathcal{P}\mathcal{P}}\right]^{k=i} * Z_{t-1}\right] * p_{ii} \\ &+ \left[\mu_{\mathcal{P}}^{k=j} + \left[\Phi_{M\mathcal{P}},\, \Phi_{\mathcal{P}\mathcal{P}}\right]^{k=j} * Z_{t-1}\right] * p_{ij} \end{aligned} \tag{3.36}$$

Table 3.6 – Scaled market prices of risks λ_0 and λ_1

Exposure to:	const	L	S	C	Inflation	Output	Deficit
Single							
L_t	-0.001	-0.067	-0.022	0.175	0.086	0.046	-0.008
S_t	0.002	0.052	-0.122	-0.077	-0.061	-0.108	-0.040
C_t	0.003	-0.054	-0.023	-0.272	0.011	0.038	0.059
Unsustainable							
L_t	-0.001	-0.099	-0.05	0.126	0.055	0.001	0.015
S_t	0.003	0.091	-0.102	-0.013	-0.029	0.001	-0.104
C_t	0.008	-0.077	-0.039	-0.328	-0.046	0.018	0.055
Sustainable							
L_t	0.001	-0.099	-0.05	0.126	0.112	0.044	-0.003
S_t	-0.001	0.091	-0.102	-0.013	-0.096	-0.111	-0.034
C_t	0.005	-0.077	-0.039	-0.328	0.040	0.038	0.060

Note: The table reports the scaled market prices of risks in the single, sustainable and unsustainable regimes. Portfolios of bonds are found in the rows while the risks factors are found in columns. The column *const* corresponds to the time-fixed price of risk λ_0 while the rest of the columns correspond to entries of the time-varying prices of risk λ_1.

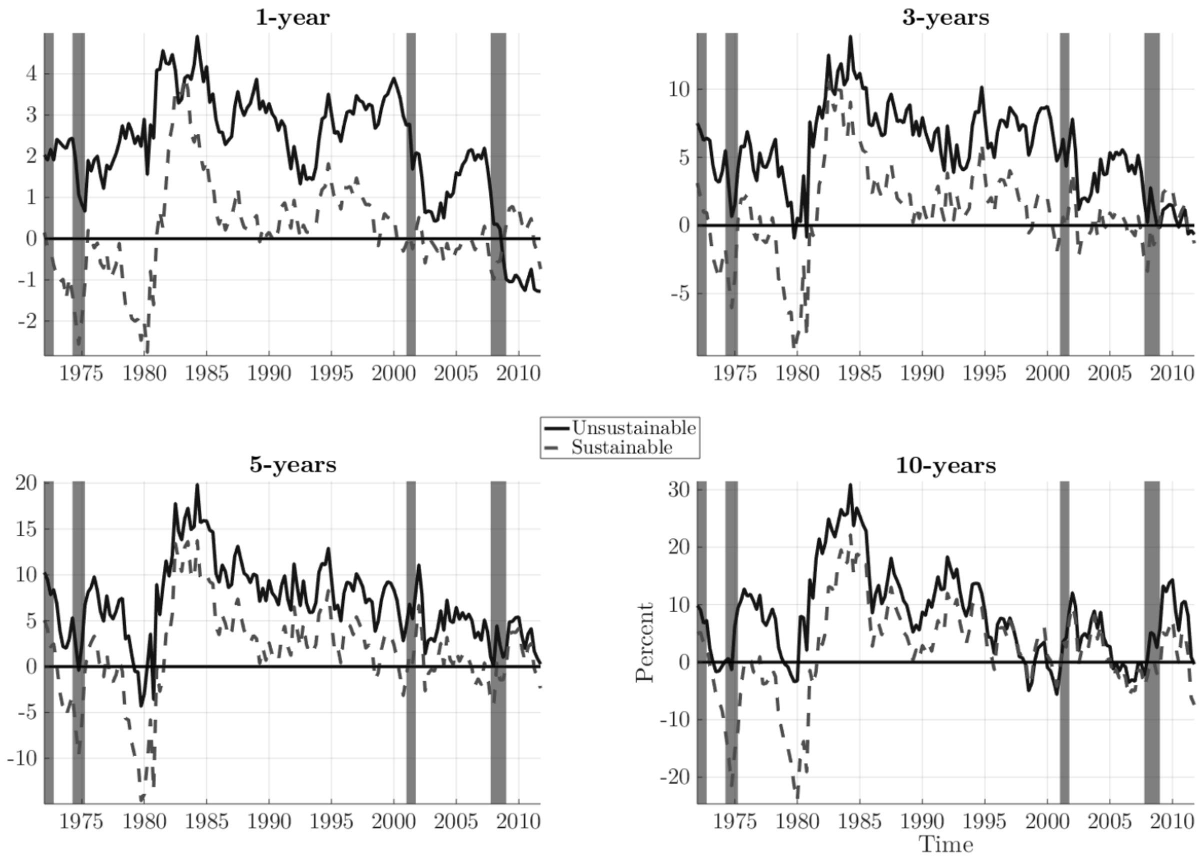
where the asterisk denotes a forecast, i is the regime considered and j the other regime. We therefore provide a counterfactual for the analysis of bond risk premia: what would have been the risk premium at time t had fiscal policy been sustainable or non-sustainable?

The estimated risk premia broadly correspond to risk premia described in Cochrane and Piazzesi (2005, 2009) with a clear business-cycle pattern. Strong negative excess returns match with the start of the monetary experiment of 1979-1982. It is clear that unsustainable fiscal policy consistently implies higher risk premia than in the sustainable or single regime, although the difference is less pronounced for long maturities. This difference is particularly large in the second half of the nineties. It is worth noting, however, that this pattern vanishes from 2010 onward where we see that risk premia associated with the sustainable regime are larger than in its unsustainable counterpart for short maturities. We conjecture that this feature is due to the accommodative monetary policy that was taking place at the time. Notice also that risk premia associated with the unsustainable fiscal policy regime experience a sharp decrease in periods of unsustainable fiscal policy while sustainable fiscal policy risk premia increase during those periods.

3.6 Conclusions

We have presented an empirical term structure model that emphasizes the role fiscal policy on sovereign yields and have estimated it between 1972 and 2012. With this in mind,

Figure 3.5 – One-period expected excess returns



Note: The figure reports the one-period expected excess returns for US yields between 1972Q1 and 2011Q4 according to the two types of regimes we consider. The solid line pertains to the unsustainable regime while the dashed line refers to the sustainable regime. The gray area corresponds to episodes of unsustainable fiscal policy.

we introduce macroeconomic variables alongside the usual three yield curve factors: level, slope and curvature. Inflation, the output gap and the primary deficit thus complete the set of risk factors that determine bond yields dynamics. The particularity of our model is that the behavior of the risk factors that describe bond yields dynamics is allowed to depend on the sustainability of debt. Such a criterion is derived from the debt-accumulation equation such that the regimes identified are grounded in theory. In order to disentangle sustainable from unsustainable periods, we apply a regime-switching regression model to a simple feedback rule that determines the current primary deficit as a function of past deficits, the business cycle and the deficit that is required to stabilize the debt-to-GDP. We show that fiscal policy in the United States has been predominantly sustainable, with a few episodes of unsustainable fiscal policy. Typically, the model identifies the periods of 1972, 1975, 2002-3 and 2008-9 as unsustainable. These correspond to well-documented decisions where governments either reduced taxes or increased spending dramatically.

In order to conclude on the effect of fiscal policy shocks on the yield curve, we present impulse response functions where the shocks are identified with sign restrictions. The impulse response functions and the variance decomposition show that conditioning on fiscal regimes is not trivial. Sovereign yields typically increase by 50 to 68 basis points after three years following an unexpected deficit shock in the unsustainable and sustainable regime, respectively. Though the increase is large in the sustainable regime, deficit shocks are better identified in the unsustainable regime. Sovereign yields also respond more quickly in the unsustainable regime. If we decompose the total effect on yields into their components, we can see that most of the movement in yields is due to the level and, to a lesser extent, the slope factor, with a more pronounced decrease in the slope of the yield curve in the unsustainable regime. Variance decomposition indicates that the influence of deficit can be twice as important in the unsustainable regime compared to its sustainable counterpart and that there is a substitution between private and public demand shocks across the two regimes.

We also characterize the risk premium embedded in the US yield curve by imposing no-arbitrage restrictions on the dynamics of the risk factors. Following Joslin, Priebsch and Singleton (2014), we relax what they call the "macro-spanning condition", that is, macroeconomic factors determine expectations of future yields but do not enter the bond-pricing equation. The risk premium derived from the model is broadly consistent with the literature, with the particularity that risk premia in the unsustainable fiscal policy regime are consistently larger than in the sustainable regime.

Chapter 4

Cross-Border Risks in the Eurozone Bond Markets

4.1 Introduction

Following the European sovereign debt crisis of 2010, academics and policymakers have shifted their focus towards understanding the causes and consequences of contagion in bond markets. When the Credit Rating Agency *Moody's* downgraded Portugal on July 5, 2011, it stated that the possible involvement of the private sector for further financing schemes in Greece would have repercussions on Portuguese financing opportunities.[1] The Portuguese downgrade and increasing fears of a Greek default led investors to rapidly sell Spanish and Italian bonds even if there were no negative announcements regarding their economic outlook.[2]

The anecdotal evidence highlighted above suggests that developments in foreign countries may affect the domestic bond market under scrutiny in a non-trivial way. It therefore seems natural to empirically assess the importance of those potential spillover effects. In this respect, the Eurozone is particularly relevant because it offers a framework where monetary policy applies uniformly to the member states but where fiscal policy remains a decentralized decision. Modeling contagion is especially meaningful for macroprudential policies because this framework can take into account direct and indirect effects of macroeconomic policies. Additionally, analyzing risk transmission within a monetary union is

[1] According to *Moody's*, one of the reasons motivating the downgrade was twofold: "[First, t]he growing risk that Portugal will require a second round of official financing before it can return to the private market, and [second,] the increasing possibility that private sector creditor participation will be required as a pre-condition. [...] European policymakers have grown increasingly concerned about the shifting of Greek debt held by private investors onto the balance sheets of the official sector. Should a Greek restructuring become necessary at some future date, a shift from private to public financing would imply that an increasingly large share of the cost would need to be borne by public sector creditors. To offset this risk, some policymakers have proposed that private sector participation should be a precondition for additional rounds of official lending to Greece."

[2] *Contagion and the European debt crisis,* Keynote lecture by Vítor Constâncio, Vice-President of the ECB at the Bocconi University/Intesa Sanpaolo conference on "Bank Competitiveness in the Post-crisis World" Milan, 10 October 2011.

sensible because the exchange rate channel of transmission between member states cannot play a role.

The present research aims to quantify the extent of the transmission of sovereign risk from one country of the eurozone to the rest of the Union. In particular, I want to determine how much of domestic spreads is attributed to foreign factors and whether there is heterogeneity in the eurozone in that respect. With this objective in mind, I employ a macro-finance model with spatial linkages where the domestic spreads vis-à-vis a common risk-free rate explicitly includes domestic, foreign and common factors. Introducing spatial linkages is particularly relevant in the European context where capital markets are integrated and cross-border financial flows are unrestricted. Moreover, using spatial econometrics techniques provides an additional transmission channel of economic shocks.

I contribute to the literature along three dimensions. First, I construct a multi-market macro-finance model for euro area countries where domestic bond spreads depend on three types of factors: domestic, foreign, and global. Foreign factors are modeled as a weighted average of developments in other countries of the zone. Global factors represent the general state of the economy and does not depend on domestic developments. Second, the multivariate setup allows me to obtain richer dynamic responses thanks to cross-equations coefficients. In contrast, univariate regressions would be silent on the effect of foreign fiscal policy on domestic inflation, for example. Third, I propose a new transmission mechanism that relies on the exposure of domestic commercial banks to foreign sovereign debt. The mechanism is as follows: in an integrated market where free movement of capital is allowed, domestic commercial banks may hold foreign debt as an asset. If economic conditions worsen in the foreign economy, the demand for its debt will decrease, driving down the price of the bonds. The commercial bank that currently holds the bond therefore sees the net present value of its claims shrinking. Its loan-to-assets ratio increases as a consequence, which in turn increases its risk of default. The bank may then adjust its amount of loans to the private sector, reducing credit to the private sector. Less investment means smaller domestic growth. A recession is therefore imported from abroad.

In terms of closest neighbors in the literature, Dewachter et al. (2015) study the influence of external factors in domestic spreads for five euro area countries. They conclude that the importance of external factors is sizeable and that this influence is country-dependent. I also extend the framework of Dewachter, Houssa and Toffano (2012) by including financial variables so as to consider both the macro side of the economy as well as its financial aspects. A third article closely related to this research is Debarsy et al. (2018) whose aim is to detect heterogeneity in the spatial transmission of sovereign bond spreads for 41 advanced and emerging economies. Their setup is different than mine because they consider univariate regressions whereas I present here a multivariate model.

I estimate the model on monthly data for ten eurozone countries for the period

2002M10 to 2017M3, which captures both expansions and downturns in Europe. The common factors include global and European variables in the form of a World Real Economic Activity (WREA) index (Kilian, 2009), the VSTOXX index that captures volatility in the European stock market (Arghyrou and Kontonikas, 2012) and proxies the Global Financial Cycle (Rey, 2015), and finally principal components that summarize the Overnight Index Swaps (OIS) curve to capture the European risk-free rate. Domestic factors include inflation, the output gap, the primary deficit and the Country-Level Indicator of Financial Stress (CLIFS) provided by the ECB. I use the impulse response functions of a Spatial Vector Autoregression model to analyze the transmission of shocks in one country of the Union to another. This modeling choice allows me to characterize the sources of movements in the domestic bond market. Variance decomposition then helps quantify to which extent global, foreign and domestic shocks matter for domestic macroeconomic policies. I identify the shocks in a similar way to Dewachter, Houssa and Toffano (2012). That is, I impose a double-sorting prior to the Cholesky decomposition: by economic size of the country, and by the sluggishness of the variables considered such that bigger countries and slow-moving variables are ordered first.

In accordance to the literature (e.g. Debarsy et al., 2018 ; Beirne and Fratzscher, 2013), results indicate that spatial components provide additional information to explain bond yields differentials. The main results can be summarized as follows. First, countries from the core (Germany, France, the Netherlands, Belgium, Finland) do not generate spillovers. This statement is true for both big and small countries. On the other hand, there is evidence of spillovers within the periphery (Italy, Spain, Ireland, Portugal). In particular, Italian shocks generate large spillovers to Spain, Ireland and Portugal. For every one percentage point increase in the 5-years Italian spread, the spreads of Spain, Ireland and Portugal increase by 90, 60 and 95 basis points, respectively. Second, around 25% of domestic spreads are due to external factors: common factors account for 10% of domestic spreads, foreign factors (i.e. factors from other countries of the eurozone) for 15%. There is considerable heterogeneity in this respect. Periphery countries tend to depend more heavily on external factors than countries in the core. For example, 40% of Portuguese spreads are due to foreign factors. This heterogeneity suggests the existence of two euro areas, on the one side a series of insulated core countries, and on the other side an archipelago of periphery countries.

The results have important implications for the conduct of macroprudential policies in Europe. First, Italy should be closely watched because of (i) the contagion it can create and (ii) the degree of exposure to its debt. Second, adjustment packages for small countries should be managed as a system and should incorporate the idea that domestic policies may have little effect on the country's spreads if a large proportion of it is explained by external factors. Third, the results suggest that increased coordination among European countries may be beneficial in terms of financing costs for governments. In particular, a strengthening of the fiscal union appears to be a solution to weather sovereign risk contagion.

The remainder of the article is structured as follows. I present the relevant related literature in Section 4.2. Section 4.3 describes the empirical methodology while Section 4.4 presents the data and their transformation prior to the analysis. I present the results and their policy implications in Sections 4.5 and 4.6, respectively. Section 4.7 presents a few avenues that could be explored in the future. Finally, Section 4.8 concludes.

4.2 Related literature

Economists have understood early on that the assessment of the transmission of macroeconomic shocks across countries was of particular importance. Eichengreen et al. (1996) and Kaminsky and Reinhart (2000) provide evidence of contagion across countries due to trade linkages and financial connectedness, respectively. Theoretical macroeconomic models have tried to incorporate these features in Dynamic Stochastic General Equilibrium (DSGE) models, mostly in a two-country model. Galí and Monacelli (2005), for instance, present a DSGE model of a small open economy where the transmission mechanism from foreign variables to domestic variables hinges on the volatility of the exchange rate that the Central Bank is willing to accept. They stress the importance of the degree of openness of the economy as well as the role of world output fluctuations. Adolfson et al. (2007) extend the closed-economy framework of Christiano, Eichenbaum and Evans (2005) by introducing the exchange rate channel. This channel of transmission rests on the assumption that there is incomplete exchange rate pass-through, that is price stickiness in the local currency. These frictions can therefore generate larger real domestic effects from foreign shocks than under a perfectly flexible exchange rate. Indeed, Robertson and Wickens (1997) note that a free-floating exchange rate ensures that nominal foreign shocks do not influence domestic inflation. The mechanism is as follows: as foreign inflation increases, the nominal exchange rate appreciates such that the real exchange rate remains the same and does not affect domestic inflation. Since domestic inflation remains the same, there would be no real effects. In the case of a peg, nominal and real shocks can have effects on the domestic economy.

Despite the growing number of theoretical models that attempt to address the transmission of macroeconomic shocks across countries, the issue mostly remains empirical. Two main strands of the literature related to my study are worth noting. The first stresses the importance of global factors to explain domestic variation. Kose, Otrok and Whiteman (2003), for instance, point to the existence of a « world business cycle » obtained through dynamic latent factor model to estimate common components in 60 countries worldwide. They show that this global factor accounts for most of the variation in the aggregates and that regional factors only play a minor role. The argument is even stronger for business cycles in advanced economies than for developing countries. Based on this idea, researchers have produced indices of global economic activity (e.g. Kilian, 2009 ;

Ravazzolo and Vespignani, 2017). Leduc and Liu (2016) complement the field regarding the importance of global factors with a DSGE model that incorporates labor search frictions such that uncertainty shocks generate real effects. When uncertainty increases, firms tend to postpone their hiring decision, and it results in fewer job position being filled. Domestic aggregate demand falls because households wealth decreases.

As Rigobon (2016) reports, the literature has proposed a large variety of methods to deal with the issue of spillovers and contagion: (extreme) correlations, principal components, event studies or regressions. The empirical literature on spillovers has produced an abundant body of evidence and suggests that foreign determinants contain valuable information about the domestic economy. Such literature typically uses spatial econometrics techniques or Global Vector Autoregressions (GVAR) popularized by Pesaran, Schuermann and Weiner (2004) to detect and quantify the spatial transmission of shocks. The shocks considered range from labor market shocks (Bettendorf, 2013) to credit shocks (Fadejeva, Feldkircher and Reininger, 2015 ; Bettendorf, 2016) and exchange rate shocks (Kelejian, Tavlas and Hondroyiannis, 2009). Particularly relevant is the literature dealing with the assessment of contagion effects on the sovereign bond market. Following the deterioration in the solvency of a country in a monetary union, investors may want to safeguard their returns and reduce their exposure to the particularly risky asset. This drop in the demand for the risky asset would drive up its yield and consequently worsen the debt sustainability of an already fragile country. The increased instability would cast doubt upon the strength of the monetary union and would translate into higher yields for the whole monetary union. Beirne and Fratzscher (2013), for example, analyze to which extent bond spreads are explained by the fundamentals of the country under consideration or by contagion, that is, correlation in excess of what could be explained by economic fundamentals. They present evidence of such contagion during the 2008-2011 crisis. This echoes Caporin et al. (2015) who show that the contagion effect remains stable across the periods considered. Recently, Debarsy et al. (2018) investigate the question of spatially-dependent bond yields spreads for 41 advanced and emerging economies. In their model, the spreads vis-à-vis the 10-year US bond yield exhibit both a contemporaneous spatial lag structure as well as a spatio-temporal lag structure. Splitting the sample into advanced and emerging economies allows them to compare the strength of the transmission mechanism within and between these two groups. Specifically, they show that spatial linkages are stronger in advanced economies than in emerging economies.

The open-economy modeling framework of the term structure of interest rates postulates that domestic capital markets are closely related to their external counterparts. The recent works by Traczyk (2013), Dewachter et al. (2015), Bauer and de los Rios (2012) and Borgy et al. (2011) fall into this category. This strand of the literature concludes that common (or external) factors account for a large proportion of the observed variation of bond yields. More precisely, Traczyk (2013) build a no-arbitrage dynamic term structure model for Canada, Germany, Norway, Switzerland and the United Kingdom where he augments domestic factors (inflation, output growth, short-term rate and the yield spread) with foreign factors (short-term rate, inflation, output growth) weighted by the importance of the ten biggest trading partners. Principal component decomposition of the yields of the countries considered points to the existence of a common level factor and, to a lesser extent, a slope and curvature factor. Dewachter et al. (2015) build a multi-country affine term structure model for five countries of the Eurozone with unspanned domestic factors, in the same vein as Bauer and de los Rios (2012). A factor is unspanned if it describes the time series properties of bond yields but does not enter the pricing equation (Joslin, Priebsch, Singleton, 2014). For each country in the analysis, they distinguish factors according to two dimensions: spanned vs. unspanned and common vs. domestic. The first two principal components of the Overnight Index Swaps are introduced alongside domestic spreads such that the domestic bond pricing equation includes both a common and an idiosyncratic component. As a consequence, several bond markets are conditioned on the same risk-neutral probability measure. Other macroeconomic factors and euro-wide spreads indicators fill the unspanned category. They find that common economic fundamentals account for 40 to 60% of the variance of bond yield spreads whereas idiosyncratic risk factors account for about 12% of the variance of bond yield spreads. The rest of the variance is explained by non-fundamental factors common to all countries.

4.3 Methodology

4.3.1 Spatial linkages in a macro-finance model

To emphasize the spatial link across markets, I build a Spatial Vector Autoregression (SpVAR) model where both the temporal and spatial dimensions of the panel of countries are taken into account. Models in spatial econometrics assume a structure among the spatial units analyzed. This structure is set *a priori* and must correspond to an economically-relevant mechanism to be interpreted.

The Spatial VAR specification differs from the Global VAR specification in several aspects. First, spatial lags in GVAR are restricted to appear with a temporal lag. The Spatial VAR is therefore more flexible in that we can assume that spatial lags enter the equations contemporaneously, with a lag, or both. Second, the GVAR approach supposes that the coefficients for the foreign variables are country-specific, which leads to a rapid explosion of the number of parameters to estimate. In this article, I restrict the spatial lag coefficients to be identical across all countries. The Spatial VAR specification presented here is therefore parsimonious in the number of parameters to estimate.

Let us define $Z_{i,t}$ the vector of L demeaned risk factors of country i at time t. The vectors $Z^*_{i,t}$ and $Z^*_{i,t-1}$ contain the spatial components of the domestic equations and correspond to a weighted average of foreign variables at time t and $t-1$, respectively.

Exogenous variables are denoted by H_t and contain exogenous factors common to the M countries. The Spatial VAR(1) for each country i takes the form:

$$\begin{cases} Z_{i,t} = & \Phi_i Z_{i,t-1} + \Gamma Z^*_{i,t} + \Xi Z^*_{i,t-1} + \kappa_i H_t + \epsilon_{i,t} \\ H_t = & \Phi_H H_{t-1} + \epsilon_{H,t} \end{cases} \tag{4.1}$$

The square matrix Φ_i is a feedback matrix capturing the temporal dynamics of the L factors in $Z_{i,t}$ for country $i = 1, \dots, M$. The vector $\epsilon_{i,t}$ contains i.i.d. shocks with mean zero and variance-covariance matrix Σ_i. Notice that H_t follows an autonomous VAR of order 1 such that $\epsilon_{H,t}$ and $\epsilon_{i,t}$ are uncorrelated. Equation 4.1 assumes that common variables in H_t have a contemporaneous effect onto the Z_i but H_t is insulated from feedback effects from Z. These foreign factors are specific to each country and are computed according to the following rules:

$$\begin{cases} Z^*_{i,t} & = \Omega_i \left(Z_{1,t}, \cdots, Z_{M,t}\right) \\ Z^*_{i,t-1} & = \Omega_i \left(Z_{1,t-1}, \cdots, Z_{M,t-1}\right) \end{cases} \tag{4.2}$$

where Ω_i is the i^{th} row of a matrix of non-zero entries except for the variables pertaining to country i that represents the strength of the linkages between the countries considered. The spatial dependence of each element $l = 1, \dots, L$ of $Z^*_{i,t}$ and $Z^*_{i,t-1}$ is given by the so-called spatial lags and spatio-temporal lags coefficients Γ and Ξ, respectively:

$$\Gamma = \begin{bmatrix} \gamma_{11} & \cdots & \gamma_{1L} \\ \vdots & \ddots & \vdots \\ \gamma_{L1} & \cdots & \gamma_{LL} \end{bmatrix} \text{and}\, \Xi = \begin{bmatrix} \xi_{11} & \cdots & \xi_{1L} \\ \vdots & \ddots & \vdots \\ \xi_{L1} & \cdots & \xi_{LL} \end{bmatrix} \tag{4.3}$$

Elements on the diagonal of Γ give the own spatial lags whereas the off-diagonal elements of Γ capture the cross-spatial lags. Analogously, elements on the diagonal of Ξ give the own spatio-temporal lags whereas the off-diagonal elements of Ξ capture the cross-spatio-temporal lags. Such a structure allows, for example, foreign inflation developments to have an effect on domestic output contemporaneously or with a lag. Exposure to the common variables H_t, represented by the coefficients in κ_i, is contemporaneous but different across countries.

Notice that the model presented in Equation (4.1) nests the standard VAR put forth by Sims (1980) if $\Gamma = 0$ and $\Xi = 0$. It also nests cross-sectional spatial models if we assume that $\Phi_i = 0$ and $\Xi = 0$ (see, for instance, Anselin, 1988 ; Cliff and Ord, 1973 ; Elhorst, 2003 ; Kapoor et al., 2007).

Stacking the M country-by-country equations yields (Beenstock and Felsenstein, 2007):

$$\begin{cases} \tilde{Z}_t = & \tilde{\Phi} \tilde{Z}_{t-1} + \tilde{\Gamma} \tilde{\Omega} \tilde{Z}^*_t + \tilde{\Xi} \tilde{\Omega} \tilde{Z}^*_{t-1} + \tilde{\kappa} H_t + \epsilon_{i,t} \\ H_t = & \Phi_H H_{t-1} + \epsilon_{H,t} \end{cases} \tag{4.4}$$

where $\tilde{\Phi} = I_M \otimes \Phi_i$, $\tilde{\Gamma} = I_M \otimes \Gamma$, $\tilde{\Omega} = I_L \otimes \Omega_i$, $\tilde{\kappa} = I_M \otimes \kappa$, I_x stands for the identity matrix of size x and $\otimes$ is the Kronecker product.

For the rest of the analysis, Z_t includes the yearly inflation rate, the output gap, the primary deficit over GDP and the Country-Level Indicator of Financial Stress. The last element aims at capturing domestic uncertainty. The vector H_t contains a measure of the global business cycle, a measure of European uncertainty and the first principal components of the OIS curve for which the number of components retained will be specified later on. Introducing common variables in the model is useful because it ensures that observed spatial diffusion is not due to unobserved common variables.

Notice that it is not possible to estimate Equation (4.1) by OLS due to the presence of the spatial components $\tilde{\Gamma}$. Indeed, there is an obvious problem of endogeneity because $Z_{i,t}$ appears on the left-hand side and the right-hand side of Equation (4.4). I therefore estimate the model by Maximum Likelihood for each equation $l = 1, \ldots, L$ separately and impose stationarity on the dynamics of Z_{li}. Stationarity criteria need to take both the temporal and the spatial dynamics into account. The VAR for the common variables is estimated by OLS.

The log-likelihood function to be maximized for each variable l is given by (Parent and LeSage, 2011):[3]

$$\begin{array}{rcl} \ln L_l & = & -(M/2)\ln(\pi\sigma_l^2) + \ln|I_M - \gamma_{ll}\Omega| - \frac{e'_{l,t}e_{l,t}}{2\sigma_l^2} \\ e_{l,t} & = & \tilde{Z}_{l,t} - \tilde{\Phi}_l\tilde{Z}_{l,t-1} - \tilde{\Gamma}_l\tilde{\Omega}\tilde{Z}^*_{l,t} - \tilde{\Xi}_l\tilde{\Omega}\tilde{Z}^*_{l,t-1} - \tilde{\kappa}_l H_t \end{array} \tag{4.5}$$

The stationarity conditions are developed in Parent and LeSage (2011) for the univariate case and are given by:

$$\begin{array}{rlll} \phi_{ll} + (\gamma_{ll} + \xi_{ll})\,|\bar{\omega}_{max}| < 1 & \text{if} & \gamma_{ll} + \xi_{ll} \geq 0 \\ \phi_{ll} + (\gamma_{ll} + \xi_{ll})\,|\bar{\omega}_{min}| < 1 & \text{if} & \gamma_{ll} + \xi_{ll} < 0 \\ \phi_{ll} - (\gamma_{ll} - \xi_{ll})\,|\bar{\omega}_{max}| > -1 & \text{if} & \gamma_{ll} - \xi_{ll} \geq 0 \\ \phi_{ll} - (\gamma_{ll} - \xi_{ll})\,|\bar{\omega}_{min}| > -1 & \text{if} & \gamma_{ll} - \xi_{ll} < 0 \end{array} \tag{4.6}$$

where $|\bar{\omega}_{min}|$ and $|\bar{\omega}_{max}|$ are the minimum and maximum moduli of Ω.

Since the parameters governing the own spatial lag γ_{ll} and own spatio-temporal lag ξ_{ll} are common across countries but the parameter governing the own temporal lag ϕ_{ll} is not, the restrictions in (4.6) are applied on the largest temporal lag across countries. Note, however, that imposing stationarity equation by equation is not equal to imposing stationarity of the VAR as a whole. As a consequence, I ensure that the restrictions imposed equation by equation also hold for the SpVAR. Written in a more compact form, equation (4.4) gives:

[3]The subscripts l indicate the variable for which the optimization is performed.

$$\begin{cases} (A + BL)\, Z_t & = \epsilon_t \\ A & = I_M - \Gamma W \\ B & = -\left(\Phi + \Xi W\right) \end{cases} \tag{4.7}$$

where L stands for the lag operator. The Wold representation of (4.7) is obtained by dividing both sides by $C = A - BL$. The model is stationary if the moduli of the eigenvalues of C lie within the unit circle.

Dewachter, Houssa and Toffano (2012) stress that the Maximum Likelihood estimate is biased because the inclusion of a lagged dependent variable in the panel estimation creates an endogeneity issue (see, for instance, Lee and Yu, 2010) and that the presence of country-specific temporal lags creates what is called the *incidental parameter problem* (see, among others, Neyman and Scott, 1948 ; Lancaster, 2000). They address the first problem by stating that lagged observed variables are independent from the current error terms. The bias in dynamic panel regressions is of the order *1/T* (Nickell, 1981). For the second problem, Beenstock and Felsenstein (2007) provide a value for the downward bias of the temporal lags:

$$b = -\frac{\frac{1+\phi}{T-1}\left(1 - \frac{1-\phi^T}{T(1-\phi)}\right)}{\left(1 - \frac{2\phi}{(1-\phi)(T-1)}\left(1 - \frac{1-\phi^T}{T(1-\phi)}\right)\right)} \tag{4.8}$$

where the bias tends to zero as T goes to infinity. The two problems highlighted above are likely to be small in my setup since I cover 10 countries over 173 periods and I control for the bias in the estimation of the temporal lags.

4.3.2 Impulse response functions

I identify the common, foreign, and domestic shocks recursively by applying the standard Cholesky decomposition to the variance-covariance matrix of the residuals $\epsilon_{i,t}$ from (4.4). Identification of common shocks is, however, carried out separately due to the separability of Equation (4.4). Common shocks are identified with the Cholesky triangular factorization. The identification of the remaining shocks hinges on two implicit assumptions. First, as for regular VARs, the ordering of the variables matters. Second, the ordering of the countries matters as well in the case of a multi-country analysis. Regarding the first assumption, the vector of domestic variables contains macroeconomic and financial variables. I therefore order the macroeconomic variables (inflation, economic activity and primary deficit) first and then the financial variables (CLIFS and principal components of sovereign spreads), consistent with the idea that financial variables react contemporaneously to macro news. Within the macro block, macroeconomic variables are ordered according to their exogeneity: inflation can have a contemporaneous effect on economic activity and the fiscal policy variable (Afonso and Martins, 2012). Economic activity may also influence the fiscal policy variable through the automatic stabilizers and is thus ordered second. The fiscal policy variable is the last macro variable because we can expect considerable lag between the implementation of the policy and its effect on the economy (Blanchard and Perotti, 2002). This structure is repeated both in the domestic part of the regression and in the spatial lags. I follow Dewachter, Houssa and Toffano (2012) and order the countries according to their economic size in terms of GDP. Doing so is consistent with the idea that bigger countries do not respond contemporaneously to shocks in smaller countries. Taken together, these two assumptions amount to grouping all the series of inflation first, then of the output gap series, fiscal policy and finally the financial variables. This re-ordering of Equation (4.4) only has an influence on the orthogonalized impulse response functions and variance decompositions.

These two sets of identifying restrictions require a matrix R that will reorder the variables and shocks accordingly. Let us define the re-ordered shocks, as in Dewachter, Houssa and Toffano (2012), as $\eta_t = R\epsilon_t$. The Cholesky decomposition of the η_t gives $\eta_t = Qv_t$ where Q is the Cholesky factorization of the variance-covariance matrix of η_t and v_t are the structural shocks ordered first by variable, then by country. Having performed the Cholesky factorization, we can rearrange the vector of residuals to their initial ordering by applying the following transformation:

$$\epsilon_t = R^{-1}QRR_t^{-1}v_t \tag{4.9}$$

We can therefore recover the original ordering of the structural shocks, that is ordered first by country and then by variable.

I bootstrap the estimation in order to obtain inference that is not based on point estimates. I consider 500 bootstraps for which the stationarity conditions hold. Technically, I use block bootstraps with a window of 24 observations. Such a choice ensures that the time dimension of the model is preserved. The window is optimally chosen by adapting the Hall and Horowitz (1996) rule for an AR(1) process in the Künsch's (1989) model to the spatial case here. Typically, the autoregressive coefficient ϕ in the Hall and Horowitz (1996) rule is replaced by $\phi_{ll} + (\gamma_{ll} + \xi_{ll})\,|\bar{\omega}_{max}|\,\forall l = 1, \ldots, L$ by analogy with (4.6).

4.4 Data

4.4.1 Economic variables

The data covers the period from October 2002 to March 2017 and include ten countries: Austria, Belgium, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal and Spain. I excluded Luxembourg because sufficient information about yields was not available. I also discarded Greece because the country did not have access to market funding for some of the sample. The observed yields would therefore not reflect market sentiment about the solvency of the Greek government.

The data can be divided into three categories according to their geographical breadth and economic content. The first group contains economic information about the global or pan-European economic situation. In particular, it covers the global economic cycle and statistics about the European stock market as well as bond market. I include Kilian's World Real Economic Activity (WREA) index (Kilian, 2009) following Kose, Otrok and Whiteman (2003) who provide evidence of a world business cycle. Regarding the European stock market, I computed the monthly return on the Eurostoxx50 index. Introducing the stock market into the model helps assess the general sentiment of financial markets. I also selected the VSTOXX index which provides information about the expected volatility of the Eurostoxx50 index several months ahead and proxies changes in the risk appetite (Gambacorta, 2014 ; Blasqués et al. 2016 ; Arghyrou and Kontonikas, 2012). The methodology to construct the VSTOXX index is fairly similar to the VIX and their time series properties are similar. Using one or the other would therefore have little influence on the results. I proxy the European risk-free rate against which domestic spreads are computed by the Overnight Index Swaps yield curve. The yields for the common yield curve are obtained from the OIS rates at 6-months. When unavailable, OIS data are spliced with Euribor 6-months swap rates. The maturities considered are 3- ,6- ,12-months and 2-, 3-, 4-, 5-, 7-, 10-years. As it is standard in the literature (e.g. Littermann and Scheinkman, 1991), I decompose the OIS yield curve into its principal components. I retain the first two principal components based on the criteria that the eigenvalue of the component should be larger than one. The second group contains country-specific macroeconomic and financial situation, namely the inflation, output gap and the deficit ratio as well as the Country-Level Indicator of Financial Stress. In particular, the Country-Level Indicator of Financial Stress can be understood as local volatility measures. The inflation, output gap and primary deficit series come from Eurostat. Inflation is computed as the yearly growth rate of the monthly HICP. The output gap is computed as the percentage deviation from quarterly potential output. Potential output is obtained by decomposing real GDP into trend and cycle with the Hodrick-Prescott filter with a smoothness parameter set to 1600 for quarterly data. Primary deficit is defined as net lending minus interest payments divided by nominal GDP such that positive values indicate deficit. When the original data were not already seasonally adjusted, I removed seasonality with the X13 procedure of the US Census Bureau. Quarterly series of the output gap and primary deficit were interpolated to monthly frequency with the Chow and Lin (1971) method with the country-specific Economic Sentiment Indicator and the Industrial Production Index provided by the ECB as high-frequency variables. In the case of Ireland, the ESI has been replaced by the Consumer Sentiment Indicator due to data availability. The Country-Level Indicators of Financial Stress come from the ECB and are available at a monthly frequency.

Country-specific yields data at par value come from Bloomberg and are readily available at a monthly frequency. The country-specific yields cover the same maturities as the OIS curve and are bootstrapped according to the Fama-Bliss (1987) procedure to obtain zero-coupon yields. [4] I compute the principal components of the spreads between the country-specific zero-coupon yields and the OIS yields of corresponding maturity. These spreads capture country-specific default and liquidity risks (Duffie and Singleton, 1999) and form the third group. The number of principal components to retain for the spreads corresponds to the maximum number of principal components which eigenvalues are greater than one in each of the ten countries. Alternative criteria and the number of factors that would be retained are found in Table 4.1.

I define the following vectors used in Equation (4.1):

$$Z_{i,t} = \begin{bmatrix} \pi_{i,t} \\ (y_{i,t} - \bar{y}_{i,t}) \\ deficit_{i,t} \\ CLIFS_{i,t} \\ Spread_{i,t}^{PC1} \\ Spread_{i,t}^{PC2} \end{bmatrix} \tag{4.10}$$

$$H_t = \begin{bmatrix} VSTOXX_t \\ StockReturns_t \\ WREA_t \\ OIS_t^{PC1} \\ OIS_t^{PC2} \end{bmatrix}' \tag{4.11}$$

I report the results of the selection procedure for the number of principal components to retain for the analysis in Table 4.1. Two main criteria can be used to select the appropriate number of principal components: (i) the eigenvalue of the component should be larger than one, and (ii) the share of the total observed variation that we want to keep. I use the eigenvalue criterion and select the number of principal components accordingly for the OIS curve and the domestic spreads.

4.4.2 Transmission mechanism

The transmission of shocks from one country to another is modeled by the Ω matrix that captures the strength of the linkages among countries. Since I focus on the temporal and spatial transmission of sovereign spreads across the euro area, the spatial structure is given by the exposure of domestic banks to sovereign debt of other euro area countries. [5]

[4] In finance, bootstrapping is a method to construct a zero-coupon yield curve from interest-bearing yields.

[5] I consider the total amount of financial assets in the form of foreign government debt securities since it better encompasses the exposure of domestic banks to sovereign risk.

Table 4.1 – Number of principal components to retain

Variable \ Criterion	**Eigenvalue>1**	**cum.** $R^2 > 90\%$	**cum.** $R^2 > 95\%$	**cum.** $R^2 > 99\%$
OIS curve	2	1	1	2
Spreads	2	3	4	7

Note: the table reports the number of principal components to retain according to various selection criteria. The variables to be decomposed into principal components are found in rows and the criteria are found in columns. The first criterion suggests that a principal component should be retained if its eigenvalue is larger than one. The other criteria propose to keep as many principal components as necessary such that the principal components explain more than 90, 95 or 99% of the variation observed in the variables.

The Transparency Exercice of the European Banking Authority is based on supervisory reporting and is published once a year since 2011 and covers a set of banks active in the countries considered (132 in 25 EU countries for the 2017 Report). I use the Transparency Exercise of December 2016 for the rest of the analysis. This choice of transmission matrix Ω emphasizes the role of the financial sector in the transmission of shocks across countries. Two mechanisms are at play when domestic banks act as intermediaries between the foreign and domestic markets. First, in an integrated market where movement of capital is unrestricted, domestic commercial banks may hold foreign debt as an asset. The commercial bank that currently holds the bond therefore sees the net present value of its claims shrinking. Its loan-to-assets ratio increases as a consequence, which in turn increases its risk of default. The bank may then adjust its amount of loans to the private sector, reducing credit to the private sector. Less investment means smaller domestic growth such that economic slowdown is imported from abroad. Second, if economic conditions worsen in the foreign economy, the demand for its debt will decrease, driving down the price of the bonds. Banks may therefore be tempted to liquidate their risky position and buy bonds from another country (i.e. *flight to safety* argument). Playing on the relative strength of demand and supply of debt may transmit shocks through the asset composition of domestic banks. This portfolio revaluation mechanism is therefore a suitable candidate for the transmission of economic and financial shocks.

Table 4.2 reports, for each reporting country in the row dimension, the share of sovereign debt of each counterparty country (in the column dimension) in percent of the total value of assets held by the reporting domestic banks. The total assets come from the Bank for International Settlements. The numbers presented in this table are likely to be an underestimation of the actual holdings of sovereign debt due to the limited coverage of the reporting banks in the EBA dataset. Nevertheless, we can see that around 8.5% of the total assets of Belgian reporting banks takes the form of French sovereign debt or that Portuguese banks hold 3.3% of their portfolio in the form of Spanish debt.

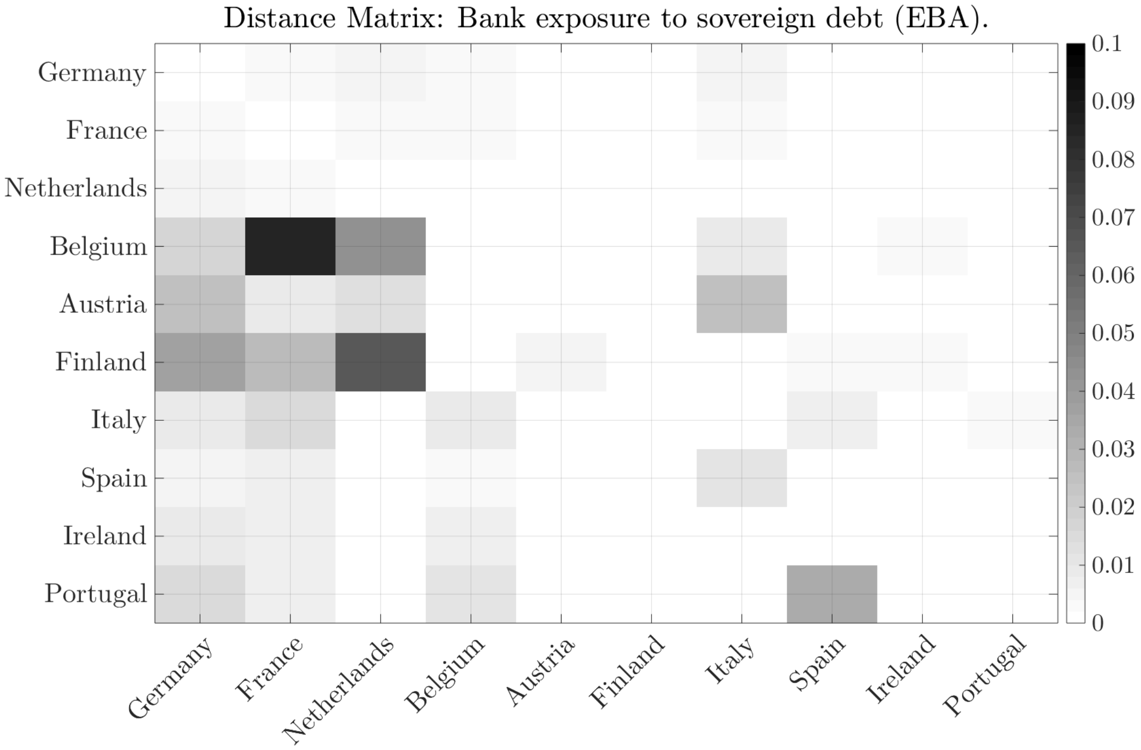
Figure 4.1 presents a visual representation of Table 4.2 sorted by the core-periphery

Table 4.2 – Domestic banks exposure to foreign sovereign debt

	Germany	**France**	**Netherlands**	**Belgium**	**Austria**	**Finland**	**Italy**	**Spain**	**Ireland**	**Portugal**
Germany	0	0.39	0.45	0.27	0.06	0.04	0.55	0.02	0.06	0.00
France	0.36	0	0.33	0.30	0.02	0.00	0.22	0.02	0.05	0.00
Netherlands	0.41	0.38	0	0.09	0.02	0.04	0.04	0.11	0.02	0.00
Belgium	1.62	8.44	4.29	0	0.14	0.08	0.86	0.09	0.31	0.00
Austria	2.57	0.95	1.39	0.19	0	0.00	2.60	0.01	0.01	0.00
Finland	3.71	2.62	6.47	0.11	0.56	0	0.12	0.23	0.21	0.00
Italy	0.87	1.48	0.13	0.96	0.06	0.00	0	0.67	0.06	0.22
Spain	0.52	0.62	0.12	0.35	0.05	0.00	1.01	0	0.10	0.10
Ireland	0.97	0.78	0.05	0.66	0.18	0.00	0.15	0.00	0	0.05
Portugal	1.46	0.66	0.02	1.19	0.09	0.00	0.08	3.27	0.05	0

Note: the table presents, for each reporting country (rows), the share of sovereign debt of each counterparty country (columns) in percent in the total value of assets. The diagonal elements are set to zero to exclude domestic holdings of domestic sovereign debt.

Figure 4.1 – Heatmap of the transmission matrix sorted by core/periphery and economic size



Note: the figure is a visual representation of the exposure of domestic commercial banks to foreign sovereign debt. The scale is given in decimal points. A darker shade indicates a larger share.

dichotomy and economic size within each group.[6] Some comments are worth mentioning. First, all countries of the euro area are generally mildly to strongly exposed to debt issued by the core countries and much less to small periphery countries like Ireland or Portugal. Second, the countries in the core have an even smaller exposure to debt from periphery countries than countries in the periphery. Nevertheless, Italy stands out because most countries hold Italian debt, reinforcing the equivocal status of Italy in the core/periphery dichotomy.[7] Lastly, Spanish debt represents a large share in Portuguese banks' portfolio.

A potential drawback for the choice of bank exposure to sovereign debt in December 2016 is that the banks could have safeguarded themselves against problematic countries after the European debt crisis such that exposure to certain countries is lower than what it was before the crisis. This could hamper the transmission of shocks from Portugal or Spain, for example. One may argue that the transition matrix is not constant over time and that it is endogenous as it is the result of investment decisions rather than exogenously determined. Notice that most transition matrices used in the literature suffer from this problem, except physical distance and contiguity. Indeed, trade intensity negatively depends on the distance between geographical units (Tinbergen, 1962). Economic

[6]Traditionally, the periphery countries refer to Italy, Spain, Ireland, Portugal and Greece.

[7]Despite being a member of the G7, Italy is often considered as part of the periphery due to the state of its public finances and competitiveness.

centers importance may therefore vary across time. Distance based on economic centers may therefore also exhibit time-varying properties. Having established that virtually all transition matrices suffer from this problem except the contiguity matrix, one needs to assess to which extent the time-varying properties of the transition matrices hinder the analysis.

To check this issue, I collected data from the Coordinated Portfolio Investment Survey from the IMF. This dataset contains the reported value of a country's foreign assets on each counterpart country. Notice, however, that foreign assets include all counterparty sectors (households, official sector and financial institutions) such that this metric captures more than foreign sovereign debt exposure. Data are collected on 31st December of each year between 2001 and 2012 and semi-annually for the subsequent years.[8] Given the availability of the data, I can track the evolution of portfolio shares spanning three recessions. Two conclusions can be drawn from the exercise. First, the country shares in the portfolios are relatively stable as can be seen in Figure 4.2. The debtor countries are found in columns while the creditor country is found in rows. The ratio of the mean share onto its standard deviation gives values well above 2.5 in most cases, indicating that the dispersion around the mean is low. Second, there is no clear pattern in the temporal evolution of the positions. In particular, there is no clear evidence that the sovereign debt crisis in Europe led to a definitive decline in the exposure towards periphery countries. Notice also that if there is a trend in the evolution of the exposures, this trend has been fairly gradual throughout the sample period. As a consequence, the issue of endogeneity of the transmission matrix appears to be limited.[9] I therefore continue the analysis with the EBA measure with the caveat that potential time-variation in the spatial transmission may provide additional insight for the issue at hand. Table C.3 in Appendix C.2 provides a comparison of the fit with alternative spatial transmission matrices.

4.5 Results

4.5.1 Impulse response functions

In this section, I present a selection of Impulse Response Functions from the set of 65 IRFs available. I report the median response of a 1 unit increase in the shock variable based on 500 stationary draws together with the 90% confidence interval derived from the empirical distribution of the draws. I have re-scaled the impulse responses by the value on impact of the shocked variable, which corresponds to one standard deviation of the shocked variable. Given the re-scaling of the shocks, I can assess the relative importance

[8] Starting in June 2013, the data are made available on a semi-annual basis. However, not all countries report their holdings at that frequency and this is the reason why I limit myself to December 2001 through December 2012, June 2014 and 2015, December 2015, December 2016 and June 2017.

[9] Recently, Blasqués et al. (2016) and Qu, Lee and Yu (2017) have devised spatial models which accommodate a time-varying transmission matrix.

Figure 4.2 – Evolution of Coordinated Portfolio Investment Survey weights between 2001 and 2016

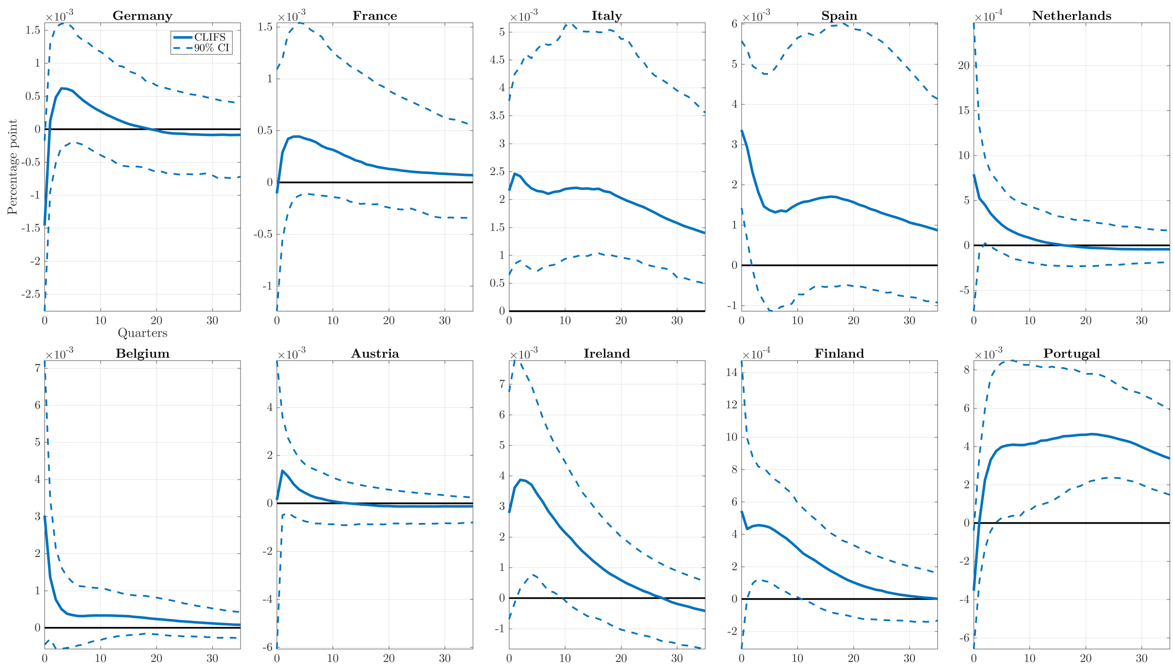
Note: the figure presents, for each reporting country (in rows) the share of total foreign assets in the counterparty country (in columns) between December 2001 and December 2016. The horizontal sum of the shares equals 1.

of the responses depending on the origin of the shocks. Comparing shocks with different scales would hamper the analysis.

4.5.1.1 Common shocks

Volatility shocks produce heterogeneous responses in terms of magnitude and significance as can be seen in Figure 4.3. Generally speaking, countries traditionally categorized in the periphery tend to respond more than the core countries. In addition, periphery countries see their spread statistically increase. The shape of the response is, however, country-specific. Indeed, while Italy sees a direct and long-lasting effect, the response of Spain is short-lived. Ireland and Portugal exhibit a delayed response of their spread, quickly decreasing for the first but long-lasting for the second. In terms of economic significance, a one unit shock in the VSTOXX corresponds to 40% of its variance, such that one should multiply the responses in Figure 4.3 by 2.5 to obtain the responses to a one standard deviation shock of the VSTOXX. For instance, the response of the Spanish spread amounts to just under 1 basis point. Volatility in the European stock market therefore has little influence on domestic spreads.

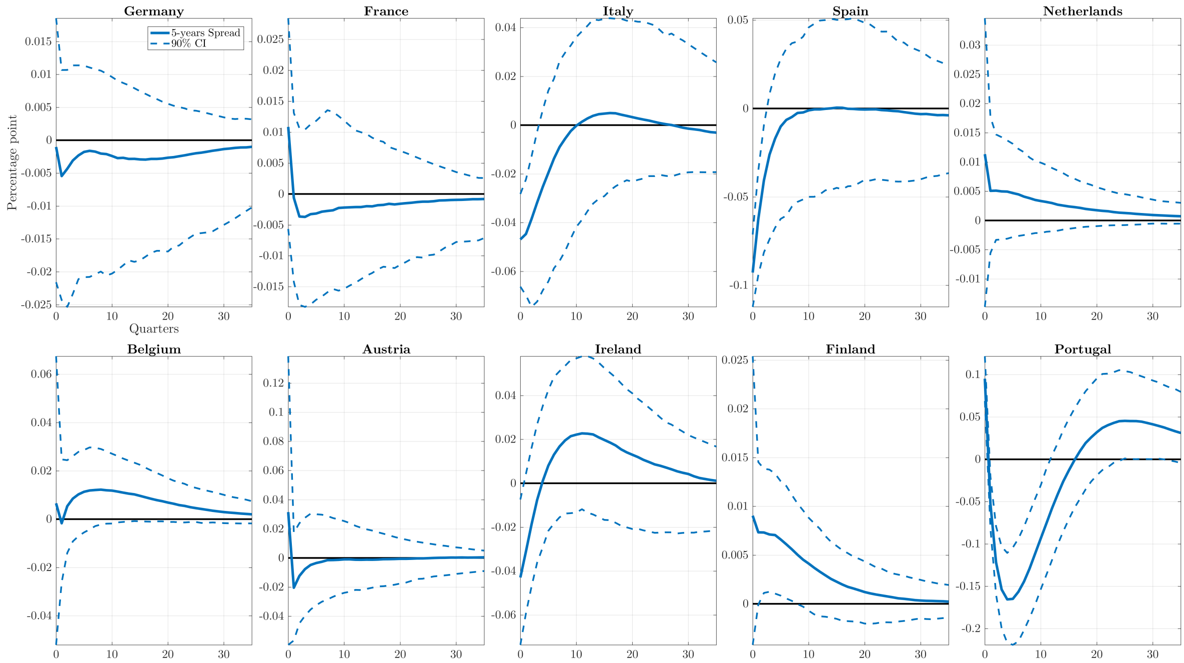
Figure 4.3 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the Volatility Index



Note: the figure presents the responses of the 5-years spread to a shock to the VSTOXX. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval on the empirical distribution of the IRFs. The size of the shock is scaled such that the volatility index increases by one unit.

Figure 4.4 reports the responses of a one percentage point increase in the 5-years OIS rate. In order to compute the responses, I apply the following method: first, the two components are shocked. Second, the responses to each shock are then weighted by the loadings of the first two principal components of the OIS yield curve given by the eigenvalue-eigenvector decomposition. Third, I sum the weighted responses and finally, I divide by the initial response of the 5-years OIS rate. The core-periphery distinction is particularly pronounced here. While core countries spreads do not respond to the impulsion, the periphery countries have a tendency to see their spreads decrease. The magnitude is in general inversely correlated with the economic size of the country. Italy reduces its spread by 4 basis points initially, while Portugal, after an initial increase, sees its spread reduced by 15 basis points.

Figure 4.4 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years OIS rate

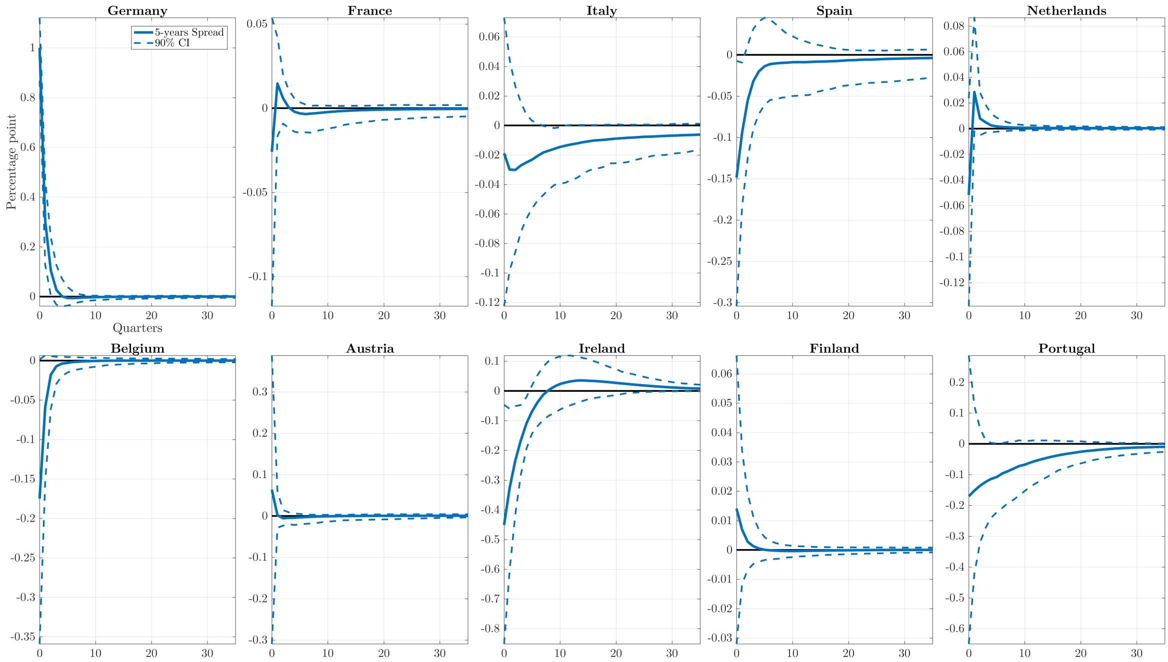


Note: the figure presents the responses of the 5-years spread to a shock to the 5-years OIS rate. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval on the empirical distribution of the IRFs. The size of the shock is scaled such that the 5-years OIS rate increases by one unit.

4.5.1.2 Domestic shocks

I report the simulated responses of the 5-years spread of European countries to a shock in another country of the zone in Figures 4.5 to 4.8. I selected as origins of the shocks Germany, Italy, Belgium and Portugal because Germany is the largest country in the eurozone and the largest in the core countries, while Italy is the largest in the periphery countries. I also selected Belgium and Portugal to cover small economies in the core and

Figure 4.5 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years German spread



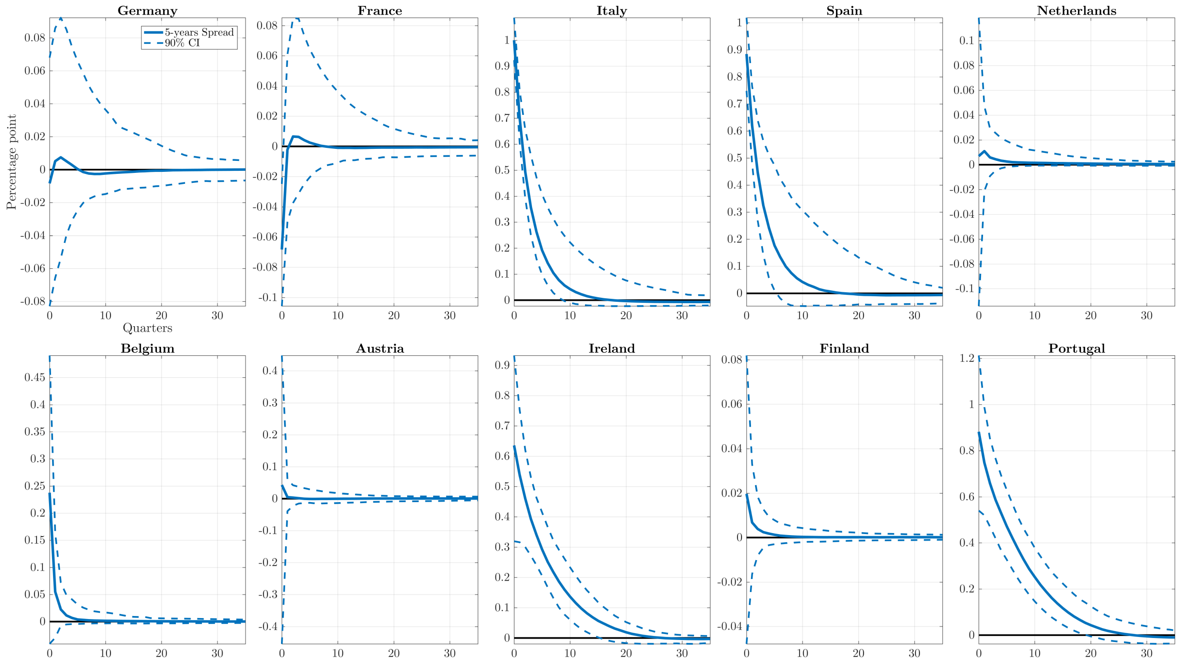
Note: the figure presents the responses of the 5-years spread to a shock to the 5-years German spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the German spread increases by one percentage point.

periphery countries, respectively.

The computation of the spread shock is as follows: each component of the spread is shocked by their respective variance. I then multiply the responses by the loadings of each component and sums the responses. I later scale them such that the country spread has increased by 1 percentage point with respect to the baseline in order to be able to compare the relative strength of the responses across countries.

Both the core-periphery and big-small dichotomies matter. Indeed, a one percentage point increase in the German spread does not produce any significant response in its neighboring countries, with the exception of Ireland. As such, Germany confirms its status of reliable debtor such that countries exposed to its debt should not see their solvency re-evaluated. If anything, periphery countries tend to decrease their spreads, although this is not statistically significant. This result is particularly interesting because despite a sizeable exposure to German debt, German spread shocks do not propagate further. However, when the Italian spread increases by one percentage point, it generates ripple effects to Spain, Ireland and Portugal. A shock from a large country in the periphery therefore typically affects other peripheral countries in a non-trivial way. The responses are also economically meaningful: the responses range from 60 basis points in Ireland to 1.5 percentage point in Portugal. Interestingly, even with a low exposure to Italian debt,

Figure 4.6 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Italian spread



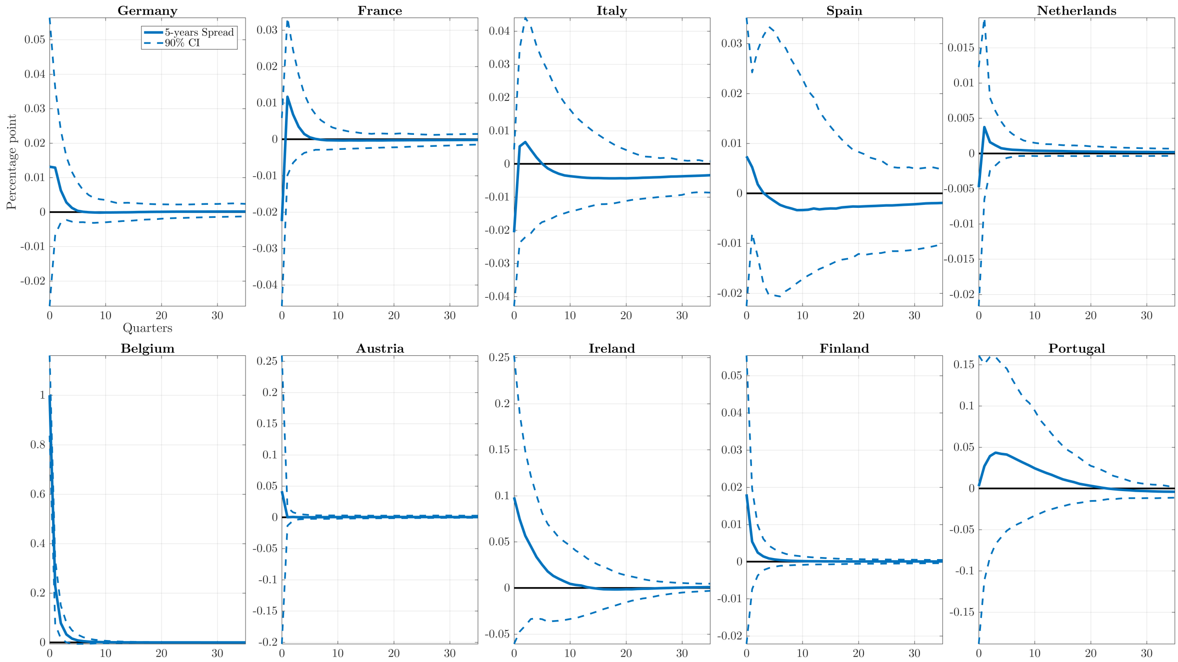
Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Italian spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Italian spread increases by one percentage point.

periphery countries experience spillover effects.

Notice, however, that small economies, whether in the core or the periphery, do not significantly affect the perceived solvency of their neighbors. Using panel spatial regression techniques on daily data from EMU countries for the period January 2007 to September 2013, Muratori (2014) reports that the spatial coefficients in sovereign spreads regressions for core and periphery countries are fairly similar across the two groups. The model presented here, however, does not make a distinction between the two groups ex-ante. Notice also that the persistence of the shock differs across the core-periphery dimension. German and Belgian shocks are shorter-lived than shocks originating in Italy or Portugal. The takeaway from this exercise is that Italy should be watched more closely than any other country from the zone regarding the potential contagion effects across bond markets. This result reinforces the idea of risk-spreading at the expense of risk-sharing, in the view of Andrew Haldane.[10] Indeed, any network is a shock absorber and a shock transmitter at the same time. The first dimension allows the shocks to disperse within the network. If the shock is too large for the system to handle, the network may then amplify the shock. In the case of our simulation, Italy appears to be a systemic player in a network prone to

[10]Andrew Haldane: “Managing Global Finance as a system”, speech given in October 2014 at the University of Birmingham.

Figure 4.7 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Belgian spread



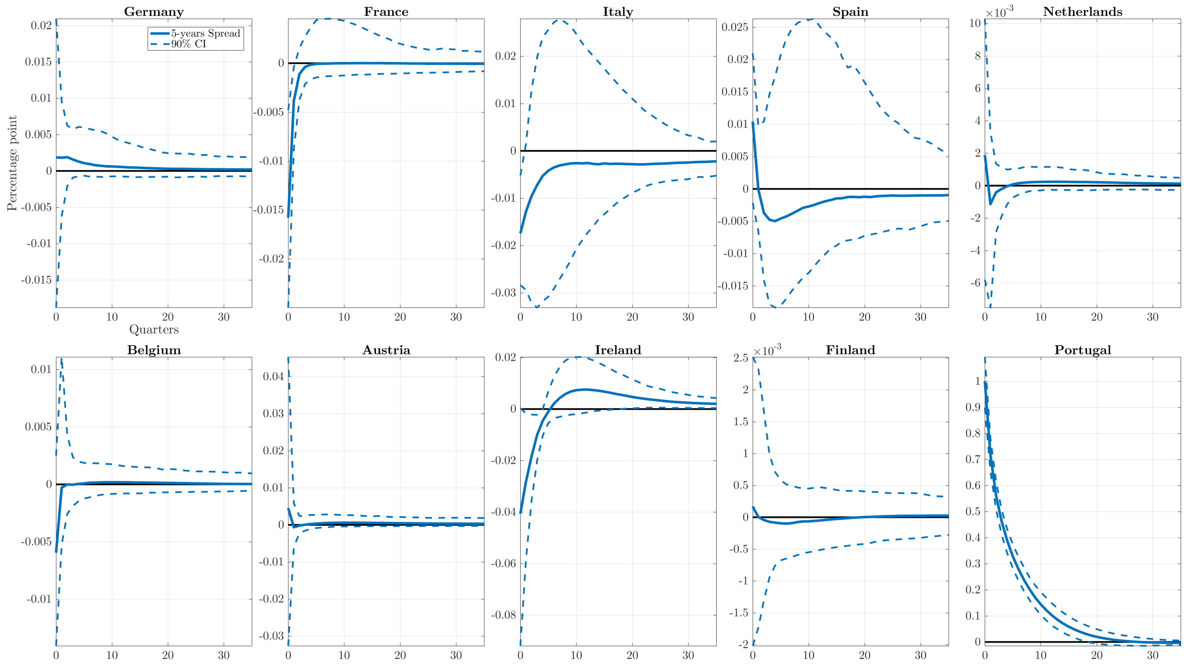
Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Belgian spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Belgian spread increases by one percentage point.

risk-spreading, at least to other periphery countries.

4.5.2 Forecast error variance decomposition

Table 4.3 reports the share of each type of shocks in the total variance of the variable considered at a given horizon averaged across the ten countries. The first column gives the share of the variance in the forecast error that is due to common shocks (volatility, real economic activity, stock returns, and OIS curve). Column 2 aggregates all domestic shocks and column 3 aggregates all foreign shocks. The sum of common, domestic and foreign shocks should be equal to 100 minus rounding errors. Three results stand out. First, domestic shocks remain the biggest driver of the variables included in the analysis. Indeed, domestic shocks explain between 95 and 60% of the forecast error between a one-month and 3-years horizon. The influence of domestic shocks is decreasing with time. Deficits remain a domestic issue as domestic factors still account for 83% of the forecast error after three years. Second, foreign factors matter more for financial variables than for macro variables. Inflation, however, seems to exhibit sizeable spillover effects. Third, foreign factors have a bigger influence on financial variables compared to common shocks while the reverse is true for macroeconomic variables. This indicates a strong co-movement

Figure 4.8 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Portuguese spread



Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Portuguese spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Portuguese spread increases by one percentage point.

in macroeconomic aggregates coupled with important spillovers in financial variables.

Turning to the variance decomposition for the spreads averaged by country in Table 4.4, we can see that numbers are comparable across the maturities. For the sake of clarity, I will therefore focus on the 5-years spreads. The first column gives the share of the variance in the forecast error that is due to common shocks (volatility, real economic activity, stock returns, and OIS curve). Column 2 aggregates all domestic shocks and column 3 aggregates all foreign shocks. The sum of common, domestic and foreign shocks should be equal to 100 provided there are no rounding errors. Spreads are mostly explained by shocks to themselves. Around 70% of the variation can still be attributed to spread shocks at the 3-years horizon. Consistent with Table 4.3, foreign shocks are the second most important driver of spreads. They explain around 16% of the spread forecast error variance. Foreign factors therefore do have a sizeable influence on domestic spreads. Lastly, common factors explain around 10% of the variation in the 5-years spread.

The numbers presented above hide in fact an important heterogeneity across countries of the zone. Table 4.5 fills this gap. In addition to the four countries for which I presented the impulse response functions, I report the results for Spain and Ireland. We can again group countries according to their size and whether they belong to the core or periphery countries. Two conclusions can be drawn from Table 4.5. First, countries from the core

Table 4.3 – Average variance decomposition by types of shocks - domestic variables

	Common shocks	Domestic shocks	Foreign shocks
	Inflation		
Horizon: 1	2	89	9
4	7	81	12
12	17	69	14
36	25	61	13
	Output		
Horizon: 1	2	93	5
4	5	89	6
12	12	81	6
36	18	76	6
	Deficit		
Horizon: 1	2	94	4
4	4	91	5
12	8	87	5
36	11	83	5
	CLIFS		
Horizon: 1	2	80	17
4	5	75	20
12	8	72	20
36	12	69	19
	PC1 Spreads OIS		
Horizon: 1	3	82	15
4	5	81	14
12	9	79	13
36	13	75	12
	PC2 Spreads OIS		
Horizon: 1	2	79	19
4	4	77	19
12	6	76	18
36	7	75	18

Note: the table reports the variance decomposition of the domestic variables based on the median impulse response, averaged by country. The first column gives the share of the variance in the forecast error that is due to common shocks (volatility, real economic activity, stock returns, and OIS curve). Columns 2 aggregates all domestic shocks and column 3 aggregates all foreign shocks. The sum of common, domestic and foreign shocks should be equal to 100 minus rounding errors. The horizon is given in months.

do not depend much on common or foreign shocks. This is true for small or big countries. Countries in the core seem therefore insulated from outside shocks. Second, countries in the periphery, on the other hand, heavily depend on common and foreign shocks, between 40 and 60%. Within the periphery countries, it is interesting to confront large and small countries. The influence of common factors on Italian spreads is rapidly increasing with the horizon, reaching 50% at a 3-year horizon. Foreign shocks, on the other hand, have little impact. For smaller countries, foreign shocks appear more important than common shocks. In particular, Irish and Portuguese spreads are explained at 30-40% by foreign shocks.

Dewachter et al. (2015) also document heterogeneity in the extent with which economic, idiosyncratic and euro-wide spreads shocks determine domestic sovereign spreads. In their setting, economic shocks relate to fundamental drivers of sovereign spreads (volatility and uncertainty, output, inflation and deficit ratio as well as the OIS curve). Their idiosyncratic shocks correspond to domestic spread shocks in our setting. They report that Italy and Belgium tend to rely more on economic determinants than France or Spain (between 55% and 60% against 40% and 35%). Interestingly, French spread is barely affected by idiosyncratic factors while Belgian and Italian idiosyncratic shocks explain 15 to 20% of the spreads. Discrepancies in the results, however, probably stems from the way foreign spreads enter the equation for the domestic spreads. Indeed, the euro-wide spreads of Dewachter et al. (2015) are treated as common across countries with a country-specific coefficient whereas I model foreign spreads as country-specific with a common coefficient. The results of Debarsy et al. (2018) also suggest heterogeneity in the diffusion process across various groups of countries. Using the dichotomy advanced vs. emerging economies, they document that shocks to one group of countries are not confined to the countries of the group but spread to all countries. The strength of the spillover effects is, however, stronger for the direction Advanced to Emerging than Emerging to Advanced. Here, I have considered a subset of their advanced economies and have showed that some countries remain isolated from adverse macroeconomic shocks. Definitive results for advanced economies may thus require more granularity.

4.6 Policy implications

The results highlighted above are particularly interesting in light of macroprudential policy. Indeed, it is often thought that stabilizing the macroeconomic situation of central players will somehow trickle down to secondary players. I have shown here, however, that there seems to exist two euro areas: one euro area which is a collection of isolated islands and another e whose members are closely connected to each other in some sort of archipelago. Policies that would target a reduction in bond yields spreads of “good students” would, in fact, prove ineffective to solve issues (and reduce spreads) in “bad students”. Conversely, if policies are instead targeted at problematic countries strongly tied to their neighbors, they can generate larger positive effects than if they were taken in isolation. The conclusion that spread shocks in core countries do not propagate beyond their borders is even more surprising given the share of core countries debt held by domestic banks (see Figure 4.1 and Table 4.2). Indeed, one would have expected a larger transmission from core to periphery than within periphery countries. In particular, I have stressed that Italy should be the most closely watched country in the eurozone due to its

Table 4.4 – Average variance decomposition by types of shocks - domestic spreads

	Common shocks	Domestic shocks	Foreign shocks
		1-year Spread	
Horizon: 1	3	80	17
4	4	79	16
12	7	77	16
36	10	76	15
		5-years Spread	
Horizon: 1	3	79	18
4	5	79	16
12	8	77	15
36	12	74	14
		10-years Spread	
Horizon: 1	2	78	20
4	4	77	20
12	7	75	18
36	10	72	17

Note: the table reports the variance decomposition of the 1-, 5- and 10 years domestic spread based on the median impulse response, averaged by country. The first column gives the share of the variance in the forecast error that is due to common shocks (volatility, real economic activity, stock returns, and OIS curve). Columns 2 aggregates all domestic shocks and column 3 aggregates all foreign shocks. The sum of common, domestic and foreign shocks should be equal to 100 minus rounding errors. The horizon is given in months.

importance for other countries, especially those in the periphery. Implementing policies that reduce Italian spreads would benefit peripheral countries.

Of course, this conclusion should be moderated by the issue that the economic content of spreads is not absolute. Indeed, historical decompositions presented in Dewachter et al. (2015) for the five countries included in their analysis (Belgium, France, Germany, Italy, Spain) show that the idiosyncratic component of bond yields spreads is less important than economic and non-fundamental components. Policies aimed at specific macroeconomic aggregates in large core countries may still generate positive outcomes in periphery countries. The results presented here therefore also suggest that stronger coordination may improve the efficiency of domestic policies.

This research follows the strand of the literature that follows what was called in the literature *real linkages* (Debarsy et al., 2018), that is transmission that is due to formal relationships across spatial units. There is another strand of the literature that focuses on *informational channels*. The transmission mechanism is different in this type of models. Market participants do not gather all relevant information but rather use one or several spatial units as proxy for other spatial units. In other words, there could be contagion that is not related to fundamentals (Pritsker, 2001). Following an adverse shock to one country, market participants will re-evaluate the situation of countries they judge similar.

Table 4.5 – Country-wise variance decomposition by type of shock - domestic 5-years spread

	Common shocks	Domestic shocks	Foreign shocks
		Germany	
Horizon: 1	5	87	8
4	4	86	9
12	7	83	10
36	7	83	10
		Italy	
Horizon: 1	7	83	10
4	14	76	10
12	30	60	9
36	51	42	7
		Spain	
Horizon: 1	4	40	56
4	5	45	50
12	7	47	45
36	14	44	42
		Belgium	
Horizon: 1	3	89	8
4	3	89	8
12	4	88	8
36	5	87	8
		Ireland	
Horizon: 1	1	70	29
4	2	69	29
12	4	71	25
36	4	73	23
		Portugal	
Horizon: 1	3	52	45
4	5	62	33
12	10	65	24
36	21	59	20

Note: the table reports the variance decomposition of the 5-years domestic spread based on the median impulse response for a selection of countries. The first column gives the share of the variance in the forecast error that is due to common shocks (volatility, real economic activity, stock returns, and OIS curve). Columns 2 aggregates all domestic shocks and column 3 aggregates all foreign shocks. The sum of common, domestic and foreign shocks should be equal to 100 minus rounding errors. The horizon is given in months.

There is therefore spillover without having explicit relationships among spatial units. If we could summarize countries in the periphery along a few dimensions (by computing principal components, for instance), we could augment a classical Vector Autoregression with the newly obtained factors in order to address differently the question whether there exists spillover effects across eurozone bond markets.

4.7 Potential extensions of the present research

There are various ways the current research could be extended. I list hereunder a few potential candidates. First, I could investigate the importance of the informational channels, as explained in the previous section. Although the model may be easier to handle, it would be at the expense of tractability. The real linkages are, in my view, preferable because the transmission mechanism is clearly identified. The informational channel would be, however, an interesting complement to the current research.

Second, I could investigate if the chosen identification strategy is determinant for the results obtained. As is the case with the Cholesky triangular factorization, the ordering of the variables and the countries may have an influence on the impulse responses. Another ordering that comes to mind is to sort countries by the schism of core-periphery and then by economic size. Indeed, in the current ordering, the core-periphery distinction is absent. Since Italy and Spain appear early in the country ordering, relegating them at the seventh and eighth position could have an influence. Another avenue of improvement regarding the identification of the shocks is to consider sign restrictions of the responses. Identification by sign restrictions has the advantages that the ordering of the variables is irrelevant and that some responses are forced to be compatible with economic theory. However, it has the disadvantage that it selects shocks that are compatible with the restrictions. There is thus identification uncertainty in this respect. To carry out this extension, I could combine two sets of sign restrictions. The first set is derived from Forni and Gambetti (2010) who identify , for a single country, a monetary policy shock, a fiscal policy shock and aggregate demand/aggregate supply shocks. The second set of restrictions is derived from De Santis and Zimic (2017). Their restrictions do not hinge on the sign itself but on the magnitude of the responses. Their rationale is that a shock in a country should produce larger domestic responses than in the foreign country. The current setup would prove very difficult for this extension because of the numerous shocks to identify. Convergence of the algorithm would be extremely slow because the difficulty of the problem increases exponentially with the number of shocks and the number of restrictions. One way to address this issue would be to group countries according to the core-periphery dichotomy such that there would remain only two blocks of six variables. Grouping could be made with an arithmetic or weighted average (by economic size or principal components). We would, however, lose the transmission mechanism.

Third, sub-sample analysis could provide additional information. For instance, a division between core and periphery would probably be informative. Appending countries that are too heterogeneous may lead to non-significant results because effects pertaining to each sub-groups could cancel each other. It would therefore be interesting to check whether the results presented above also hold for each sub-group taken separately. This extension would be closer in spirit to Muratori (2014). I could also divide the sample according to the time dimension. This would address the potential issue of time-varying spatial diffusion. Given my dataset, I could distinguish between a period pre-European debt crisis, crisis, and post-crisis. I suspect that spatial transmission behaved differently in those periods. Although less granular than our dataset, Haldane (2014) presents evidence of that the correlation of bond yields tended to be much stronger before 2005 and that the correlation across assets between European periphery countries has, however, increased after the crisis. The sub-periods may also be endogenously determined. I could, for instance, apply a Markov-switching filter to the data to extract a high- vs low-uncertainty regime. Lastly, I could also estimate rolling-window regressions and assess whether spatial diffusion is time-dependent. Very recently, Afonso et al. (2017) have proposed a framework which allows them to assess whether the pricing of bond yields vary across time. They find a pre- and post-European debt crisis regime. The latter regime is characterized by a weaker link between spreads and fundamentals.

The current framework could also be adapted and be used as an early-warning system. Indeed, the maximum likelihood estimation is versatile enough to accommodate various functional form. One equation of the VAR would then be estimated with a spatial Probit/Logit model where the dependent variable would be the occurrence of a crisis. The remaining equations of the VAR would then serve as auxiliary regressions to explain the dynamics of the independent variables included in the Probit/Logit regression. The suggested approach here would be close in spirit to Amaral, Abreu and Mendes (2010, 2014) but with the advantage of the dynamic multivariate setup.

To summarize, the framework presented here remains fairly versatile and is open to various sorts of extensions.

4.8 Conclusions

In this chapter, I have built a macro-finance model that takes into account potential spillover effects from neighboring countries. I have applied the model to euro area countries where the spatial transmission mechanism takes advantage of the relative exposure of domestic commercial banks to foreign sovereign debt. The framework allows macroeconomic and financial variables to generate contemporaneous as well as temporally lagged spatial diffusion. Shocks are identified in such a way that financial variables react rapidly with macro news and shocks in smaller countries do not directly affect larger countries, although they can have feedback effects.

The results have shown that spillover effects of financial shocks are large for the periphery countries. Financial shocks from large core countries do not propagate to other core countries, nor periphery countries. Spreads shocks from periphery countries, however, transmit to other periphery countries, but not to core countries. In particular, for every percentage point increase in Italian spreads, Spanish, Irish and Portuguese spreads increase by 90, 60 and 95 basis points on impact. Variance decompositions have shown that foreign shocks matter more for financial variables than macroeconomic variables. Typically, foreign variables are twice as important for financial variables than they are for macroeconomic variables. Around 10% and 15% of domestic spreads can on average be explained by common and foreign factors. However, I have also documented important heterogeneity in the behavior of eurozone members. Typically, countries differ according to their economic size and whether or not they are part of the core or the periphery countries. Smaller countries and countries from the periphery rely the most on common and foreign factors compared to core countries.

The results highlighted above, and most importantly the evidence of sizeable heterogeneity in the eurozone countries, point towards the need for policies that are aimed at specific countries rather than a *one size fits all*-type of policies. In particular, policymakers that have systemic stability at heart should unveil and understand the strong linkages across economies of the zone while trying to address the heterogeneity of the responses.

References

Adolfson, M., S. Laseen, J. Linde, and M. Villani (2007, July). Bayesian estimation of an open economy DSGE model with incomplete pass-through. *Journal of International Economics 72*(2), 481–511.

Afonso, A., M. G. Arghyrou, M. D. Gadea, and A. Kontonikas (2017, September). "Whatever it takes" to resolve the European sovereign debt crisis? Bond pricing regime switches and monetary policy effects. Cardiff Economics Working Papers E2017/12, Cardiff University, Cardiff Business School, Economics Section.

Afonso, A. and M. M. Martins (2012). Level, slope, curvature of the sovereign yield curve, and fiscal behaviour. *Journal of Banking & Finance 36*(6), 1789–1807.

Amaral, A., M. Abreu, and V. Mendes (2010, January). Contagion in Banking Crises: A Spatial Probit Model. Working Papers Department of Economics 2010/03, ISEG - Lisbon School of Economics and Management, Department of Economics, Universidade de Lisboa.

Amaral, A., M. Abreu, and V. Mendes (2014). The Spatial Probit Model. An Application to the Study of Banking Crises at the End of the 90s. CEFAGE-UE Working Papers 2014(05), University of Evora, CEFAGE-UE (Portugal).

Ang, A., S. Dong, and M. Piazzesi (2005). No-arbitrage Taylor rules. *Proceedings*.

Ang, A. and M. Piazzesi (2003, May). A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables. *Journal of Monetary Economics 50*(4), 745–787.

Anselin, L. (1988). A test for spatial autocorrelation in seemingly unrelated regressions. *Economics Letters 28*(4), 335–341.

Arellano, C. (2008, June). Default risk and income fluctuations in emerging economies. *American Economic Review 98*(3), 690–712.

Arghyrou, M. G. and A. Kontonikas (2012). The EMU sovereign-debt crisis: Fundamentals, expectations and contagion. *Journal of International Financial Markets, Institutions and Money 22*(4), 658–677.

Auerbach, A. and Y. Gorodnichenko (2013). Output spillovers from fiscal policy. *American Economic Review 103*(3), 141–46.

Auerbach, A. J. and Y. Gorodnichenko (2012, November). Fiscal Multipliers in Recession and Expansion. In *Fiscal Policy after the Financial Crisis*, NBER Chapters, pp. 63–98. National Bureau of Economic Research, Inc.

Auerbach, A. J. and Y. Gorodnichenko (2017, September). Fiscal stimulus and fiscal sustainability. Working Paper 23789, National Bureau of Economic Research.

Bailey, M. J. (1962). *National Income and the Price Level.* New York: McGraw-Hill.

Barro, R. J. (1974, Nov.-Dec.). Are Government Bonds Net Wealth? *Journal of Political Economy 82*(6), 1095–1117.

Barro, R. J. (1989, Spring). The Ricardian Approach to Budget Deficits. *Journal of Economic Perspectives 3*(2), 37–54.

Barro, R. J. (1996, March). Reflections on Ricardian Equivalence. NBER Working Papers 5502, National Bureau of Economic Research, Inc.

Barth, J. R. I., G. Russek, and M. Wohar (1991). The effects of fereal budget deficits on interest rates and the composition of domestic output. In Penner (Ed.), *The Great Fiscal Experiment*, Chapter 2, pp. 69–142. Urban Institute Press.

Bauer, G. H. and A. D. de los Rios (2012). An International Dynamic Term Structure Model with Economic Restrictions and Unspanned Risks. Staff Working Papers 12-5, Bank of Canada.

Bauer, M. D. and G. D. Rudebusch (2015, January). Resolving the spanning puzzle in macro-finance term structure models. Working Paper Series 2015-1, Federal Reserve Bank of San Francisco.

Baumeister, C. and J. D. Hamilton (2015, September). Sign restrictions, structural vector autoregressions, and useful prior information. *Econometrica 83*(5), 1963–1999.

Beenstock, M. and D. Felsenstein (2007). Spatial Vector Autoregressions. *Spatial Economic Analysis 2*(2), 167–196.

Beirne, J. and M. Fratzscher (2013). The pricing of sovereign risk and contagion during the European sovereign debt crisis. *Journal of International Money and Finance 34*(C), 60–82.

Beltran, D. O., M. Kretchmer, J. Marquez, and C. P. Thomas (2013). Foreign holdings of u.s. treasuries and u.s. treasury yields. *Journal of International Money and Finance 32*, 1120 – 1143.

Bettendorf, T. (2013). Feeding the Global VAR with theory: Is German wage moderation to blame for European imbalances? Annual Conference 2013 (Duesseldorf): Competition Policy and Regulation in a Global Economic Order 79710, Verein für Socialpolitik / German Economic Association.

Bettendorf, T. (2016). Spillover effects of credit default risk in the euro area and the effects on the euro: A GVAR approach. Discussion Papers 42/2016, Deutsche Bundesbank.

Blanchard, O. and R. Perotti (2002, November). An empirical characterization of the dynamic effects of changes in government spending and taxes on output. *The Quarterly Journal of Economics 117*(4), 1329–1368.

Blasques, F., S. J. Koopman, A. Lucas, and J. Schaumburg (2016). Spillover dynamics for systemic risk measurement using spatial financial time series models. *Journal of Econometrics 195*(2), 211–223.

Bohn, H. (1998). The behavior of u. s. public debt and deficits. *The Quarterly Journal of Economics 113*(3), 949–963.

Bonciani, D. and B. v. Roye (2016). Uncertainty shocks, banking frictions and economic activity. *Journal of Economic Dynamics and Control 73*(C), 200–219.

Borgy, V., T. Laubach, J.-S. Mésonnier, and J.-P. Renne (2011). Fiscal Sustainability, Default Risk and Euro Area Sovereign Bond Spreads Markets. Working papers 350, Banque de France.

Buiter, W. H. (1977, June). 'Crowding out' and the effectiveness of fiscal policy. *Journal of Public Economics 7*(3), 309–328.

Canzoneri, M. B., R. E. Cumby, and B. T. Diba (2002). Should the European Central Bank and the Federal Reserve be concerned about fiscal policy? *Proceedings - Economic Policy Symposium - Jackson Hole*, 333–389.

Caporin, M., L. Pelizzon, F. Ravazzolo, and R. Rigobon (2015). Measuring sovereign contagion in Europe. SAFE Working Paper Series 103, Research Center SAFE - Sustainable Architecture for Finance in Europe, Goethe University Frankfurt.

Cho, J. S. and H. White (2007). Testing for regime switching. *Econometrica 75*(6), 1671–1720.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005, February). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy 113*(1), 1–45.

Cliff, A. and J. Ord (1973). *Spatial Autocorrelation.* Pion.

Cochrane, J. and M. Piazzesi (2009). Decomposing the Yield Curve. 2009 Meeting Papers 18, Society for Economic Dynamics.

Cochrane, J. H. and M. Piazzesi (2005, March). Bond Risk Premia. *American Economic Review 95*(1), 138–160.

Cooper, I. (2009, July). Time-Varying Risk Premiums and the Output Gap. *Review of Financial Studies 22*(7), 2601–2633.

Dai, Q. and T. Philippon (2005, August). Fiscal policy and the term structure of interest rates. NBER Working Papers 11574, National Bureau of Economic Research, Inc.

Dai, Q. and K. J. Singleton (2000, October). Specification Analysis of Affine Term Structure Models. *Journal of Finance 55*(5), 1943–1978.

Dai, Q., K. J. Singleton, and W. Yang (2007, 2007 12). Regime Shifts in a Dynamic Term Structure Model of U.S. Treasury Bond Yields. *Review of Financial Studies 20*(5), 1669–1706.

Davig, T. and E. M. Leeper (2005, December). Generalizing the taylor principle. NBER Working Papers 11874, National Bureau of Economic Research, Inc.

Davig, T. and E. M. Leeper (2007, May). *Fluctuating Macro Policies and the Fiscal Theory*, pp. 247–316. MIT Press.

Davig, T. and E. M. Leeper (2011, February). Monetary-fiscal policy interactions and fiscal stimulus. *European Economic Review 55*(2), 211–227.

Davig, T., E. M. Leeper, and H. Chung (2004, March). Monetary and fiscal policy switching. NBER Working Papers 10362, National Bureau of Economic Research, Inc.

De Santis, R. A. and S. Zimic (2017, May). Spillovers among sovereign debt markets: identification by absolute magnitude restrictions. Working Paper Series 2055, European Central Bank.

Debarsy, N., C. Dossougoin, C. Ertur, and J.-Y. Gnabo (2018). Measuring sovereign risk spillovers and assessing the role of transmission channels: A spatial econometrics approach. *Journal of Economic Dynamics and Control 87*(C), 21–45.

Dewachter, H., R. Houssa, and P. Toffano (2012, June). Spatial propagation of macroeconomic shocks in Europe. *Review of World Economics (Weltwirtschaftliches Archiv) 148*(2), 377–402.

Dewachter, H., L. Iania, M. Lyrio, and M. de Sola Perea (2015). A macro-financial analysis of the euro area sovereign bond market. *Journal of Banking & Finance 50*(C), 308–325.

Dewachter, H. and P. Toffano (2012). Fiscal activism and the cost of debt financing. *International Journal Of Finance And Economics 17*, 14–22.

Diebold, F. X. and C. Li (2006, February). Forecasting the term structure of government bond yields. *Journal of Econometrics 130*(2), 337–364.

Dillen, H. (1997, September). A model of the term structure of interest rates in an open economy with regime shifts. *Journal of International Money and Finance 16*(5), 795–819.

Duffee, G. R. (2002, 02). Term Premia and Interest Rate Forecasts in Affine Models. *Journal of Finance 57*(1), 405–443.

Duffee, G. R. (2011). Information in (and not in) the Term Structure. *Review of Financial Studies 24*(9), 2895–2934.

Duffee, G. R. (2012, June). Bond pricing and the macroeconomy. Economics Working Paper Archive 598, The Johns Hopkins University,Department of Economics.

Duffie, D. and K. J. Singleton (1999). Modeling Term Structures of Defaultable Bonds. *Review of Financial Studies 12*(4), 687–720.

Eaton, J. and M. Gersovitz (1981, April). Debt with potential repudiation: Theoretical and empirical analysis. *Review of Economic Studies 48*(2), 289–309.

Eichengreen, B., A. K. Rose, and C. Wyplosz (1996, August). Contagious Currency Crises. CEPR Discussion Papers 1453, C.E.P.R. Discussion Papers.

Elhorst, J. P. (2003, July). Specification and Estimation of Spatial Panel Data Models. *International Regional Science Review 26*(3), 244–268.

Elmendorf, D. W. and N. Gregory Mankiw (1999). Government debt. In J. B. Taylor and M. Woodford (Eds.), *Handbook of Macroeconomics*, Volume 1 of *Handbook of Macroeconomics*, Chapter 25, pp. 1615–1669. Elsevier.

Estrella, A. and F. S. Mishkin (1998, February). Predicting U.S. Recessions: Financial Variables As Leading Indicators. *The Review of Economics and Statistics 80*(1), 45–61.

Evans, C. L. and D. A. Marshall (2007, October). Economic determinants of the nominal treasury yield curve. *Journal of Monetary Economics 54*(7), 1986–2003.

Evans, P. (1985, March). Do large deficits produce high interest rates? *American Economic Review 75*(1), 68–87.

Evans, P. (1987, February). Interest rates and expected future budget deficits in the united states. *Journal of Political Economy 95*(1), 34–58.

Fadejeva, L., M. Feldkircher, and T. Reininger (2015, January). Spillovers from Euro Area and U.S. Credit and Demand Shocks: Comparing Emerging Europe on the Basis of a GVAR Model. Working Papers 198, Oesterreichische Nationalbank (Austrian Central Bank).

Fama, E. F. and R. R. Bliss (1987). The information in long-maturity forward rates. *The American Economic Review 77*(4), 680–692.

Favero, C. and T. Monacelli (2005). Fiscal policy rules and regime (in)stability: Evidence from the u.s. Working Papers 282, IGIER (Innocenzo Gasparini Institute for Economic Research), Bocconi University.

Feldstein, M. (1980, September). Fiscal Policies, Inflation, and Capital Formation. *American Economic Review 70*(4), 636–650.

Feldstein, M. (1986, July). Budget deficits, tax rules, and real interest rates. NBER Working Papers 1970, National Bureau of Economic Research, Inc.

Forni, M. and L. Gambetti (2010, February). Macroeconomic Shocks and the Business Cycle: Evidence from a Structural Factor Model. CEPR Discussion Papers 7692, C.E.P.R. Discussion Papers.

Frankel, J. A. and A. K. Rose (1998, July). The Endogeneity of the Optimum Currency Area Criteria. *Economic Journal 108*(449), 1009–1025.

Fry, R. and A. Pagan (2011, December). Sign restrictions in structural vector autoregressions: A critical review. *Journal of Economic Literature 49*(4), 938–60.

Gale, W. G. and P. R. Orszag (2003, September). Economic Effects of Sustained Budget Deficits. *National Tax Journal 56*(3), 463–485.

Galí, J. and T. Monacelli (2005). Monetary Policy and Exchange Rate Volatility in a Small Open Economy. *Review of Economic Studies 72*(3), 707–734.

Goodfriend, M. (2002). The phases of u.s. monetary policy : 1987 to 2001. *Economic Quarterly* (Fall), 1–17.

Greenwood, R. and D. Vayanos (2008, February). Bond Supply and Excess Bond Returns. CEPR Discussion Papers 6694, C.E.P.R. Discussion Papers.

Gruss, B. and K. Mertens (2009). Regime switching interest rates and fluctuations in emerging markets. Economics Working Papers ECO2009/22, European University Institute.

Hall, P. and J. L. Horowitz (1996, July). Bootstrap Critical Values for Tests Based on Generalized-Method-of-Moments Estimators. *Econometrica 64*(4), 891–916.

Hamilton, J. D. (1988). Rational-expectations econometric analysis of changes in regime : An investigation of the term structure of interest rates. *Journal of Economic Dynamics and Control 12*(2-3), 385–423.

Hamilton, J. D. (1994). *Time Series Analysis*. Princeton University Press.

Harvey, C. (1986, December). *Recovering Expectations of Consumption Growth from an Equilibrium Model of the Term Structure of Interest Rates*. Ph. D. thesis, University of Chicago.

Hodrick, R. J. and E. Prescott (1981, May). Post-war u.s. business cycles: An empirical investigation. Discussion Papers 451, Northwestern University, Center for Mathematical Studies in Economics and Management Science.

Hofmann, B. and B. Bogdanova (2012, September). Taylor rules and monetary policy: a global 'great deviation'? *BIS Quarterly Review*.

Hondroyiannis, G., H. Kelejian, and G. Tavlas (2009). Spatial Aspects of Contagion among Emerging Economies. *Spatial Economic Analysis 4*(2), 191–211.

Houssa, R. and O. Hubert (2015). Macroeconomic policy interactions and the effects of fiscal stimulus.

Hubbard, G. (2012, January). Consequences of government deficits and debts. *International Journal of Central Banking 8*(S1), 203–235.

Joslin, S., M. Priebsch, and K. J. Singleton (2014, 06). Risk Premiums in Dynamic Term Structure Models with Unspanned Macro Risks. *Journal of Finance 69*(3), 1197–1233.

Joslin, S., K. J. Singleton, and H. Zhu (2011). A New Perspective on Gaussian Dynamic Term Structure Models. *Review of Financial Studies 24*(3), 926–970.

Kaminsky, G. L. and C. M. Reinhart (2000, June). On crises, contagion, and confusion. *Journal of International Economics 51*(1), 145–168.

Kapoor, M., H. H. Kelejian, and I. R. Prucha (2007, September). Panel data models with spatially correlated error components. *Journal of Econometrics 140*(1), 97–130.

Keen, H. (1989). The yield curve as a predictor of business cycle turning points. *Business Economics 24*(4), 37–43.

Keynes, J. M. (1936). *The General Theory of Employment, Interest and Money.* Macmillan. 14th edition, 1973.

Kilian, L. (2009, June). Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market. *American Economic Review 99*(3), 1053–1069.

Kim, C.-J. (1994). Dynamic linear models with Markov-switching. *Journal of Econometrics 60*(1-2), 1–22.

Kose, M. A., C. Otrok, and C. H. Whiteman (2003, September). International Business Cycles: World, Region, and Country-Specific Factors. *American Economic Review 93*(4), 1216–1239.

Künsch, H. R. (1989). The jackknife and the bootstrap for gerneral stationary observations. *The Annals of Statistics 17*(3), 1217–1241.

Lancaster, T. (2000, April). The incidental parameter problem since 1948. *Journal of Econometrics 95*(2), 391–413.

Laubach, T. (2009, 06). New evidence on the interest rate effects of budget deficits and debt. *Journal of the European Economic Association 7*(4), 858–885.

Leduc, S. and Z. Liu (2016). Uncertainty shocks are aggregate demand shocks. *Journal of Monetary Economics 82*(C), 20–35.

Lee, L.-f. and J. Yu (2010, April). A Spatial Dynamic Panel Data Model With Both Time And Individual Fixed Effects. *Econometric Theory 26*(02), 564–597.

Leeper, E. M. (1991, February). Equilibria under 'active' and 'passive' monetary and fiscal policies. *Journal of Monetary Economics 27*(1), 129–147.

Leeper, E. M. and C. Leith (2016, January). Understanding Inflation as a Joint Monetary-Fiscal Phenomenon. NBER Working Papers 21867, National Bureau of Economic Research, Inc.

Litterman, R. and J. Scheikman (1991). Common factors affecting bond returns. *Journal of Fixed Income 1 (1)*, 54–61.

Ludvigson, S. C. and S. Ng (2009, July). A Factor Analysis of Bond Risk Premia. NBER Working Papers 15188, National Bureau of Economic Research, Inc.

May, A. M. (1990, June). President Eisenhower, Economic Policy, and the 1960 Presidential Election. *The Journal of Economic History 50*(02), 417–427.

Mise, E., T.-H. Kim, and P. Newbold (2005, March). On suboptimality of the hodrick-prescott filter at time series endpoints. *Journal of Macroeconomics 27*(1), 53–67.

Modigliani, F. (1961). Long-run implications of alternative fiscal policies and the burden of the national debt. *The Economic Journal 71*(284), 730–755.

Modigliani, F. and M. H. Miller (1958). The cost of capital, corporation finance and the theory of investment. *The American Economic Review 48*(3), 261–297.

Mundell, R. (1971). *Monetary Theory*, Chapter Money, Debt, and the Rate of Interest. Pacific Palisades, California: Goodyear.

Muratori, U. (2014, December). Contagion in the Euro Area Sovereign Bond Market. *Social Sciences 4*(1), 1–17.

Neyman, J. and E. L. Scott (1948). Consistent estimates based on partially consistent observations. *Econometrica 16*(1), 1–32.

Owyang, M. T., V. A. Ramey, and S. Zubairy (2013, May). Are government spending multipliers greater during periods of slack? evidence from twentieth-century historical data. *American Economic Review 103*(3), 129–34.

Parent, O. and J. P. LeSage (2011, January). A space-time filter for panel data models containing random effects. *Computational Statistics & Data Analysis 55*(1), 475–490.

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

Pescatori, A., D. Leigh, J. Guajardo, and P. Devries (2011, June). A New Action-Based Dataset of Fiscal Consolidation. IMF Working Papers 11/128, International Monetary Fund.

Pritsker, M. (2001). *International Financial Contagion*, Chapter The Channels for financial contagion, pp. 67–95. Springer.

Qu, X., L.-f. Lee, and J. Yu (2017). QML estimation of spatial dynamic panel data models with endogenous time varying spatial weights matrices. *Journal of Econometrics 197*(2), 173–201.

Ramey, V. (2012). Comment on "roads to prosperity or bridges to nowhere? theory and evidence on the impact of public infrastructure investment". In *NBER Macroeconomics Annual 2012, Volume 27*, pp. 147–153. National Bureau of Economic Research, Inc.

Ravazzolo, F. and J. Vespignani (2017, June). World steel production: A new monthly indicator of global real economic activity. CAMA Working Papers 2017-42, Centre for Applied Macroeconomic Analysis, Crawford School of Public Policy, The Australian National University.

Rigobon, R. (2016, November). Contagion, spillover and interdependence. Working Paper 1975, European Central Bank.

Robertson, D. and M. R. Wickens (1997, February). Measuring Real and Nominal Macroeconomic Shocks and Their International Transmission under Different Monetary Systems. *Oxford Bulletin of Economics and Statistics 59*(1), 5–27.

Romer, C. D. and D. H. Romer (2010, June). The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks. *American Economic Review 100*(3), 763–801.

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

Sargent, T. J. and N. Wallace (1981). Some unpleasant monetarist arithmetic. *Quarterly Review* (Fall).

Ãscar JordÃ (2005, March). Estimation and Inference of Impulse Responses by Local Projections. *American Economic Review 95*(1), 161–182.

Sims, C. (1980). Macroeconomics and reality. *Econometrica 48*(1), 1–48.

Sims, C. A. (1994). A Simple Model for Study of the Determination of the Price Level and the Interaction of Monetary and Fiscal Policy. *Economic Theory 4*(3), 381–399.

Taylor, J. B. (1993, December). Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy 39*(1), 195–214.

Thompson, E. A. (1967). Debt instruments in both macroeconomic theory and capital theory. *The American Economic Review 57*(5), 1196–1210.

Tinbergen, J. (1962). *Shaping the World Economy: Suggestion for an International Economic Policy.* Newy York: Twentieth Century Fund.

Tobin, J. (1965, December). The Burden Of The Public Debt: A Review Article. *Journal of Finance 20*(4), 679–682.

Traczyk, A. (2013). Financial integration and the term structure of interest rates. *Empirical Economics 45*(3), 1267–1305.

Traum, N. and S.-C. S. Yang (2011, January). Monetary and fiscal policy interactions in the post-war U.S. *European Economic Review 55*(1), 140–164.

Warnock, F. E., V. C. Warnock, F. E. Warnock, and V. C. Warnock (2009). International capital flows and u.s. interest rates. *Journal of International Money and Finance*, 903–919.

Woodford, M. (1996, July). Control of the public debt: A requirement for price stability? NBER Working Papers 5684, National Bureau of Economic Research, Inc.

Appendices

Appendix A

Appendix for *Macroeconomic Policy Interactions and the Effects of Fiscal Stimulus*

A.1 Alternative fiscal policy rule

It is informative to confront our results to alternative measures of fiscal sustainability. In particular, the tax rule of Davig and Leeper (2007, 2011) seems particularly relevant. Their rule posits that taxes may react to debt developments, controlling for the output gap and government expenditures. The rule therefore reads:

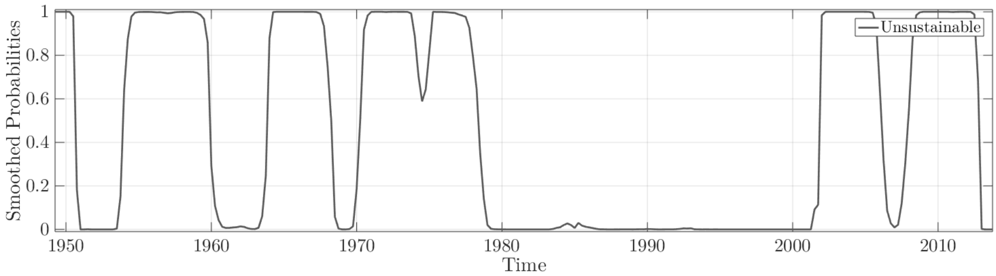
$$\tau_t = \gamma_0^{s_t^\tau} + \gamma_b^{s_t^\tau} b_{t-1} + \gamma_y^{s_t^\tau} (y_t - y_t^*) + \gamma_g^{s_t^\tau} \omega_t + \epsilon_t^{s_t^\tau} \tag{A.1}$$

where τ is tax revenues less transfer payments, b_t is the debt held by the public divided by GDP, $(y_t - y_t^*)$ is the output gap and ω_t is current government purchases. The superscript s_t^τ stands for the fiscal policy regime under the Davig and Leeper rule. Notice that the variance is regime-dependent. Removing transfers from tax revenues partly removes the natural movement of tax revenue due to automatic stabilizers. The identification of sustainable and unsustainable fiscal policy depends on the sign of the coefficient γ_b. A positive sign indicates a sustainable fiscal policy while a negative co-movement is evidence of an unsustainable fiscal policy. Davig and Leeper (2007, 2011) identify fiscal policy as unsustainable in 1955-67, 1969-1971, 1975, 1979-86, and 2002-2004. [1] We extend the analysis of Davig and Leeper (2007, 2011) to the period 1949Q2 to 2014Q3 to estimate the rule, but the local projections are based on the 1967Q1-2012Q1 sample.

Figure A.1 reports estimates of sustainable and unsustainable fiscal policy according to Equation A.1 while Figures A.2 and A.3 report the responses of the variables of interest

[1] Note that their estimation does not cover the period after 2007. Given the size of the stimulus packages put in place after 2008, it is very likely that periods post-2007 would be considered as unsustainable.

Figure A.1 – Davig and Leeper (2007, 2011) fiscal policy rule



Note: the figure presents the estimated periods of unsustainable fiscal policy according to the Davig and Leeper (2007, 2011) tax rule.

and the sovereign yields, respectively. We can see from Figure A.2 that the unsustainable regime does not generate larger output or inflation. However, in the sustainable regime, the negative responses of GDP and, to a lesser extent, CPI remain. Yields drop only in the sustainable regime, and the 10-years exhibit a feeble positive response at long horizon. Analysis of the effects of fiscal policy on the yield curve therefore seems dependent on the sustainability criterion one uses. Nevertheless, the negative response of yields in the sustainable regime remains a robust feature.

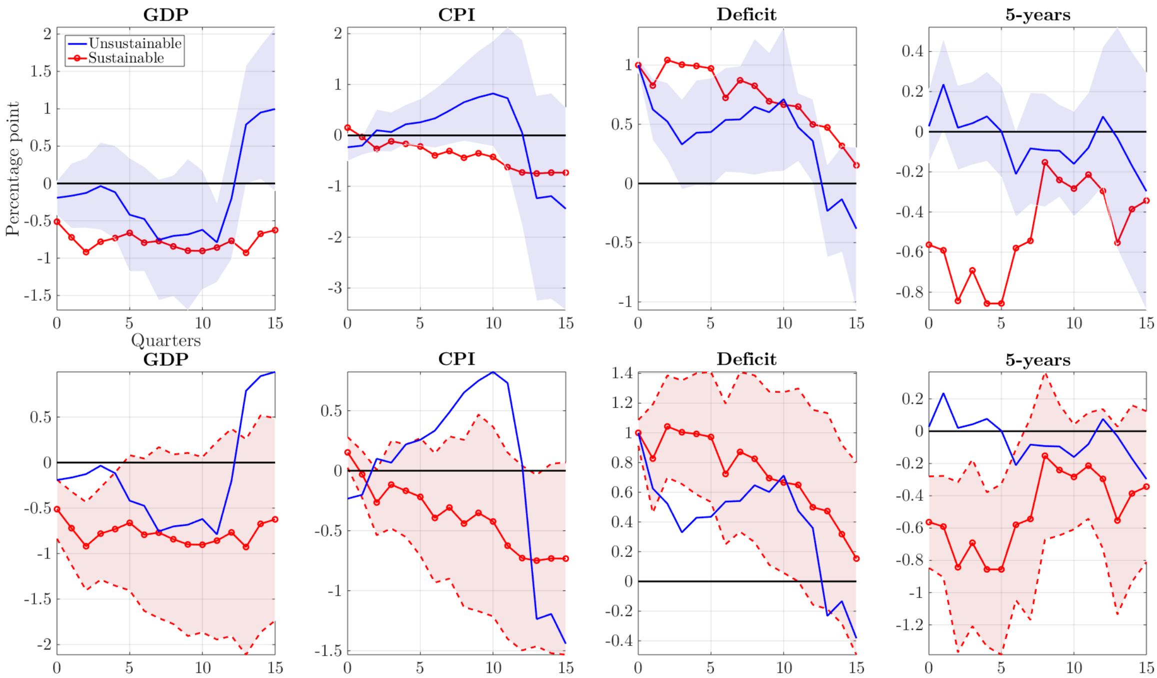
We believe that the rule (2.6) is more flexible than (A.1) for two reasons. First, Davig and Leeper consider that taxes are the only fiscal instrument while we consider both taxes and government spending since they are embedded in the primary deficit. In addition to this, we also consider the impact of interest payments in the budget. Second, the rule of Davig and Leeper has an implicit constraint on the coefficient γ^b. Indeed, recall that our measure of the stabilizing deficit d_t^S is computed as $d_t^S = \frac{(\zeta_t - i_t^b)}{(1+\zeta_t)} * b_{t-1}$. The multiplying factor in front of the lagged value of the debt is therefore time-varying and oscillates around 1 in our rule, whereas it is fixed to 1 in the rule of Davig and Leeper. These two distinctions may explain the differences in the identification of regimes.

A.2 Alternative specification

A.2.1 Macroeconomic policy regimes obtained with joint estimation of fiscal and monetary policy rules

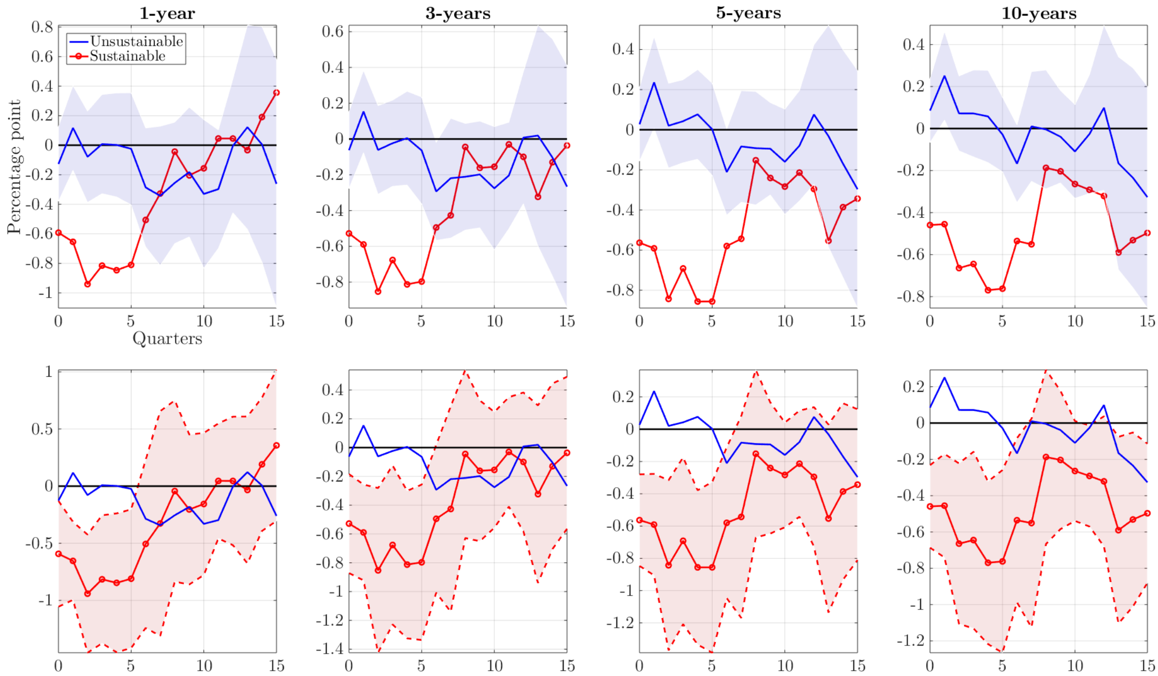
We report the dynamic responses of the dependent variables and yields where the regimes correspond to the joint estimation of the fiscal and monetary policy rules in Figures A.4 and A.5. Responses are qualitatively similar to the case where rules are combined. The only difference lies in the responses of the yields in the FTPL. Their responses are no longer statistically significant. Yet, their point estimate remains higher that the Indeterminate and Ricardian regime.

Figure A.2 – Impulse responses of dependent variables to deficit shocks – sustainable vs. unsustainable fiscal policy regimes from tax rule



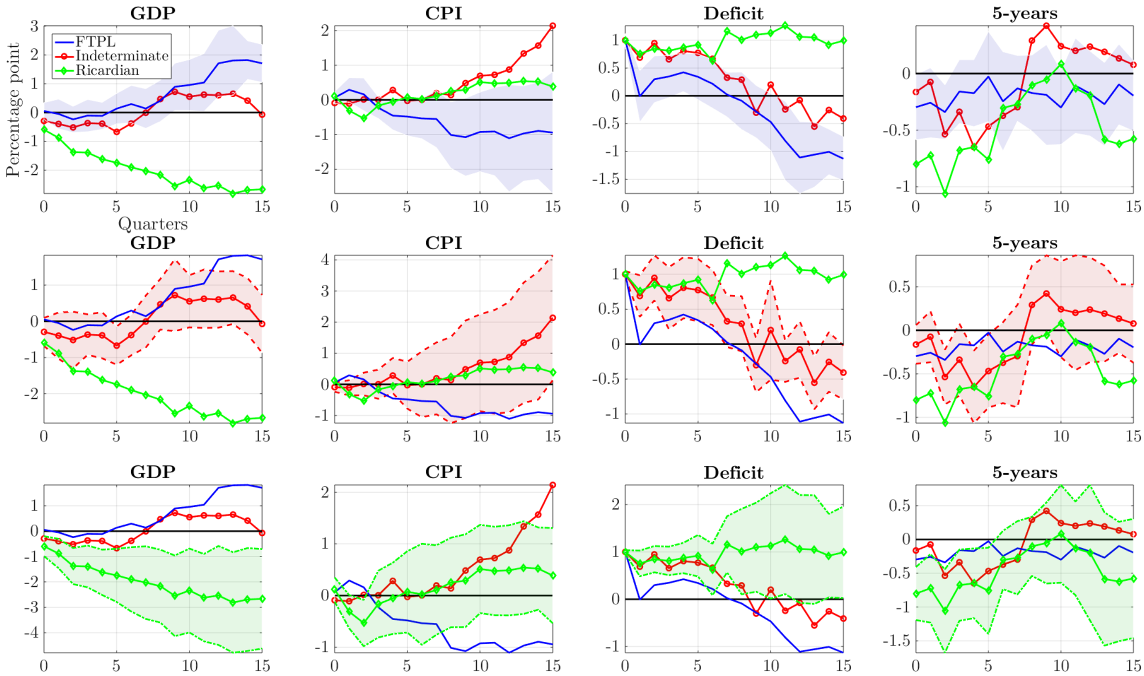
Note: the figure presents the responses of output growth, inflation, deficit and the 5-years nominal yield to a 1 percentage point increase in the deficit-to-GDP ratio. The solid lines represent the point estimate and are derived from the multi-regimes local projections (2.13) to (2.16). The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h. The first row reports the confidence bands from the unsustainable regime while the second row reports the confidence bands from the sustainable regime. The regimes correspond to Markov-switching estimation of the Davig and Leeper tax rule in Equation (A.1).

Figure A.3 – Impulse responses of nominal yields to deficit shocks – sustainable vs. unsustainable fiscal policy regimes from tax rule



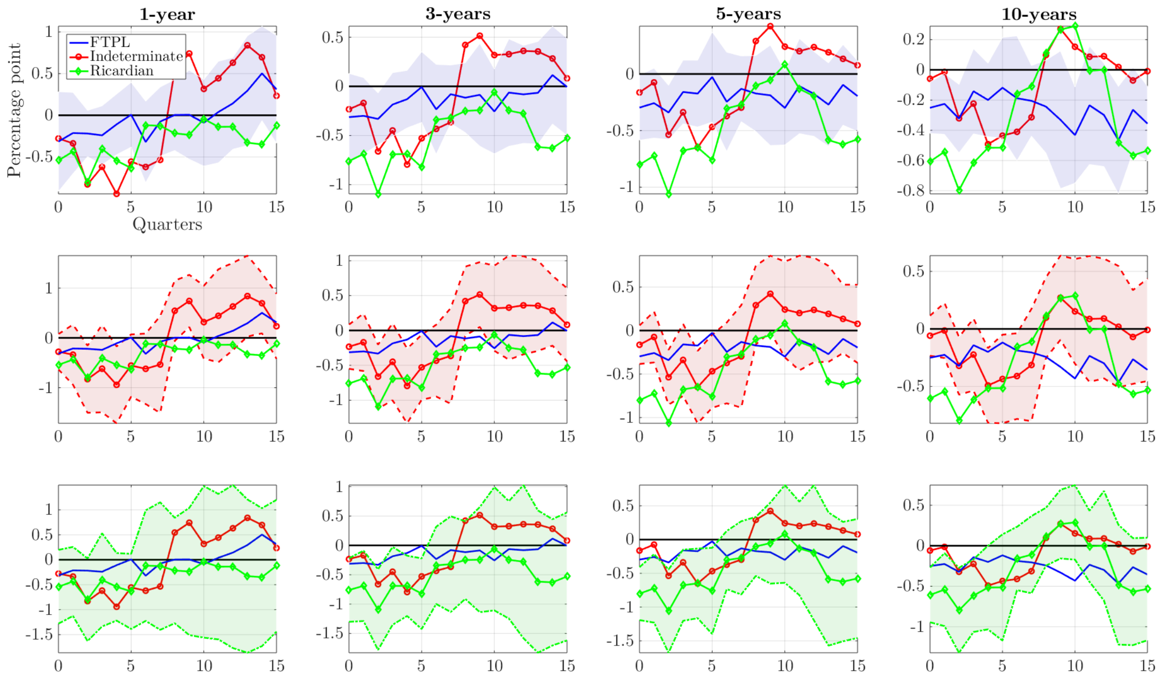
Note: the figure presents the responses of nominal yields of maturities 1-, 3-, 5-, 10-years to a 1 percentage point increase in the deficit-to-GDP ratio. The solid lines represent the point estimate and are derived from the multi-regimes local projections (2.16). The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h. The first row reports the confidence bands from the unsustainable regime while the second row reports the confidence bands from the sustainable regime. The regimes correspond to the Markov-switching estimation of the Davig and Leeper tax rule in Equation (A.1).

Figure A.4 – Impulse responses of dependent variables to deficit shocks – fiscal-monetary policy mix (joint estimation of fiscal and monetary policy rules (joint estimation of regimes)



Note: the figure presents the responses of output growth, inflation, deficit and the 5-years nominal yield to a 1 percentage point increase in the deficit-to-GDP ratio. The solid lines represent the point estimate and are derived from the multi-regimes local projections (2.13) to (2.16). The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h. The first row reports the confidence bands from the FTPL regime, the second row the confidence bands from the Indeterminate regime and the third row from the Ricardian regime.

Figure A.5 – Impulse responses of nominal yields to deficit shocks – fiscal-monetary policy mix (joint estimation of regimes)



Note: the figure presents the responses of output growth, inflation, deficit and the 5-years nominal yield to a 1 percentage point increase in the deficit-to-GDP ratio. The solid lines represent the point estimate and are derived from the multi-regimes local projections (2.13) to (2.16). The shaded area corresponds to the Newey-West 90% confidence interval bounded by the dashed lines. For each horizon h, the Newey-West lag correction is set to h. The first row reports the confidence bands from the FTPL regime, the second row the confidence bands from the Indeterminate regime and the third row from the Ricardian regime.

Appendix B

Appendix for *Nonlinear Impacts of Fiscal Policy on the Yield Curve*

B.1 Data sources and treatments

Yields The yields data are provided by Joslin, Priebsch and Singleton (2014). They reproduce the bootstrapping method of Fama and Bliss (1987) on US CRSP Treasury coupon bonds where they first removed illiquid bonds and bonds with embedded options. The resulting yields are unsmoothed 6-months, 1, 2, 3, 4, 5 and 10-years that cover the period from January 1972 to December 2011. Since the rest of the estimation is done in quarters, monthly yields are transformed to quarterly by taking the last observation of the quarter.

Primary deficit Primary deficit is defined as Federal Government Expenditures (line 23 of NIPA Table 3.2.) minus Government Receipts (line 1 of NIPA Table 3.2.) minus Interest Payments (line 32 of NIPA Table 3.2.) This difference is then divided by current nominal GDP (line 1 of NIPA Table 1.1.5.)

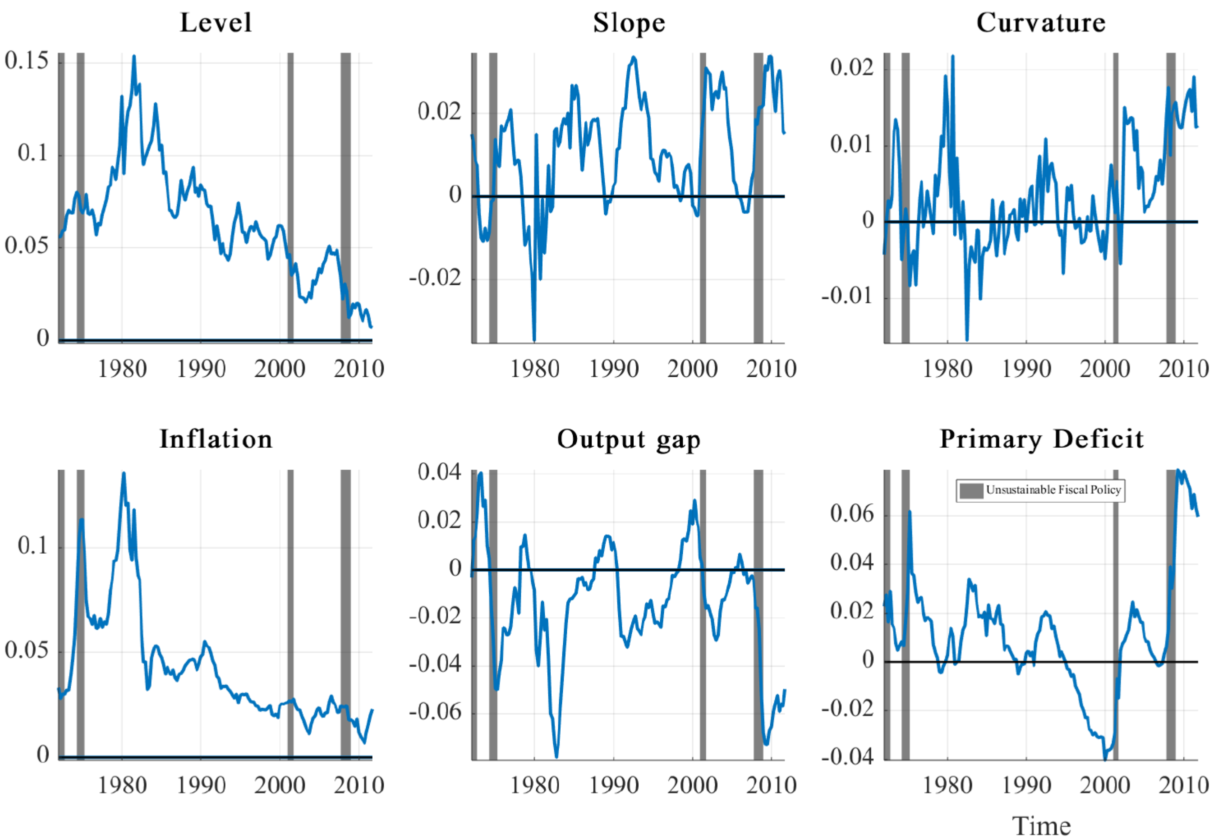
Total debt The debt series comes from the Dallas Fed. We select the privately held gross federal debt at market value as a measure of debt so as to remove holding by the Central Bank and governmental institutions. We then divide it by current nominal GDP series.

Output gap While nominal GDP is provided in line 1 of NIPA Table 1.1.5, the potential nominal GDP series is provided by the Bureau of Economic Analysis. The output gap is computed as the log difference between nominal GDP and potential nominal GDP.

Inflation The inflation series is computed as the annual growth rate of core CPI, that is, the Consumer Price Index for all urban consumers minus food and energy prices.

Figure B.1 contains the six risk factors used in the analysis. The level factor broadly follows the average of the yield curve. Except from the period 1972-1982, the level factor exhibits a downward trend, with some cyclical movements associated with business cycles and recessions. The slope factor is much more volatile than the level factor, positive on average but with some negative values. Extreme negative values are found in 1980 at the beginning of the monetary experiment of Paul Volcker, the then-Chairman of the Federal Reserve. Harvey (1986) has stressed the importance of the slope factor to predict upcoming recessions: an inverted yield curve (a negative slope coefficient) accurately forecasts recessions two to six quarters ahead. Two alternative definitions of the slope factors (the difference between the 10-years and 3-months yields or the difference between the 10-years and Federal Funds Rate) are even published in the *Financial Stress Index* of the St. Louis Fed and the *Index of Leading Economic Indicators* of the Conference Board. The curvature factor is quite choppy and reaches its maximum at around the same time the slope factor reaches its minimum. High values correspond to convex yield curves and are found at, or around, times of economic recessions.

Figure B.1 – Data



Note: The figure displays the data over the sample period: 1972Q1 to 2011Q4. The gray area represents the unsustainable fiscal policy periods identified through the Markov-switching fiscal policy rule.

Core CPI inflation has experienced two peaks: 1975 and 1980. These two peaks correspond to the aftermath of the first oil shock and the Iran-Iraq war, respectively. After 1982, core inflation has remained constant for over a decade before entering a smooth decline since 1990. The output gap variable exhibits a clear cyclical pattern. However the amplitude and the regularity of the cycles are not constant across time.

B.2 Regime-specific dynamics

Table B.1 reports the results that motivates the use of regime-specific dynamics for the Dewachter and Toffano rule. One can see that both the Fully Interacted VAR and the Partially Interacted VAR, that is, the VAR with $\Phi_{\mathcal{PP}}$ identical across regimes, statistically improve the fit to the data with respect to the single-regime VAR. The Fully Interacted VAR is also statistically different from the Partially Interacted VAR at 1% significance level. The restriction that $\Phi_{\mathcal{PP}}$ be identical across regimes is therefore rejected by the data.

Table B.1 – Log-Likelihood ratio tests

	LLR value	**Critical value at 1%**	**Rejection of H_0= no statistical difference**
Single Regime vs. Full Interaction	205.99	92.01	Yes, at 1%
Single Regime vs. Partial Interaction	168.74	73.68	Yes, at 1%
Full Interaction vs. Partial Interaction	37.25	30.58	Yes, at 1%

Note: the table reports the results of the Log-likelihood ratio test for different econometric specifications of the models presented in sections 3.2.2 and 3.5.1. The Log-Likelihood ratio test compares an unrestricted model to a restricted model and concludes whether the fit of the unrestricted model to the data is statistically significant from the restricted model. The null hypothesis is the statistical equality of the two models. The test statistic is given by $2 * (\mathscr{L}_{unrestricted} - \mathscr{L}_{restricted}) \sim \chi^2(\kappa)$, where $\mathscr{L}$ denotes the Log-Likelihood value and κ is the number of restrictions between the full model and its nested version.

B.3 A dynamic term structure model with unspanned macro risks

B.3.1 Factor dynamics under the real-world measure $\mathbb{P}$

Let Z_t be the state vector such that its dynamics under the real-world measure is:

$$Z_t = \mu + \Phi Z_{t-1} + \epsilon_t, \tag{B.1}$$

where $Z_t = [\mathcal{P}_t,\, M_t]$ and ϵ_t is a multi-variate Normal with zero mean and covariance Σ.

B.3.2 Pricing kernel and risk-neutral dynamics $\mathbb{Q}$

Under the risk-neutral measure $\mathbb{Q}$ the price of an n-periods maturity bond is given by:

$$P_t^{(n)} = E^{\mathbb{Q}}\left[m_{t+1} P_{t+1}^{(n-1)}\right] \tag{B.2}$$

We assume that the pricing kernel takes the following form:

$$m_{t+1} = \exp\left(-r_t - \frac{1}{2}\lambda_t^{'}\lambda_t - \lambda_t^{'}\epsilon_{t+1}\right), \tag{B.3}$$

where $\lambda_t = \lambda_0 + \lambda_1 \left[\mathcal{P}_t,\, M_t\right]^{'}$ and $r_t = \delta_0 + \delta_1^{'}\mathcal{P}_t$ represents the dynamics of the one-period interest rate.

It follows that under the risk-neutral measure $\mathbb{Q}$ the state dynamics follows:

$$\begin{cases} \mathcal{P}_t & = \mu_{\mathcal{P}}^{\mathbb{Q}} + \Phi_{\mathcal{P}}^{\mathbb{Q}}\mathcal{P}_{t-1} + \epsilon_t^{\mathbb{Q}} \\ \mu_{\mathcal{P}}^{\mathbb{Q}} & = \mu_{\mathcal{P}} - \Sigma_{\mathcal{P}\mathcal{P}}\lambda_0 \\ \Phi_{\mathcal{P}}^{\mathbb{Q}} & = \Phi_{\mathcal{P}\mathcal{P}} - \Sigma_{\mathcal{P}\mathcal{P}}\lambda_1 \end{cases} \tag{B.4}$$

and $\epsilon_t^{\mathbb{Q}}$ is multi-variate normal with zero mean and covariance matrix Σ under $\mathbb{Q}$.

B.3.3 Bond pricing

Given the assumptions above, the price of a zero-coupon bond of maturity n is given by $P_t^{(n)} = \exp\left(-A_n - B_n^{'}\mathcal{P}_t\right)$, where A_n and B_n solve the first-order difference equations:

$$\begin{cases} A_{n+1} & = A_n + B_n^{'}\mu^{\mathbb{Q}} + \frac{1}{2}B_n^{'}\Sigma_{\mathcal{P}\mathcal{P}}\Sigma_{\mathcal{P}\mathcal{P}}^{'}B_n + A_1 \\ B_{n+1} & = B_n^{'}\Phi_{\mathcal{P}\mathcal{P}}^{\mathbb{Q}} + B_1 \end{cases} \tag{B.5}$$

with initial conditions $A_0 = 0,\, B_0 = 0$ and $A_1 = \delta_0,\, B_1 = \delta_1$.

It follows that the zero-coupon bond yields are given by:

$$y_t^{(n)} = a_n + b_n^{'}\mathcal{P}_t \tag{B.6}$$

where $a_n \equiv -A_n/n$ and $b_n \equiv -B_n/n$ for $n = 1, 2, 3\ldots$.

B.4 Mapping between fundamental parameters and model parameters

JPS follow the methodology of Joslin, Singleton and Zhu (2011) and show that there exists a mapping between the fundamental parameters $\left(r_{\infty}^{\mathbb{Q}}, |\lambda^{\mathbb{Q}}|, \gamma_0, \gamma_1, \Sigma, \mu, \Phi\right)$ and the parameters of the model $\left(\rho_0, \rho_1, \mu^{\mathbb{Q}}, \Phi^{\mathbb{Q}}\right)$ where:

$r_{\infty}^{\mathbb{Q}}$ is the long run risk-neutral mean of the short-rate, $|\lambda^{\mathbb{Q}}|$ are the eigenvalues of $\Phi^{\mathbb{Q}}$, $\gamma_{0,1}$ are the coefficients of a projection of yield factors onto macro factors, Σ is the variance-covariance matrix of residuals under the real-world probability measure, μ and Φ are given by the VAR. Parameters $\rho_{0,1}$ give the loadings of risk factors on the short-rate, $\mu^{\mathbb{Q}}$ and $\Phi^{\mathbb{Q}}$ determine the time-series properties of yields under the risk-neutral measure. The normalizations above ensure econometric identification (Joslin, Singleton and Zhu, 2011).

B.5 Evidence of unspanned macro risks

Virtually all previous macro-finance models suppose that the macro variables are spanned by the first $\mathcal{N}$ yield portfolios. However, JPS provide evidence of unspanned macro risks using three types of regressions.

B.5.1 Macroeconomic risks regressions

We estimate the following regression:

$$M_t^i = \beta_0 + \beta_1' \mathcal{P}_t^{\kappa} + \beta_2' M_t^{-i} + u_t, \tag{B.7}$$

where M^i corresponds to the i^{th} macroeconomic risk factor, κ takes the values 3 and 5 and represent the first 3 or 5 Principal Components and M^{-i} represents the macroeconomic factors, except the dependent variable.

We report the adjusted-R^2 of the regressions in Table B.2. Besides inflation which sees an adjusted-R^2 of acceptable magnitude, the adjusted-R^2 of the other regressions are fairly low. The added power comes mainly from the addition of the other macroeconomic factors, except for inflation.

B.5.2 Excess holding returns regressions

In the regression:

$$rx_{t,t+4}^{(n)} = \beta_0 + \beta_1' \mathcal{P}_t + \beta_2' M_t + u_{t+4}, \tag{B.8}$$

where $rx_{t,t+4}^{(n)}$ is the one-year holding-period excess return on a bond of maturity n and the set of macro factors M_t can include one or more macro variables, we test the null

Table B.2 – Evidence of unspanned macro risks

	Adjusted R^2	**Inflation**	**Output Gap**	**Deficit**
PC_{1-3}	*No macro*	0.61	0.33	0.37
	Macro	0.64	0.55	0.57
PC_{1-5}	*No macro*	0.63	0.35	0.38
	Macro	0.66	0.56	0.58

Note: the table presents the adjusted R-squared from regressions where the dependent is found in column and the regressors can be found in rows. The odd rows only include the first three or five principal component of the yield curve, while the even rows add the remaining macro variables as explanatory variables.

hypothesis $\beta_2 = 0$. The average adjusted-R^2 for expression (B.8) is 27.8%. This proportion decreases to 25% under the null hypothesis $\beta_2 = 0$ and 23.3% under the restriction $\beta_1 = 0$. Predictability is inversely related to the maturity. We can therefore conclude that excess holding returns are forecastable. Dai and Philippon (2005) report similar values for their excess returns regressions, while Cochrane and Piazzesi (2005) use forward rates and they can predict up to 40% of bond excess returns.

As Figure B.2 indicates, we can reject the hypothesis that macroeconomic factors do not explain excess holding returns. This conclusion is especially relevant for maturities below 8 quarters. Almost 3/4 of the regressions show a statistically significant improvement in fit at a significance level of 5% when macroeconomic variables are included and 100% are significant at the 10% significance level. These results strongly indicate that excess holding returns are forecastable and that macroeconomic variables are a valuable addition to the yield curve factors. Joslin, Priebsch and Singleton (2014), Cooper (2009) and Ludvigson and Ng (2009)) support this claim.

B.5.3 Forecasts of macroeconomic risks

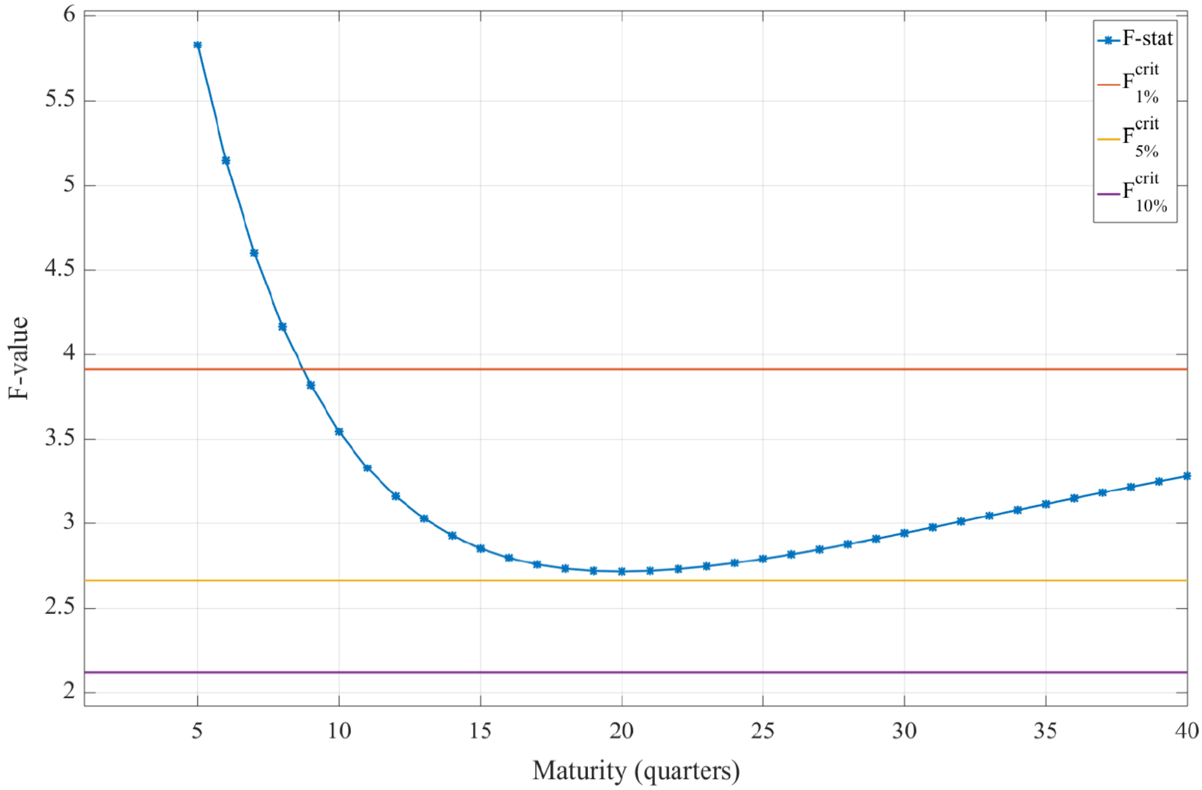
If macroeconomic factors were spanned by the yield curve current macroeconomic variables would not carry additional information to forecast macroeconomic variables than the yield curve factors already have. To test this hypothesis, we estimate Equation (B.9) and test whether $\beta_2 = 0$:

$$M_{t+1} = \beta_0 + \beta_1^{'}\mathcal{P}_t + \beta_2^{'}M_t + u_t. \tag{B.9}$$

A rejection of the null hypothesis indicates a rejection of the macro-spanning condition. We report the Log-Likelihood ratio test results below.

The Log-Likelihood ratio test compares an unrestricted model to a restricted model and concludes whether the fit of the unrestricted model to the data is statistically significant from the restricted model. The null hypothesis is the statistical equality of the two models. The test statistic is given by $2 * (\mathscr{L}_{unrestricted} - \mathscr{L}_{restricted}) \sim \chi^2(\kappa)$, where

Figure B.2 – Joint test of $\beta_2 = 0$ in the regression $rx^{(n)}_{t,t+4} = \beta_0 + \beta_1'\mathcal{P}_t + \beta_2'M_t + u_{t+4}$, where $rx^{(n)}_{t,t+4}$ stands for the realized one-year excess returns



Note: the figure displays the Fisher statistic (with markers) of the joint test of irrelevance of macro factors for predicting realized one-year excess returns for various maturity. The horizontal lines correspond to critical values of the F-statistic at 1, 5 and 10% respectively. Values of the F-statistic above the critical values indicate rejection of the null hypothesis.

$\mathscr{L}$ denotes the Log-Likelihood value and κ is the number of restrictions between the full model and its nested version. The test statistic reaches 65.7 and the critical value at 1% statistical significance is 21.67. We can safely reject the null hypothesis and conclude that past values of macroeconomic variables provide additional information to forecast macroeconomic variables over and above the information that the yield curve contains. Duffee (2011, 2012) provide strong evidence against the null hypothesis $\beta_2 = 0$.

B.6 Alternative fiscal policy rule

We reproduce the analysis of Davig and Leeper (2007, 2011) by estimating Equation (3.15) between 1972 and 2012. The parameters in Table B.3 bring some interesting features. First, Panel (a) indicates that fiscal policy in the US is generally unsustainable, as indicates the sign of γ_b. Taxes react positively to output and government consumption. Panel (b) provides the estimates for the Markov-switching policy rule. The sustainable regime sees an absence of sensitivity to debt developments whereas the unsustainable regime exhibits a negative co-movement between taxes and the debt level. The relation

Table B.3 – Estimates of Davig and Leeper (2007, 2011) tax rule (1972Q1 – 2011Q4)

	Estimates of Davig and Leeper fiscal policy rule (1972Q1:2011Q4)							
	γ_0	γ_b	γ_y	γ_g	σ_ϵx100	p_{SS}	p_{UU}	*Log Lik.*
Panel (a)	Single-regime model							
	0.082***	-0.045***	0.607***	0.154***	0.02			441.49
	(0.001)	(0.004)	(0.043)	(0.014)				
Panel (b)	Markov-switching model							
Sustainable	0.091***	0.001	0.241***	-0.614***	0.005	0.98		556.12
	(0.00)	(0.004)	(0.00)	(0.00)				
Unsustainable	0.094***	-0.104***	0.652***	0.072***	0.006		0.98	
	(0.00)	(0.00)	(0.00)	(0.00)				

Note: the table reports the estimated parameters of the rule presented in Davig and Leeper (2007, 2011) for the sample period 1972Q1 to 2011Q4. Panel (a) reports the single-regime while panel (b) presents the optimization results from the Markov-switching model.

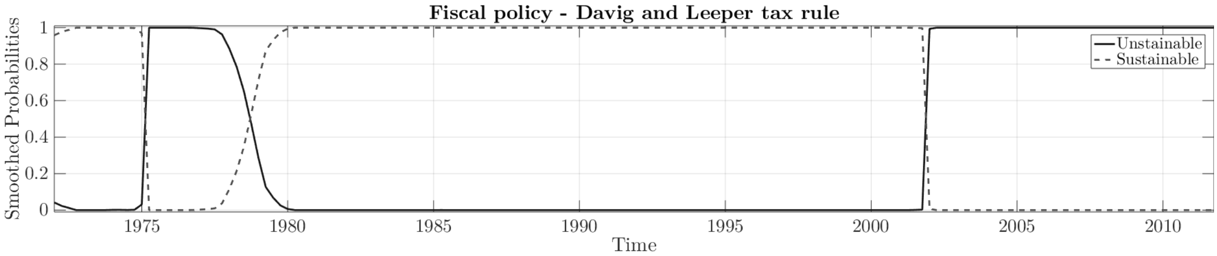
between government expenditures and taxes is much more negative in the sustainable regime than in the unsustainable, indicating that the government focuses on one instrument during these periods of unsustainable fiscal policy.

Figure B.3 presents the smoothed probabilities of being in an unsustainable regime from the Markov-switching regression. The alternative tax rule produces different parameters and periods of active fiscal policy compared to Dewachter and Toffano (2012). Typically, episodes of unsustainable fiscal policy are much more persistent. Nevertheless, they agree on several important aspects. The first is that 1975 is categorized as an unsustainable fiscal policy. The second is that the first few years of the 2000s and the last few years of the 2000s are also characterized as unsustainable. Thirdly, they also agree that the period between 1980 and 2000 saw a sustainable fiscal policy.

B.6.1 Impulse response functions

We provide impulse response functions from the Davig and Leeper rule for illustrative purposes. Generally speaking, there is little difference across regimes identified with the Davig and Leeper (2007, 2011) tax rule. The magnitude of the responses is broadly consistent with the Dewachter and Toffano (2012) identification, ranging from 50 basis points to 100 basis points. One difference, however, is that the yields in the unsustainable regime respond more quickly than in the sustainable regime, although they only lead

Figure B.3 – Davig and Leeper fiscal policy rule (1972Q1-2011Q4)



Note: the figure presents the estimated periods of unsustainable fiscal policy according to the Davig and Leeper (2007, 2011) rule.

by three quarters. If we decompose the yields responses into the components, we can see that now all three components of the yield curve are affected by fiscal policy shocks, compared to only the level and the slope in the Dewachter and Toffano (2012) identification. The inflation and output schedules also exhibit starkly different shapes between the two identification strategies. Indeed, while output remains consistently higher in the unsustainable regime, national income exhibit a U-shaped response, with the through at 16-20 quarters after the shock. The results show that regimes are still relevant, especially for the responses of macro variables. Indeed, although the restrictions are imposed on the signs of the responses, their shape is left unrestricted. Having different shapes in the responses seems therefore an interesting feature.

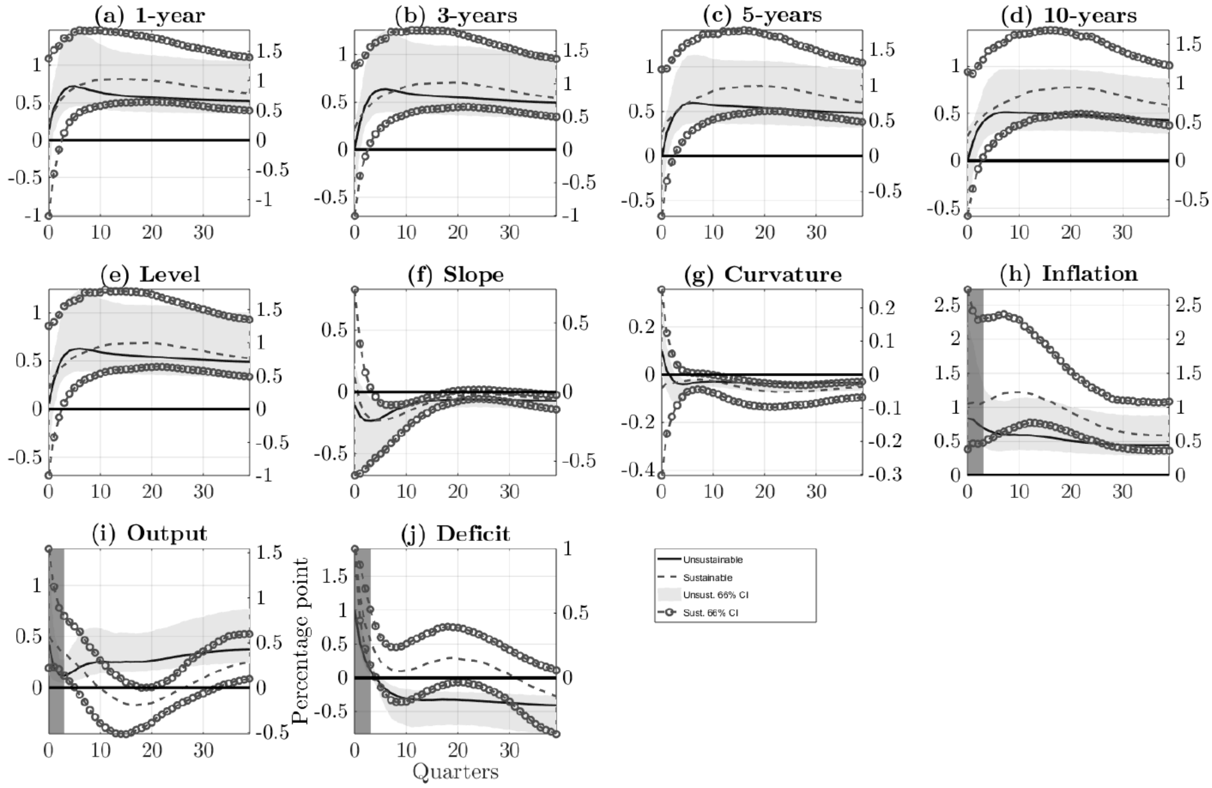
B.6.2 Variance decomposition

Variance decomposition based on the IRFs presented in B.6.1 lead to different conclusions compared to the Dewachter and Toffano (2012) identification strategy. In particular, deficit shocks do not seem particularly relevant for sovereign yields at the short end of the yield curve. However, deficit shocks do have a sizeable influence at the long end of the yield curve. The aggregate demand shocks follow the same trend. Additionally, we can observe that the distinction across regime diminishes.

B.6.3 Excess returns

Excess returns under the Davig and Leeper (DL) rule are presented in Figure B.5. They share three main characteristics with the excess returns in the Dewachter and Toffano rule (DT). First, they share the same general patterns set forth by Cochrane and Piazzesi (2005, 2009). Second, the unsustainable regime particularly stands out from the single and sustainable regimes. Third, excess returns in the unsustainable regimes are consistently larger than in the single and sustainable regimes. They even are mostly positive across

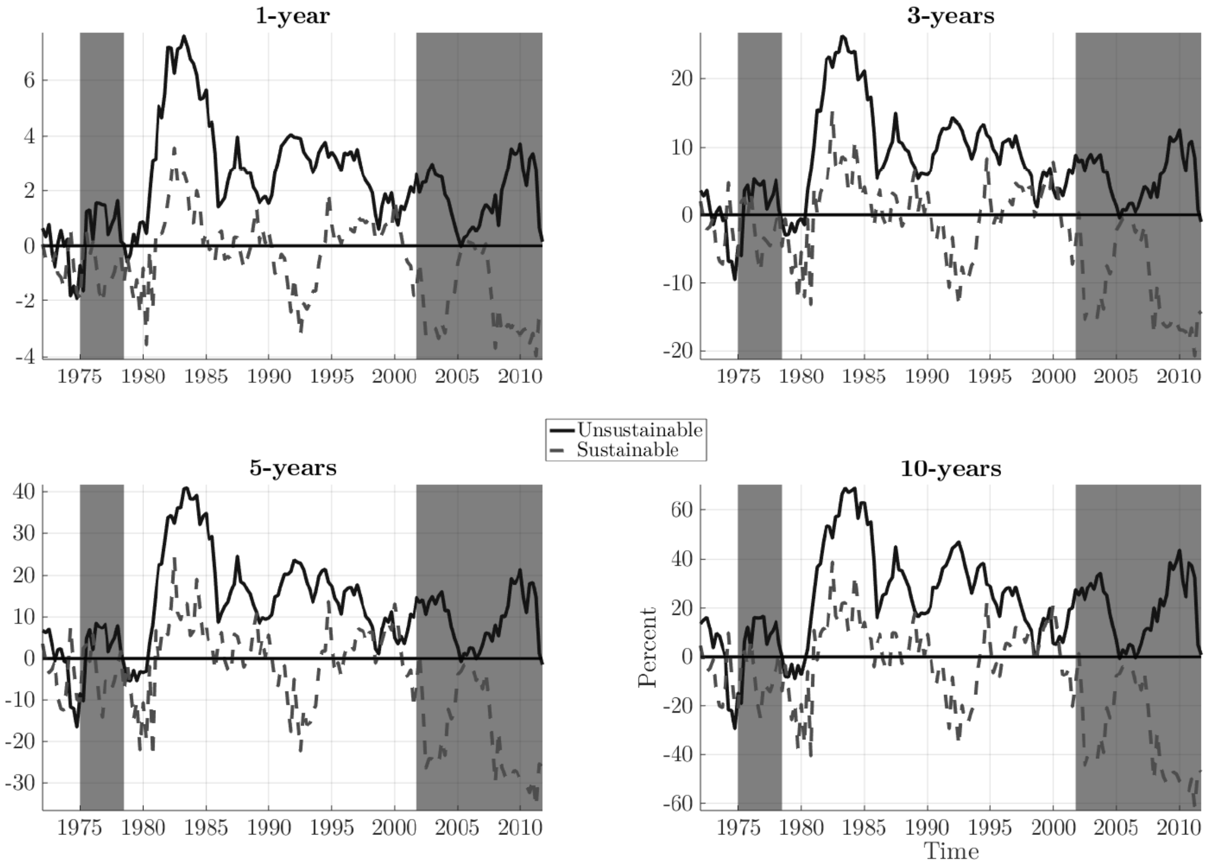
Figure B.4 – Impulse response functions - Davig and Leeper tax rule



Note: The figure presents the responses of the yields and variables included in the VAR to a one-percentage increase in the deficit. The shocks are identified with sign restrictions. The horizon of the restrictions corresponds to the dark shade. The light shade gives the 90% confidence bands of the unsustainable regime (left axis) around its median in solid line while the dashed and circled lines pertain to the sustainable regime (right axis). Both axes give the response of the variables in percentage points.

time whereas The distinction is especially marked at the beginning of the eighties as well as during the mid-nineties. However, the two rules also lead to some differences. The peak in excess returns at the start of the eighties is more pronounced in the Davig and Leeper rule than in the Dewachter and Toffano rule. Second, the risk premium in the sustainable regime after 2010 is negative for the DL rule whereas it is positive in the DT rule. As already mentioned, the post-2010 period saw unconventional monetary policy measures and that could explain the discrepancy. Third, there seems to be a negative correlation between the excess returns across the two regimes, and especially so after the nineties. Further investigation on the differences across regimes and specifications is called for.

Figure B.5 – One-period expected excess returns - Davig and Leeper tax rule



Note: The figure reports the one-period expected excess returns for US yields between 1972Q1 and 2011Q4 according to the two types of regimes we consider. The solid line pertains to the unsustainable regime while the dashed line refers to the sustainable regime. The gray area corresponds to episodes of unsustainable fiscal policy.

Table B.4 – Median variance decomposition for yields (1-year, 3-years) - Davig and Leeper tax rule

Shock to:	**Others**	**Supply**	**Demand**	**Deficit**
		1-year		
Single				
Horizon: 1	70	11	17	**2**
4	71	13	14	**2**
20	71	14	13	**2**
40	71	15	11	**3**
Unsustainable				
Horizon: 1	69	10	18	**3**
4	69	13	16	**2**
20	67	16	15	**2**
40	65	20	13	**2**
Sustainable				
Horizon: 1	65	18	14	**4**
4	64	18	14	**4**
20	64	17	14	**5**
40	65	17	14	**5**
		3-years		
Single				
Horizon: 1	67	12	19	**3**
4	67	14	17	**3**
20	66	15	15	**3**
40	67	16	13	**4**
Unsustainable				
Horizon: 1	62	5	26	**7**
4	63	8	24	**5**
20	62	11	22	**5**
40	61	15	20	**5**
Sustainable				
Horizon: 1	62	16	17	**5**
4	59	17	18	**6**
20	59	17	18	**6**
40	60	17	17	**6**

Note: The table reports the variance decomposition for yields of maturity 1- and 3-years. The rows may not sum to 100 due to rounding. The shocks are identified with sign restrictions. Unidentified shocks are grouped under the label *Others*.

Table B.5 – Median Variance Decomposition for yields (5-years, 10-years) - Davig and Leeper tax rule

Shock to:	Others	Supply	Demand	Deficit
		5-years		
Single				
Horizon: 1	62	6	25	**7**
4	61	7	24	**8**
20	61	8	23	**8**
40	60	9	23	**9**
Unsustainable				
Horizon: 1	56	2	31	**11**
4	55	3	30	**11**
20	55	4	29	**11**
40	55	6	28	**11**
Sustainable				
Horizon: 1	53	9	23	**15**
4	52	9	24	**16**
20	51	9	23	**16**
40	51	10	23	**17**
		10-years		
Single				
Horizon: 1	62	6	25	**7**
4	61	6	25	**8**
20	61	6	24	**8**
40	61	7	24	**9**
Unsustainable				
Horizon: 1	55	2	32	**12**
4	55	3	31	**12**
20	55	3	30	**12**
40	54	4	29	**12**
Sustainable				
Horizon: 1	50	7	23	**20**
4	50	7	22	**21**
20	49	7	22	**22**
40	48	7	22	**23**

Note: The table reports the variance decomposition for yields of maturity 1- and 3-years. The rows may not sum to 100 due to rounding. The shocks are identified with sign restrictions. Unidentified shocks are grouped under the label *Others*.

Appendix C

Appendix for *Cross-Border Risks in the Eurozone Bond Markets*

C.1 Importance of spatial lags

Table C.1 – Spatial parameters - Γ

	Inflation	**Output gap**	**Deficit**	**CLIFS**	**PC1 Spreads**	**PC2 Spreads**
Inflation	0.0733	**0.1353**	-0.0201	0.5946	0.0355	-0.0117
	[-0.008 ; 0.138]	[0.054 ; 0.211]	[-0.256 ; 0.202]	[-0.465 ; 1.635]	[-0.116 ; 0.185]	[-0.074 ; 0.050]
Output gap	-0.0032	**-0.0313**	-0.1223	-1,1463	0.0220	-0.0167
	[-0.0264 ; 0.018]	[-0.060 ; -0.003]	[-0.367 ; 0.140]	[-2.503 ; 0.180]	[-0.168 ; 0.210]	[-0.089 ; 0.068]
Deficit	**0.0043**	-0.0044	-0.0006	0.1520	0.0300	0.0013
	[0.000 ; 0.008]	[-0.009 ; 0.001]	[-0.015 ; 0.013]	[-0.210 ; 0.526]	[-0.016 ; 0.078]	[-0.018 ; 0.022]
CLIFS	0.0244	0.0267	0.0794	0.0124	0.0002	0.0010
	[-0.018 ; 0.073]	[-0.034 ; 0.084]	[-0.069 ; 0.223]	[-0.566 ; 0.297]	[-0.008 ; 0.008]	[-0.003 ; 0.005]
PC1 Spreads	-0.0221	-0.0775	0.0399	0.4053	-0.0653	-0.0283
	[-0.155 ; 0.099]	[-0.22 ; 0.063]	[-0.367 ; 0.443]	[-1.647 ; 2.306]	[-0.300 ; 0.163]	[-0.062 ; 0.008]
PC2 Spreads	**0.0774**	-0.0442	-0.0531	0.1174	0.0584	0.0203
	[0.067 ; 0.126]	[-0.122 ; 0.044]	[-0.307 ; 0.203]	[-0.902 ; 1,191]	[-0.103 ; 0.224]	[-0.053 ; 0.085]

Note: the table reports the median value of the spatial parameters based on 500 stationary bootstraps. The 90% confidence bounds based on the empirical distribution of the parameters are found below the median value. Bold font indicates significance at 10% confidence level.

Tables C.1 and C.2 report the values of the spatial lags and spatio-temporal lags coefficients based on 500 stationary bootstraps. The dependent variables are found in columns while the spatial independent variables are found in rows. The 90% confidence interval based on the empirical distribution of the draws are found below the median. Interestingly, some parameters of Γ and Ξ are statistically significant, mostly in the macro group of the model. Spatial transmission generally occurs with a temporal lag. In general, the diagonal elements of Ξ are significant and positive, indicating a self-exciting behavior for these variables. Notice also that foreign output gaps significantly influence domestic deficits and that foreign inflation rates determine in part domestic output. Deficits exhibit spatial diffusion only with a lag, as one would expect given the considerable policy lag implementation (Blanchard and Perotti, 2002). Taken together, this indicates that there exists some transmission across macroeconomic variables. We could understand this result as an indication of an integrated business cycle. Turning to the CLIFS, we can conclude that financial stability within a country depends partly on the financial stability in neighboring countries. The two financial variables that summarize the domestic spreads vis-à-vis the OIS yield curve exhibit a self-exciting behavior for the first, but appear with a negative sign for the second. This positive sign would indicate that if a country faces difficult times such that investors cast doubt on its solvency, this increased risk spills over to neighboring countries.

Table C.2 – Spatial parameters - Ξ

	Inflation	**Output gap**	**Deficit**	**CLIFS**	**PC1 Spreads**	**PC2 Spreads**
Inflation	**0.1108**	**0.0908**	0.0382	1.2554	0.0249	0.0149
	[0.060 ; 0.121]	[0.088 ; 0.134]	[-0.258 ; 0.295]	[-0.034 ; 2.535]	[-0.169 ; 0.199]	[-0.067 ; 0.090]
Output gap	0.0282	**0.0952**	**0.1067**	0.2815	0.0287	0.0091
	[-0.040 ; 0.111]	[0.048 ; 0.097]	[0.041 ; 0.177]	[-0.096 ; 0.650]	[-0.022 ; 0.078]	[-0.011 ; 0.029]
Deficit	0.0039	-0.0011	0.0420	0.0540	-0.0051	-0.0005
	[-0.019 ; 0.025]	[-0.029 ; 0.029]	[-0.011 ; 0.088]	[-0.028 ; 0.072]	[-0.016 ; 0.006]	[-0.005 ; 0.005]
CLIFS	-0.0013	**-0.0092**	0.0090	**0.1470**	**0.0621**	0.0286
	[-0.006 ; 0.003]	[-0.016 ; -0.003]	[-0.008 ; 0.027]	[0.120 ; 0.240]	[0.040 ; 0.102]	[-0.017 ; 0.065]
PC1 Spreads	-0.0088	0.0527	-0.0387	0.2771	**0.0924**	0.0249
	[-0.054 ; 0.034]	[-0.004 ; 0.108]	[-0.184 ; 0.114]	[-0.243 ; 0.910]	[0.035 ; 0.107]	[-0.087 ; 0.136]
PC2 Spreads	-0.0029	0.0045	0.1471	2.0585	0.2138	**-0.0960**
	[-0.133 ; 0.114]	[-0.149 ; 0.162]	[-0.255 ; 0.570]	[-0.191 ; 4.153]	[-0.101 ; 0.479]	[-0.133 ; -0.064]

Note: the table reports the median value of the spatial parameters based on 500 stationary bootstraps. The 90% confidence bounds based on the empirical distribution of the parameters are found below the median value. Bold font indicates significance at 10% confidence level.

C.2 Alternative transmission mechanisms

I list hereunder four possible alternative candidates for the transmission matrix. The first three are standard in the literature (e.g. Dewachter, Houssa and Toffano 2012, Anselin 1988, Cesa-Bianchi et al. 2012) and are based either on geographical distance or trade distance.

Contiguity Elements in the contiguity matrix take the value 1 if the two entities share a border or, in other words, are first-order neighbors, and 0 otherwise. This transmission matrix posits that geographically closer countries have closer links in economic or cultural terms such that shocks in one country transmits easily to the other. Clearly, this matrix

Table C.3 – Alternative transmission matrix

Log-likelihood: $\Gamma \neq 0; \Xi \neq 0$	**Inflation**	**Output**	**Deficit**	**CLIFS**	**PC1 Spread OIS**	**PC2 Spread OIS**
Geographical distance	277.11	-661.00	-2410.65	-5002.66*	-230.63*	26.42
Trade Intensity	272.56	-669.46	-2413.86	-5113.02	-267.18	8.03
Contiguity	239.05	-691.69	-2418.93	-5969.30	-288.36	61.54*
Bank exposure (EBA)	288.64*	-676.38	-2417.50	-5039.00	-258.65	4.68
Coordinated Portfolio Invest. Survey (IMF)	281.20	-660.42*	-2409.97*	-5018.94	-235.15	-5.73

Note: the table reports the Log-likelihood value of the regressions for each of the dependent variables (in columns). A star indicates the best transition matrix for that variable.

is not well-suited for the analysis at hand because some countries (Finland and Ireland) have no first-order neighbors. This would preclude potential spillovers to and from those two countries.

Distance between capitals and economic centers The distance between capitals and economic centers refers to the distance *as a bird flies* between two capitals and economic centers. The distance is computed from the coordinates of the cities, taking into account the curvature of the Earth. The coordinates and distances are provided by CEPII. The transmission mechanism mirrors the contiguity matrix.

Trade weights Trade weights refer to trade between country i and country j. In order to weather the risk of misreporting trade flows values, I computed trade weights between country i and country j as $\frac{M_{ij}+X_{ij}}{2}$ where M_{ij} stands for imports of country i from country j and X_{ij} stands for exports of country i to country j. The literature has shown that countries which trade more have more correlated business cycles (see, for instance, Frankel and Rose 1998). The mechanism works as follows: better economic conditions in country i will cause its consumers to consume and import more from abroad, including country j, such that the foreign countries increase their production capacity. Better economic conditions in country i also lead firms in country i to increase their production and raise exports. Data for this spatial weighting matrix is taken from the Direction of Trade database of the IMF.

Domestic banks holdings of foreign banks This weighting scheme resembles the previous one with the difference that there is no explicit reference to the sovereign debt market. The portfolio rebalancing mechanism is, however, still present. Data comes from the Consolidated Banking Statistics of the Bank for International Settlements. In order to grasp the real exposure of domestic banks to foreign banks, I build the weighting matrix based on Ultimate Risk for all types of instruments, maturities and currencies. There is, however, one data point missing: German banks have not reported holdings on Finnish banks.

C.3 Variance decomposition of spreads for other maturities

I provide in Tables C.8 and C.9 the variance decomposition of the 1-year and 10-years spreads, respectively. It is instructive to compare the shares across the 1-year, 5-years and 10-years spreads. Starting with Germany, we can see that the influence of common shocks is larger at the short end of the yield curve rather than at the medium or long end. The influence of foreign shocks, on the other hand, remains fairly constant across maturities. While foreign shocks in Italy affect the spreads in a similar way for the three

Table C.4 – Spatial weights - contiguity

	Germany	France	Netherlands	Belgium	Austria	Finland	Italy	Spain	Ireland	Portugal
Germany	0	0.25	0.25	0.25	0.25					
France	0.25	0		0.25			0.25	0.25		
Netherlands	0.5		0	0.5						
Belgium	0.33	0.33	0.33	0						
Austria	0.5				0		0.5			
Finland						0				
Italy		0.5			0.5		0			
Spain		0.5						0		0.5
Ireland									0	
Portugal								1		0

Note: the table reports whether country in row is contiguous to country in column. The rows are standardized such that the sum equals 1.

Table C.5 – Spatial weights - Distance between capitals and economic centers

	Germany	**France**	**Netherlands**	**Belgium**	**Austria**	**Finland**	**Italy**	**Spain**	**Ireland**	**Portugal**
Germany	0	0.12	0.18	0.16	0.20	0.09	0.09	0.05	0.08	0.04
France	0.09	0	0.19	0.30	0.08	0.04	0.07	0.08	0.10	0.05
Netherlands	0.12	0.16	0	0.39	0.07	0.04	0.05	0.05	0.09	0.04
Belgium	0.09	0.23	0.36	0	0.07	0.04	0.05	0.05	0.08	0.04
Austria	0.22	0.11	0.12	0.13	0	0.08	0.15	0.06	0.07	0.05
Finland	0.18	0.11	0.13	0.12	0.14	0	0.09	0.07	0.10	0.06
Italy	0.12	0.13	0.11	0.12	0.19	0.07	0	0.11	0.08	0.08
Spain	0.07	0.13	0.09	0.11	0.08	0.05	0.10	0	0.10	0.28
Ireland	0.10	0.17	0.17	0.17	0.08	0.07	0.07	0.09	0	0.08
Portugal	0.07	0.11	0.09	0.10	0.07	0.05	0.09	0.33	0.10	0

Note: the table reports, for each country in columns, the share of the distance to its capital in the total distance to the other countries capitals such that the sum of each row equals 1.

Table C.6 – Spatial weights - trade weights

	Germany	France	Netherlands	Belgium	Austria	Finland	Italy	Spain	Ireland	Portugal
Germany	0	0.22	0.25	0.14	0.12	0.02	0.14	0.08	0.02	0.02
France	0.34	0	0.12	0.18	0.02	0.01	0.15	0.14	0.01	0.02
Netherlands	0.44	0.14	0	0.23	0.02	0.02	0.07	0.05	0.02	0.01
Belgium	0.29	0.24	0.28	0	0.01	0.01	0.07	0.04	0.04	0.01
Austria	0.67	0.06	0.06	0.04	0	0.01	0.13	0.03	0.01	0.00
Finland	0.40	0.10	0.22	0.10	0.02	0	0.08	0.05	0.01	0.01
Italy	0.35	0.24	0.10	0.09	0.06	0.01	0	0.12	0.01	0.02
Spain	0.25	0.28	0.09	0.06	0.02	0.01	0.15	0	0.02	0.12
Ireland	0.23	0.14	0.15	0.29	0.01	0.01	0.08	0.08	0	0.01
Portugal	0.19	0.15	0.08	0.05	0.01	0.01	0.08	0.44	0.01	0

Note: the table presents, for each reporting country (in rows), the share of trade with counterparty country (in columns) in the total trade value such that the sum of each row equals 1.

Table C.7 – Spatial weights - domestic banks holdings of foreign banks

	Germany	**France**	**Netherlands**	**Belgium**	**Austria**	**Finland**	**Italy**	**Spain**	**Ireland**	**Portugal**
Germany	0	0.04	0.01	0.01	0.03	–	0.01	0.06	0.10	0.75
France	0.01	0	0.04	0.28	0.16	0.03	0.02	0.17	0.20	0.09
Netherlands	0.00	0.01	0	0.00	0.04	0.01	0.80	0.02	0.10	0.02
Belgium	0.01	0.42	0.06	0	0.10	0.02	0.01	0.13	0.10	0.15
Austria	0.00	0.06	0.69	0.01	0	0.02	0.02	0.05	0.12	0.03
Finland	0.00	0.03	0.01	0.01	0.07	0	0.00	0.81	0.05	0.03
Italy	0.00	0.03	0.02	0.01	0.03	0.01	0	0.03	0.86	0.02
Spain	0.00	0.05	0.06	0.01	0.07	0.56	0.01	0	0.07	0.17
Ireland	0.00	0.01	0.01	0.00	0.93	0.00	0.03	0.01	0	0.01
Portugal	0.90	0.01	0.01	0.00	0.01	0.01	0.01	0.03	0.04	0

Note: the table reports, for each reporting country (in rows), the share of the holdings of the banking sector on the banking sector of the counterparty country (in columns) such that the sum of each row equals 1.

Table C.8 – Country-wise Variance Decomposition by type of shock - Domestic 1-year spread

Shock to:	**Common shocks**	**Domestic shocks**	**Foreign shocks**
		Germany	
Horizon: 1	6	86	8
4	10	83	8
12	14	79	8
36	17	75	7
		Italy	
Horizon: 1	6	82	13
4	9	79	12
12	16	73	12
36	20	69	11
		Spain	
Horizon: 1	5	54	41
4	7	53	39
12	11	53	36
36	20	48	33
		Belgium	
Horizon: 1	2	83	14
4	2	83	14
12	3	83	14
36	3	83	14
		Ireland	
Horizon: 1	1	82	17
4	1	83	16
12	2	83	15
36	3	82	15
		Portugal	
Horizon: 1	3	66	32
4	5	67	29
12	8	66	25
36	13	63	23

Note: the table reports the variance decomposition of the 5-years domestic spread based on the median impulse response for a selection of countries. The first column gives the share of the variance in the forecast error that is due to common shocks (volatility, real economic activity, stock returns, and OIS curve). Columns 2 aggregates all domestic shocks and column 3 aggregates all foreign shocks. The sum of common, domestic and foreign shocks should be equal to 100 minus rounding errors. The horizon is given in months.

maturities considered, the effect of common shocks has an inverted U-shape and peaks at the medium term. The difference here is quite sizeable: 20% for the 1-year spread, 51% for the 5-years and finally 37% for the 10-years. Spain is also particular because the influence of foreign shocks linearly increases with maturity, from 33% to 53% for the 1-year and the 10-years spread, respectively. The conclusions for the smaller countries are

Table C.9 – Country-wise Variance Decomposition by type of shock - Domestic 10-years spread

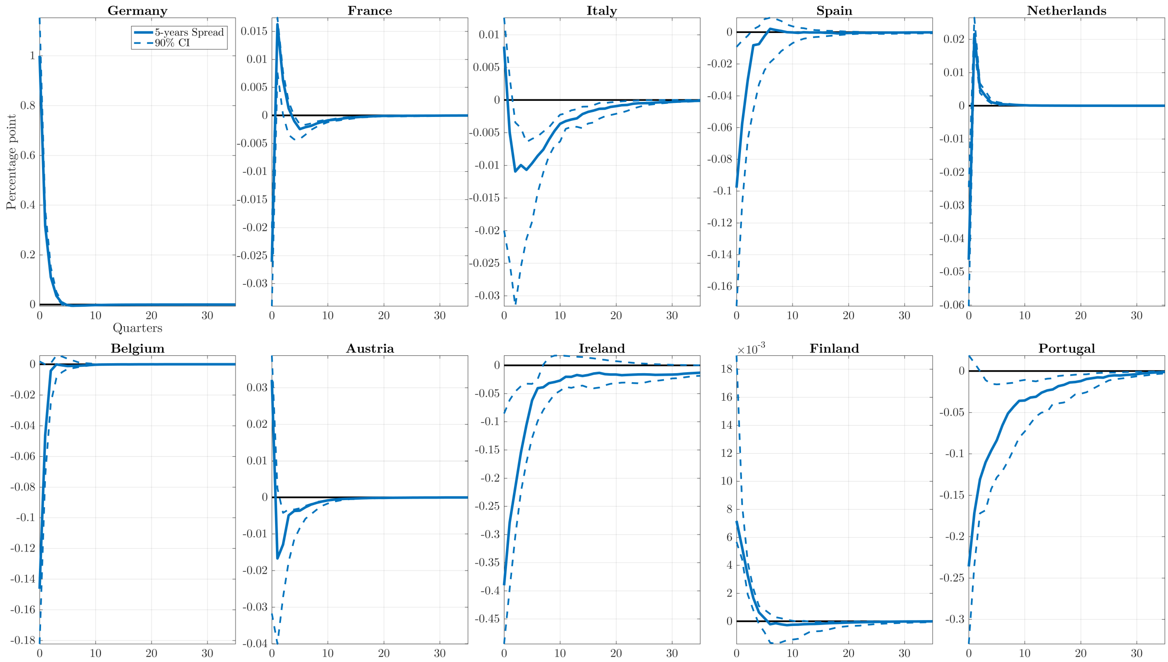
Shock to:	**Common shocks**	**Domestic shocks**	**Foreign shocks**
		Germany	
Horizon: 1	2	90	8
4	2	88	10
12	3	87	11
36	5	85	10
		Italy	
Horizon: 1	2	83	15
4	5	81	14
12	17	71	12
36	37	54	10
		Spain	
Horizon: 1	5	36	59
4	6	37	57
12	7	38	55
36	9	37	53
		Belgium	
Horizon: 1	1	89	10
4	1	89	10
12	1	89	10
36	1	89	10
		Ireland	
Horizon: 1	0	72	27
4	1	75	24
12	2	78	20
36	3	78	19
		Portugal	
Horizon: 1	4	49	46
4	6	50	44
12	11	51	38
36	21	47	33

Note: the table reports the variance decomposition of the 5-years domestic spread based on the median impulse response for a selection of countries. The first column gives the share of the variance in the forecast error that is due to common shocks (volatility, real economic activity, stock returns, and OIS curve). Columns 2 aggregates all domestic shocks and column 3 aggregates all foreign shocks. The sum of common, domestic and foreign shocks should be equal to 100 minus rounding errors. The horizon is given in months.

essentially unaffected, although foreign factors in Portugal increase in importance at the long end of the yield curve.

To summarize, there is some variability in the influence of common and foreign factors for the larger countries of the eurozone, and much less for smaller countries.

Figure C.1 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years German spread



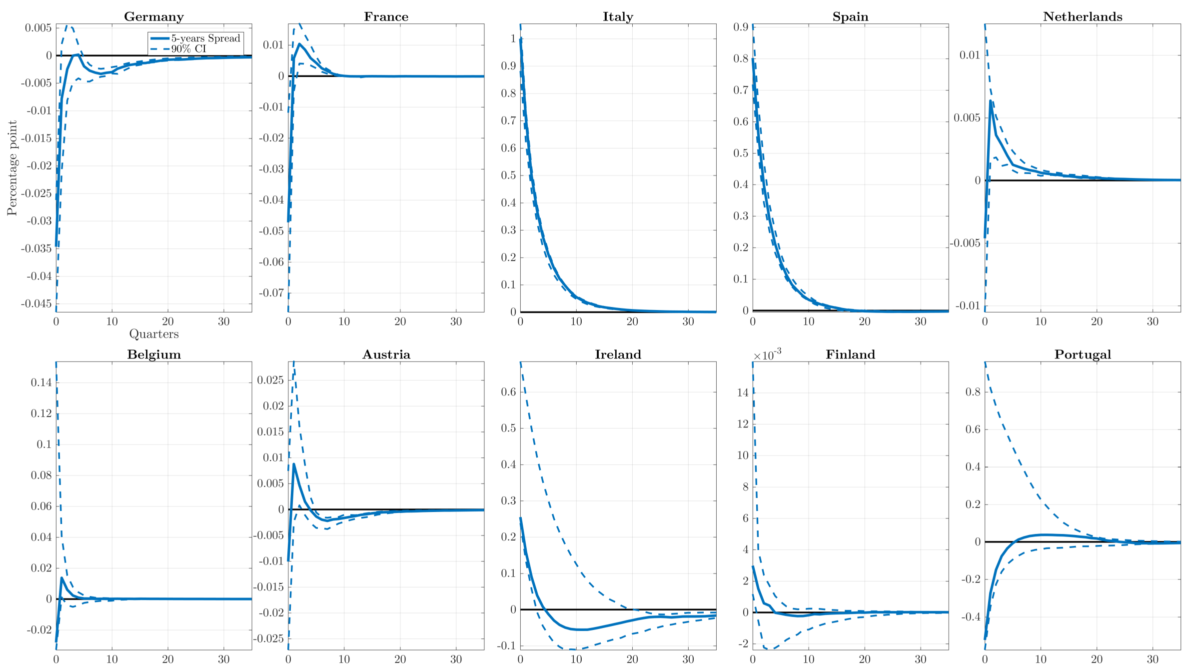
Note: the figure presents the responses of the 5-years spread to a shock to the 5-years German spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the German spread increases by one percentage point.

C.4 Alternative identification of shocks

In this section, I revisit the identification of shocks by proposing alternative orderings of the countries and the variables. In the current setting, i.e. 10 countries and 6 variables, the number of possible permutations reaches 5 billion. To reduce the number of permutations, I grouped countries and variables as blocks within which there is no permutation. For the country groups, I created four groups along two dimensions: large vs. small economic size and core vs. periphery countries. The Big-Core group includes Germany and France, the Big-Periphery group includes Italy and Spain, the Small-Core group includes the Netherlands, Belgium, Austria and Finland, the Small-Periphery group includes Ireland and Portugal. While it may be sensible to permute those groups, the ordering within the group seems of secondary importance. For the permutation of the variables, I created three groups: the macro block (inflation, output gap, deficit) as one group, the CLIFS as a second group and finally the principal components of the spreads as the financial group. I therefore have 144 possible combinations.

In order to summarize the information from 144 bootstrapped models, I decided to use the *quicksort* algorithm used in Computer Sciences. This algorithm approximates the median value in two steps: the first step creates a series of medians based on subgroups while the second step takes the median of those medians. Due to computer limitations, the number of bootstrapped replications has been downsized from 500 to 100. Confidence intervals are computed as the empirical 5th and 95th percentiles of the distribution of first-step medians. Results are presented in Figures C.1 to C.4. First, German spread shocks now generate spillover effects to neighboring countries. However, the extent of those is limited when we consider big or core countries. Nevertheless, an increase in the German spread depresses Irish, Portuguese and, to a lesser extent, Spanish spreads. Second, Italian spread shocks remain important drivers of other countries spreads, typically in the periphery. The spillover effect is large: 80 basis points increase in Spain, 25 basis points for Ireland. Third, Belgian spread shocks gain in statistical significance but still do not seem strongly economically relevant. Lastly, Portuguese shocks now generate a negative response of Irish spreads, although a 3 basis points decrease should not be seen as strongly economically relevant.

Figure C.2 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Italian spread

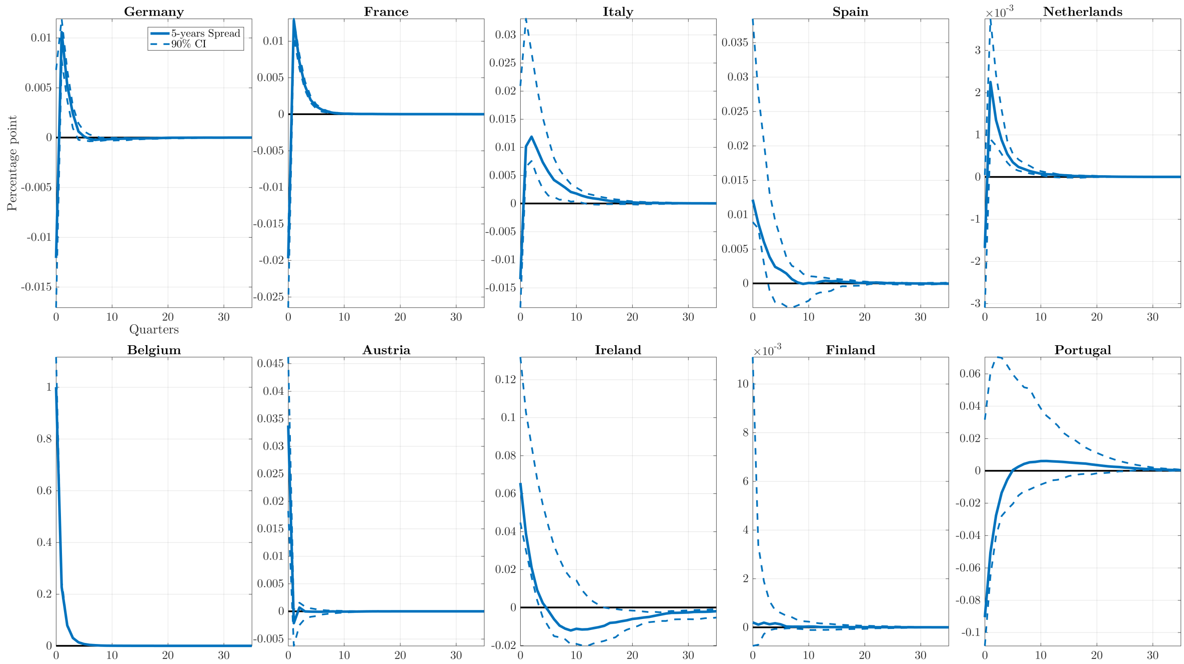


Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Italian spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Italian spread increases by one percentage point.

C.5 Spatial dependence of the shocks

In this section, I present a special case of the model where shocks are not spatially-dependent. Technically, the Cholesky decomposition of the variance-covariance matrix

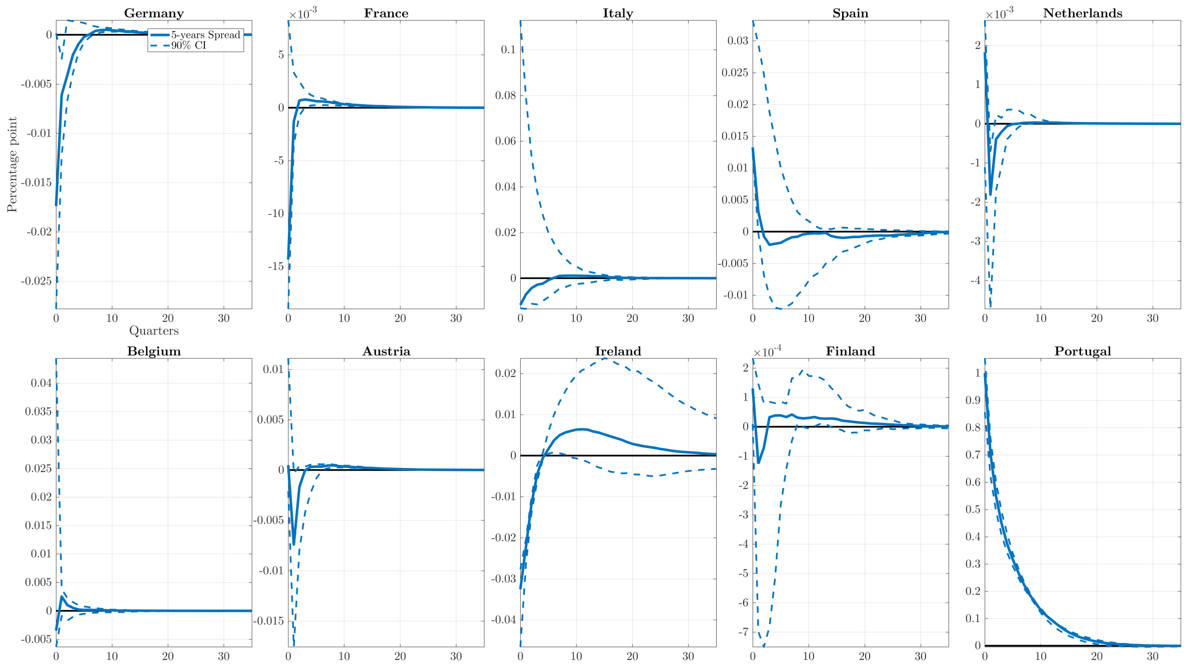
Figure C.3 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Belgian spread



Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Belgian spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Belgian spread increases by one percentage point.

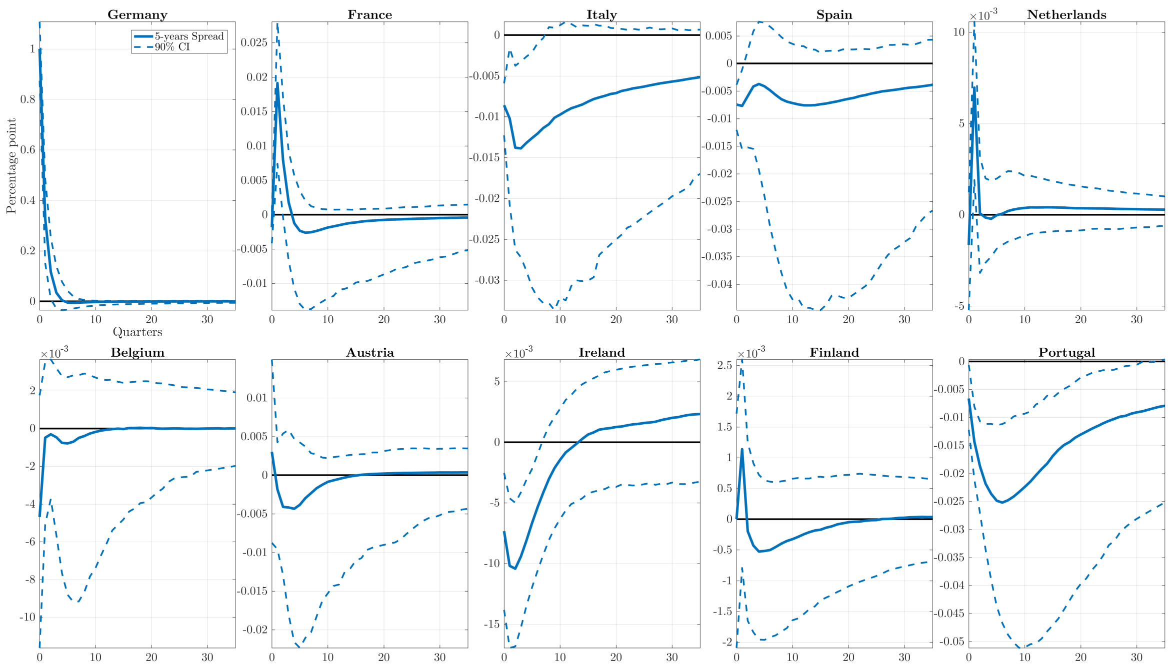
of the residuals is performed country-by-country. The variance-covariance matrix is restricted to be block-diagonal. The spatial transmission on impact therefore solely comes from the spatial lags Γ. Subsequent periods rely on the temporal and spatial diffusion Φ, Γ and Ξ. I report the results in Figures C.5 to C.8. We can conclude that, in this setting, only big countries generate spillovers and that those spillovers are fairly small. Considering spatial dependence of the shocks therefore seems important.

Figure C.4 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Portuguese spread



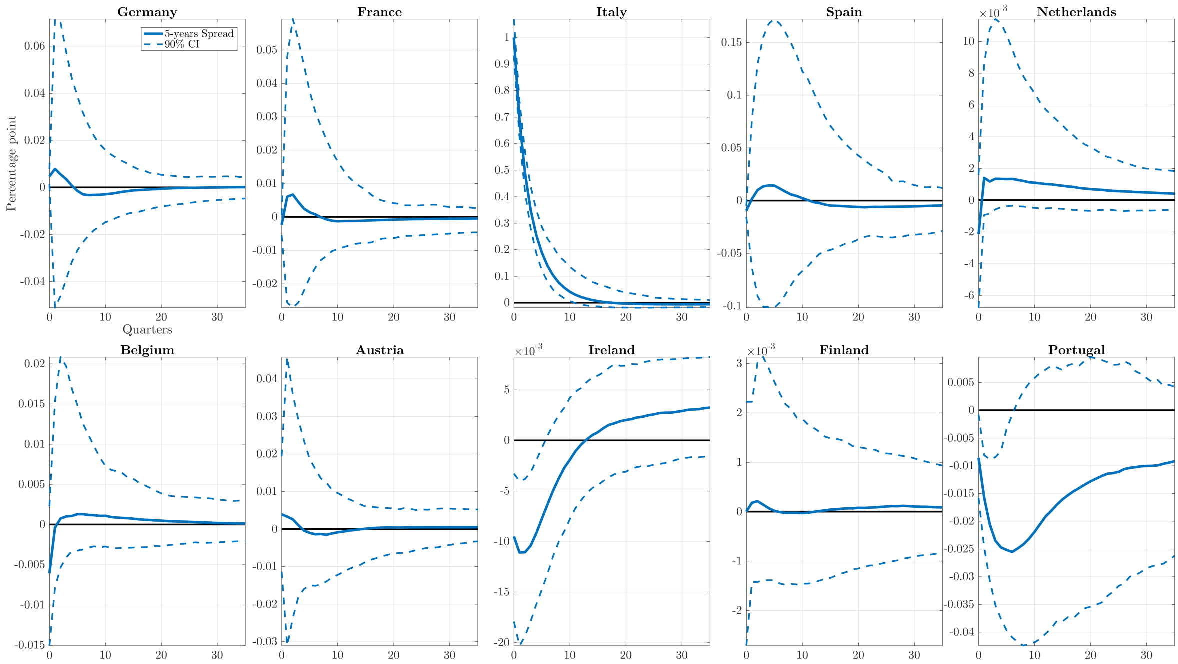
Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Portuguese spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Portuguese spread increases by one percentage point.

Figure C.5 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years German spread



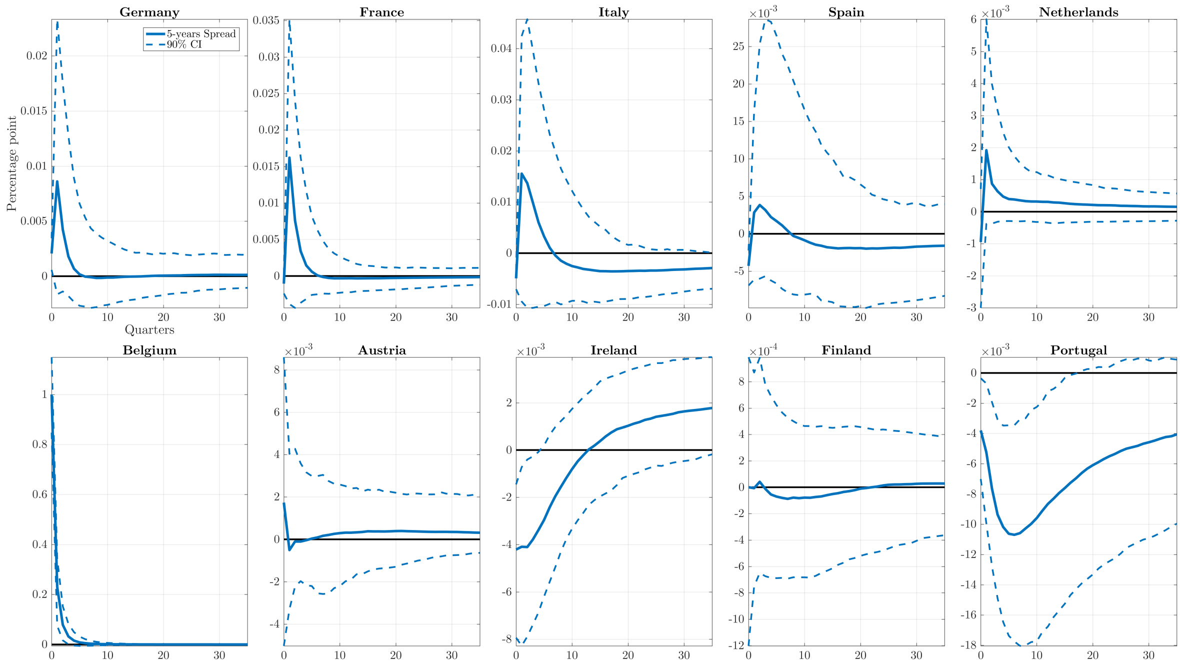
Note: the figure presents the responses of the 5-years spread to a shock to the 5-years German spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the German spread increases by one percentage point.

Figure C.6 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Italian spread



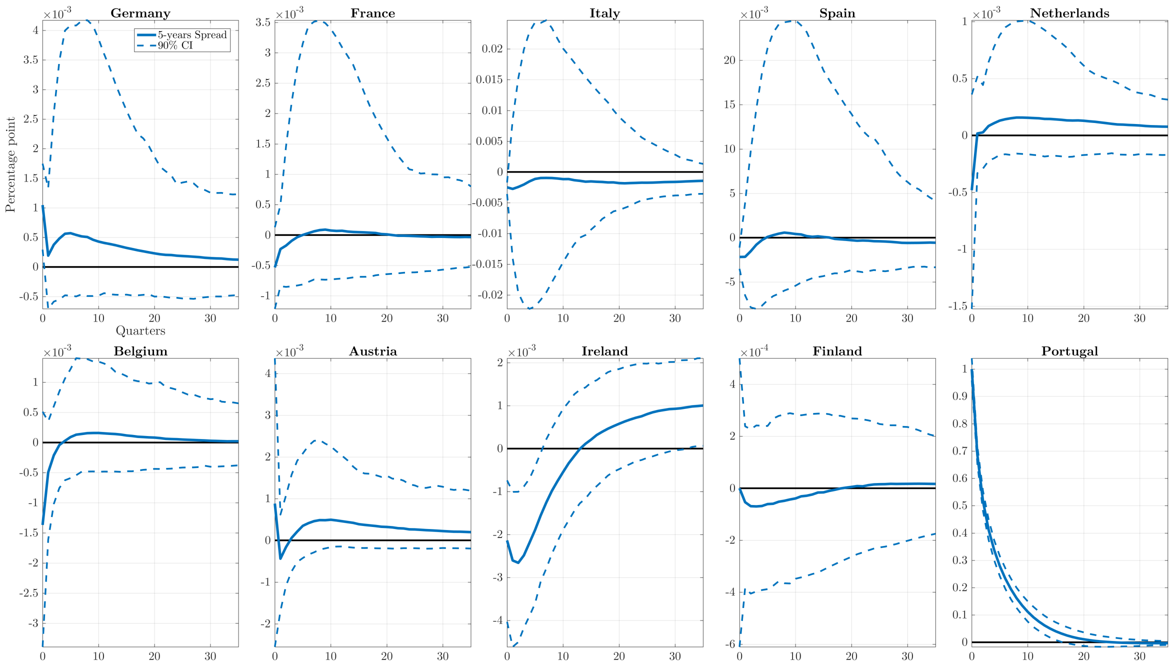
Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Italian spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Italian spread increases by one percentage point.

Figure C.7 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Belgian spread



Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Belgian spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Belgian spread increases by one percentage point.

Figure C.8 – Response of euro area countries 5-years spreads following a 1 percentage point increase in the 5-years Portuguese spread



Note: the figure presents the responses of the 5-years spread to a shock to the 5-years Portuguese spread. The IRFs are Orthogonalized IRFs. The continuous line is the median response based on 500 stationary bootstraps while the dashed lines correspond to the 90% confidence interval based on the empirical distribution of the IRFs. The size of the shock is scaled such that the Portuguese spread increases by one percentage point.